The National **Bioenergy Strategy** for Lebanon 2012

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2012
National Bioenergy Strategy for Lebanon

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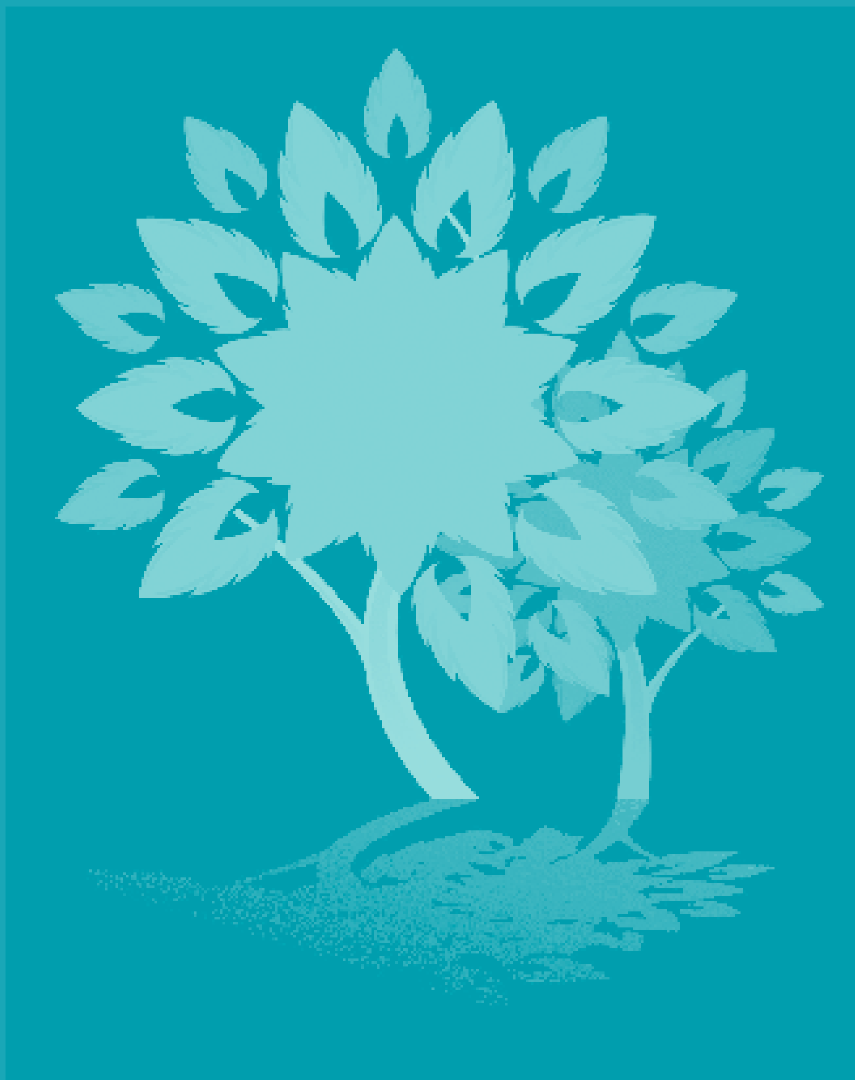
EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

Lebanon has a relatively abundant availability of bioenergy resources as approximately one third of the country's land is arable, with the most fertile areas being located along the coastal strip and in the Beqaa valley. Traditional use of biomass in rural areas is intensive; however, the development of sustainable bioenergy is lagging behind the modest goals that have been formulated in the past.

The goal of this study is to define and develop thoroughly all key elements to be considered in the formulation of the National Bioenergy Strategy for Lebanon. This Strategy shall contribute decisively to the Government's goal of achieving 12% of the country's total energy needs from renewable energy sources by 2020. The objective of this study is to assess the realistic and sustainable biomass potential in the country and match it with the most suitable conversion technologies that mitigate environmental, economic and social impacts produced by the bioenergy development in the country.

BIOMASS RESOURCE ASSESSMENT IN LEBANON

Chapter 1 presents an accurate and detailed assessment of relevant biomass resources duly defined and characterized to avoid mis-interpretations or double-counting. A total of twenty three (23) biomass streams representing a potential resource for energy production have been identified and fully characterised. These streams have been grouped according their source of origin in:

a)Forestry
b)Wood and paper industries
c)Agriculture
d)Energy crops
e)Food processing industry
f)Municipal solid waste and non-hazardous industrial waste

An overall evaluation of all biomass resources has been performed. This evaluation assessed quantity, energy potential, competition with other uses, accessibility and the current legal framework impacting biomass resource potentials in Lebanon. With this purpose, detailed statistics research have been combined with remote sensing data, on-ground surveys and key stakeholders interviews. This evaluation has allowed the identification of those biomass streams with the largest potential for development in the country.

A ranking of biomass streams that excludes streams with the lowest energy potential and streams with major sustainability or accessibility issues have been elaborated as shown in the next table.

Ranking of bioenergy streams in Lebanon (colour coded)

	Biomass resources	Primary energy potential (TJ)	Energy potential	Sustainability	Accessibility	Legal framework	Ranking
Forestry	Woody biomass and fellings	1,952 - 2,510					Not ranked
	Residues from fellings	1,378 -1,771					1
Wood and paper industries	Wood residues from sawmilling, wood-working, furniture industry	0					Not ranked
	By-products from paper industry	0					Not ranked
Agriculture	Residues of olive trees	842 - 968					2
	Residues of fruit trees	2,110					
	Residues of Cereals	2,116 - 2,233					3
	Manure	1,500					Not ranked
Energy crops	Jatropha	491 - 3,051					4
	Miscanthus	464 - 1,857					
	Eucalyptus	445 - 1,780					
	Sunflower	184 - 296					
	Giant Reed	1,990 - 3,180					
Food processing industry	Animal fat	258					8
	Slaughterhouse residues	495					
	Olive cake by-products	460 - 1,083					5
	Organic residues and waste from food processing industry	N.A.					Not ranked
	Wastewater and sludge from food processing industry	0					Not ranked
Municipal solid waste and non-hazardous industrial wast	Biodegradable fraction of municipal solid waste	2,011					Treated separately
	Landfill gas recovery potential	585					10
	Industrial and commercial waste	N.A.					Not ranked
	Waste wood	583					6
	Municipal sewage sludge	666					7
	Landscape management residues	15					Not ranked
	Yellow grease	495 - 562					9

* Wet Basis

Color code:

High potential

Medium potential

As a result, the ranking of the ten most promising bioenergy streams are;

1. Residues from forestry fellings
2. Residues from fruit and olive trees
3. Residues from cereals
4. Energy crops on currently unused land
5. Olive cake by-products
6. Waste wood
7. Municipal sewage sludge
8. Animal fat and slaughterhouse residues
9. Yellow grease
10. Landfill gas recovery (specifically Naameh landfill)

The biodegradable fraction of municipal solid waste as feedstock for Waste-to-Energy plants also has a large potential for development; however, it is not considered in the above-ranked categories, as the strategy for this potential is dealt with separately by the Waste-to-Energy Plan issued under Decision 55 to promote Waste-to-Energy (WTE) technologies in large cities. The 2010 plan already suggests up to 4 Waste-to-Energy sites (Beirut, Tripoli, Tyr and Baalbek). The sites and specifications of the incinerators have not been laid out at this stage and are currently subject to study by external consultants. Preliminary information indicates that the capacity of each incinerator should not be less than 1,000 to 1,500 tons per day in order to be efficient. The organic fraction will be dried and then incinerated. Ashes will be sent to landfills. The availability of this bioenergy stream is linked to the waste management master plan.

SELECTED CONVERSION OPTIONS FOR LEBANON

A variety of technology options exist for the conversion of biomass streams of interest in Lebanon into power, heat and liquid fuels. Many of these options rely on several feedstock alternatives. These options can be implemented from large-scale industrial applications to small-scale and rural end-uses. A total of 20 conversion technologies have been selected and studied in Chapter 2. These options are listed below, and cover mature and developing technologies.

- **Mature technologies**

a) Liquid fuels production

1. Vegetable oil biodiesel: Alternative to fossil diesel fuel, made from plant oils
2. First generation bioethanol: Alternative to fossil gasoline, made from agricultural crops
3. Animal fat and recycled oil biodiesel: Alternative to fossil diesel fuel, made from waste fats and oils
4. Fischer Tropsch biodiesel: Feedstock gasified into syngas then condensed into a diesel replacement

b) Biogas production

5. Anaerobic co-digestion (manure and agro residues): Feedstocks are converted by bacteria into biogas
6. Anaerobic digestion of sewage sludge: Sewage sludge is converted into biogas by bacteria
7. Slaughterhouse waste biogas: Slaughterhouse waste is sterilized, then converted into biogas by bacteria
8. Landfill gas: Biogas is released by landfills, which can be collected and purified for fuel usage

c) Direct combustion

9. Waste to energy: Waste-to-energy (WtE) is the process of creating energy by combusting waste
10. Combustion combined heat & power: Simultaneous generation of useful bioenergy
11. Combustion boiler: Converts biomass into heat
12. Co-combustion of biomass and coal: Partial substitution of coal by biomass in coal fired power plant

d) Pretreatment

13. Pelletization: Drying and pressing biomass under high pressure into pellets with an improved energy density
14. Torrefaction: Heating at atmospheric pressure in the absence of oxygen to improve energy density
15. Gasification-CHP: Thermal conversion of solid fuel into a combustible gas under oxygen limitation
16. Pyrolysis: Direct thermal decomposition of biomass into gas, bio-oil and char

e) Promising technologies

17. Algae options (centered in biodiesel): Simple organisms that use sunlight to grow and produce oil (or other products)
18. Salicornia biodiesel: Salicornia as a salt tolerant plant that produces oil
19. Lignocellulosic ethanol: Woody biomass, grasses, or the non-edible parts of plants are broken down into ethanol
20. Fuel from MSW: Using waste to produce a high quality biofuel

Chapter 2 provides a thorough assessment and discussion of all selected bioenergy conversion technologies, along with a full comparison of their comparative advantages and their costs. Furthermore, it matches those selected technologies with the resource assessment elaborated in Chapter 1, and proposes the potentially best combinations resource-technology per each Mofahaza of Lebanon.

The performed assessment indicate that all technologies for liquid fuels production are commercially available, except for the Fischer-Tropsch biodiesel technology. Biogas production technologies can be developed at any scale and all are commercially available, except for gasification CHP. There are various direct combustion technologies as well for power and heat generation that are commercially available. Pre-treatment technologies such as pelletisation are commercially available, while torrefaction and pyrolysis are expected to become available in the short term. Promising technologies are, as the term implies, not yet commercially available but will most probably be within the next two decades. Among those, cellulosic ethanol conversion is expected to become commercially available in the short-term.

Technologies can be combined in different ways, resulting in different bioenergy chains. These combinations of technologies are not applicable in all mohafazats, as they depend on the availability of biomass resources. New technologies and processes continue to develop, this includes second-generation options. These options should be tracked and assessed by Lebanon, especially in conjunction with the potential that energy crops could provide. Furthermore, a combination of feedstock resources can be integrated over time to secure long-term feedstock supply and feedstock prices. Bioenergy plants can be built now, relying on currently available feedstocks, while establishing new energy plantations and feedstock collection systems, to make sure there is enough feedstock to keep up with the growth of the bioenergy industry in Lebanon.
The most relevant technologies for Lebanon are the ones involving liquid fuels production and direct combustion of biomass for the production of power and heat. The findings of this chapter are intended to support decision-making regarding future investments. The information provided is explorative and is by no means intended to replace dedicated feasibility studies.

- **Liquid fuels production**

Feedstock for liquid fuels production in Lebanon are derived from several sources; although many of the commercial options may create competition with food and, consequently, rising feedstock prices. For this reason, it is important to look at more advanced technologies such as Fischer-Tropsch biofuel and lignocellulosic ethanol that use non-food feedstock and that can actually use a wide variety of residues. All technologies for liquid fuels production are commercially available for capacities ranging from 5 kton per year up to 600 kt per year for biodiesel production from vegetable oil. Annual operational costs for these technologies are generally 4 to 7% of total investment costs. Investment costs are competitive with other technologies, except for Fischer-Tropsch production that still has a large investment cost. The Mohafazats with larger potential to develop biofuels are North Lebanon, followed by the Beqaa region. Biodiesel production from yellow grease is a possibility in most populated cities of Lebanon, while more advanced technologies like Fischer-Tropsch biodiesel seem suitable over time for North Lebanon, Mount Lebanon and the Beqaa region. Production of bioethanol from energy lignocellulosic crops is the most relevant future technology for Lebanon. Species like Giant Reed is of interesting application, for example, for the production of bioethanol through enzymatic fermentation.
Food energy crops such as oil seeds or sugar/starch crops could be converted into first generation biofuels in basically all regions of Lebanon, with exception of Beirut and Mount Lebanon.
Animal fat and yellow grease can clearly be used for the production of biodiesel. All regions in Lebanon offer the possibility of this type of combination biomass resource/technology. Local production of biodiesel will lower the dependence on foreign fossil fuel diesel and at the same time environmental impacts of the disposal of used oil could be avoided.
Agricultural residues could offer interesting options for the production of second-generation biofuels, especially in North Lebanon and the Beqaa region.
Lignocellulosic energy crops offer interesting possibilities as they can be combined with direct combustion technologies in North Lebanon, and the Beqaa and Nabatiyeh regions. But this biomass stream could offer far better options for the country if they are used for the production of second generation biofuels (biodiesel and bioethanol).

- **Direct combustion of solid biomass for the production of power and heat**

There are various commercially available technologies for direct combustion of solid biomass to produce power and heat. The size of production units ranges from 4 kW (household level) to 50 MW in the case of co-combustion or combined heat and power (CHP) installations. Specific technologies, such as Waste-to-Energy combustion, can solve waste disposal problems as well. Other technologies such as CHP and co-combustion technologies can use a variety of feedstock resources. Combustion of waste, and especially combustion of woody and agricultural residues from cereals, fruit or olive trees for power and heat production are possible for basically all the country. These feedstock resources are found in all regions, although they predominate in Beirut, North Lebanon, Mount Lebanon and the Beqaa.

The biomass fraction from municipal solid waste is an important energy resource in Lebanon that can be used in Waste-to-Energy plants (WTE) for the production of electricity and heat. This option is feasible nearby densely populated areas. Beirut offers the largest potential for this type of projects, followed by North Lebanon and Beqaa regions.

Forest residues and short rotation coppices residues are very suitable for co-firing in power plants, for heat production in boilers, or for combustion in CHP plants. Considering the resources available, they are a latent opportunitiy for projects in Beirut, North and Mount Lebanon. These combinations of biomass-technology are not an option for neither the Beqaa region, nor the South Lebanon or Nabatiyeh.

Agricultural residues could be used with direct combustion technologies as it is the case for forestry residues, but they could also be used in the future for the production of second generation biofuels. For their combination with direct combustion technologies, the best projects could be planned in North Lebanon and the Beqaa region and to a lesser extent in the other mohafazats.

Industrial wood residues could also use be combined with the same direct combustion technologies. However this combination resource-technology could only be interesting for the Beirut area.

- **Biogas conversion for the production of power and heat**

Anaerobic digestion for biogas production offers the option to convert both dry and wet biomass into biogas. Conversion options for biogas production are all commercially available at any scale. Biogas production from anaerobic digestion of sewage sludge and from slaughterhouse waste is also interesting for Lebanon, especially for more densely populated areas such as the Beirut area, Mount Lebanon and the Beqaa regions and due to the lack of alternative treatment for these waste streams. CHP and co-combustion can use a variety of feedstock resources; options for boiler combustion are larger. The biggest barrier for this technology group is financial; multiple conditions have to be met for making biogas projects become economically viable.

Municipal solid waste is also an important energy resource when landfilled in large amounts; the methane produced can be recovered and combusted in stationary generators for the production of electricity and heat.

Animal manure could be used for biogas production with anaerobic digestion processes. North Lebanon, Mount Lebanon and the Beqaa regions are potentially the most suitable for these types of projects.

Slaughterhouse waste and sewage sludge could be turned into biogas through anaerobic digestion processes basically in all the regions of the country.

FUTURE SCENARIOS

The electricity generation policy in Lebanon is targeting a total installed capacity of 4,000 MW by 2014 and 5,000 MW thereafter (MEoW, 2010). The government of Lebanon aims to have 12% of its total energy needs from renewable energy sources (RES) in 2020. This means roughly the production of 1800 GWh of electricity coming from renewable energy sources by 2020 if this entire objective is met through electricity-supplying sources only. This amount of energy production leads to 670 MW of installed capacity if we consider an average capacity factor of 30% for all renewable energy plants. The specific required biomass input to meet a share of this expected demand largely depends on the selected technologies, their conversion efficiencies, and end-uses.

Four scenarios have been elaborated to explore various bioenergy perspectives over time contributing to this target. These scenarios take into consideration the previously discussed options of technology and resource combinations. They should not be considered as fixed predictions into the future, but as providers of insights to the elements that can accelerate or slow down the deployment of bioenergy in Lebanon. Scenarios presented in this study expose unintended barriers and opportunities for the market development of bioenergy in the country.

The general characteristics of these four scenarios are:

Scenario I: Well being and development	KEY TRENDS: Peace in the country and in the region. Strong growing economy. Bioenergy development is promoted. Strict sustainability levels and policies are considered for bioenergy development.
Scenario II: Economic crisis	KEY TRENDS: Peace in the country and in the region, apart from incidental unrest. Economic growth in Lebanon is slow, limiting the possibilities for bioenergy development. Minimum sustainability levels are considered for bioenergy development.
Scenario III: Underdevelopment and poverty	KEY TRENDS: Lebanon is in political turmoil, which affects the economy with increasing socio-economic disparities across Lebanese regions. Bioenergy development has limited to no priority in national strategies. No sustainability levels are considered for bioenergy development.
Scenario IV: Political challenges	KEY TRENDS: There is a strong economy; some regions remain underdeveloped due to large political and social unrest. Bioenergy is used for reducing energy deficits and export. A minimum level of sustainability is considered for bioenergy development.

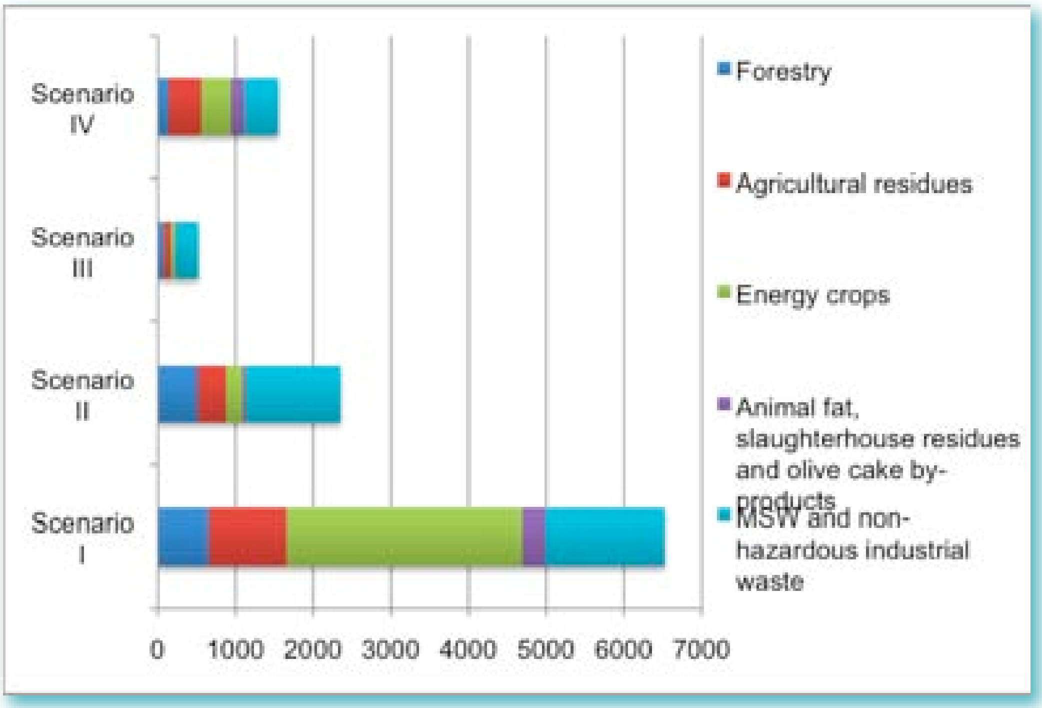
The contribution of bioenergy to various types of end-use is shown in the table below (contribution based on story lines, the available biomass resources, and the studied technologies).

Annual contribution of bioenergy to end-uses, year 2030

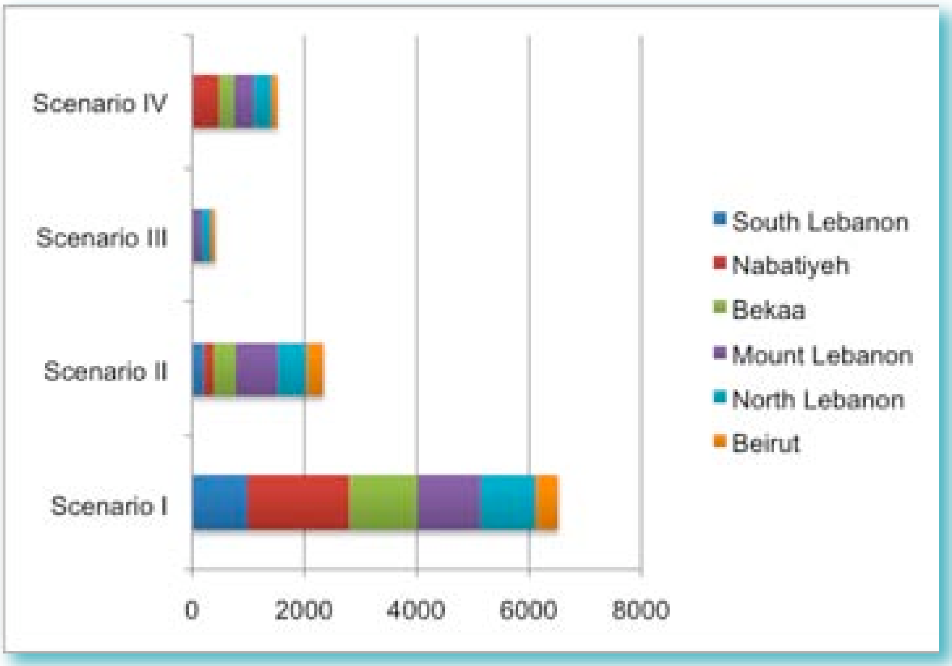
Energy use	Scenario I	Scenario II	Scenario III	Scenario IV
Primary energy (GWh)	6953	2354	517	1543
Final energy				
Electricity (GWh)	934	475	73	261
Electricity (MWe)	119	62	9	33
Heat (ktoe)	131	78	14	39
Heat (MWt)	222	134	23	66
Transport (ktoe)	271	28	14	39

The potential contribution of the various biomass resources and the contribution of each mohafazat to the deployment of bioenergy differ per scenario as below figures show.

Potential contribution of bioenergy resource categories by 2030
(in GWh of total primary energy)



Contribution of mohafazats to bioenergy deployment by 2030
(in GWh of total primary energy)



The main conclusions from the scenarios analysis are:

1. Only scenario I is able to contribute substantially with about half of the electricity needed to reach the 12% target with a relative small capacity installed of 119 MWe. This is possible because the capacity factor for biomass plants ranges from 80% to 90%, which is much larger than other sources of renewable energies (capacity factors for wind and solar plants range from 15% to 35%).
2. The potential contribution of energy crops for biomass production fluctuates largely in the various scenarios, depending on i) competition of the land and possible alternative uses and ii) the decision of government and private sector to exploit this opportunity or not;
3. The potential production of liquid fuels from lignocellulosic energy crops. The possibility of producing an important amount of liquid fuels from lignocellulosic biomass (not from food crops) could help to decrease in a relevant way the dependency on imported fossil fuels for transport. Scenario 1 establishes a potential production of 271 ktoe of liquid fuels produced under strict sustainable criteria and regulation; this represents 18% of current total fossil fuel consumption. The available land for energy crop production is largest in the Beqaa region, followed by Mount Lebanon, North Lebanon and Nabatiyeh. Additionally, the deployment of the liquid fuels industry brings many other socioeconomic benefits such as work for farmers and crops substitution (drug crops by instance) when properly regulated.
4. The biomass fraction from the municipal solid waste is an important resource of immediate application for its conversion to electricity and heat in Waste-to-Energy plants. According to the estimations performed in this study, up to 301 GWh of electricity could be produced from the biomass fraction of municipal waste, which could result in a total installed capacity of up to 38 MWe. If it is not only the biomass fraction used in the Waste-to-Energy plants, then the capacity of these plants could reach 70 MW. If an ambitious waste management master plan is pursued; this is about 2.8% of the current electricity consumption in the country, which could almost immediately contribute to the renewable energy target of 12%.
5. The contribution of forestry, wood and paper industries and waste streams also shows fluctuations for the different scenarios, although to a lesser extent. However, their total contribution can still be significant, especially when combined for the production of electricity and heat. About 930 GWh of electricity could be produced, with most of it coming from the combustion of these streams
6. The potential contribution of the food processing industry is limited for all scenarios;
7. All Mohafazats, except Beirut, can contribute substantially to the total potential deployment of bioenergy.

SUSTAINABILITY IMPACT ASSESSMENT

The development of a sustainable bioenergy industry depends not only on the available biomass potential and the economic performance of its conversion option(s). It also depends on its environmental and social sustainability. A condition for a sustainable bioenergy development is therefore to ensure that negative sustainability impacts are avoided.

Lebanon ranks 90 in the list of 149 countries ranked by the Environmental Performance Index (EPI) on indicators covering: environmental health, air pollution, water resources, biodiversity and habitat, productive natural resources, and climate change. Pressing environmental issues in Lebanon are related to biodiversity loss, climate change (high per-capita CO2 emissions), water-related problems (with serious implications on ecosystems present in Lebanon) and high air pollution loads. The latter has, in combination with deficient solid waste management practices, an impact on the environmental burden of disease.

Solid waste in Lebanon continues to be a major environmental problem with more than 700 open dumps used by the municipalities and where, furthermore, 50% of this waste is being burned. This causes major underground water pollution and air pollution (MDG, 2008). Water availability remains a critical issue of national importance in Lebanon due to the high demand for water, the large losses in the public water distribution networks and the high level of water pollution (MDG, 2008). Biodiversity loss and land degradation were further degraded due to the July/August 2006 war.

The list of sustainability impacts that are relevant to the Lebanese context is shown in the next table.

List of sustainability aspects for strict sustainability level

Requirements related to legal compliance (individual) producers
Human and labour rights [1 2]
Responsible community relations
Respect customary water rights
Land rights and land use rights
Reducing GHG emissions and energy use
Reducing GHG emissions
Promote national energy security
Economic affordability of energy use
Biodiversity impacts
Carbon conservation: maintenance carbon stocks
Biodiversity conservation: No risk for conservation high biodiversity value areas
Biodiversity conservation: No risk for land degradation by deforestation [3]
Biodiversity conservation: No risk for invasiveness species
Environmental impacts
Soil conservation: Risk for soil degradation
Soil conservation: Risk for soil health
Water conservation: Risk for water quantity
Water conservation: Risk for water quality
Air pollution shall be minimized [4]
Socio-economic impacts
Poverty reduction: Contribution to socio-economic development [5]
Employment generation
Reducing fuel poverty in regions
Competition with food and other uses
Biomass production does not impair food security, which is defined under: • Food availability (reduced food cultivated and land price increases); [6] • Food access; • Food vulnerability
No risk on local (non-food) biomass applications [7]
Good agricultural practices as defined as: [8]
Crop protection: Responsible use of fertilizers
Crop protection: responsible use of pesticides and chemicals
Responsible waste management
No risk for forest fires
Best management practices

[1] Labour rights include decent work and well-being for workers (e.g. safe working conditions, health), also refers to Good Agricultural Practices as defined by (FAO, 2003).
[2] Labour rights includes no discrimination (e.g. related to gender)
[3] Risk of land degradation by desertification is included under soil conservation
[4] Includes risk of air pollution from burning residues and waste (in open air)
[5] Assumed that profitability of bioenergy chain creates added value and possibility for substitution for non-desired crops). Recommendations for possibilities to replace non-desired crops will also be partly retrieved from outputs under the impact 'community relations'.
[6] It is assumed that increased land prices and decreased cultivated land for food will also lead to a risk for increased competition of land resources. This is not included as a separate item.
[7] Includes competition of co-products
[8] This methodology has covered, under the item Good Agricultural Practices, those aspects that are not explicitly covered under other sustainability principles or aspects. These are: Crop protection: Fertilizer and pesticides use, Waste management and Best management practices including selection of most suitable crops and practices for sustainable management, on-farm processing and storage.

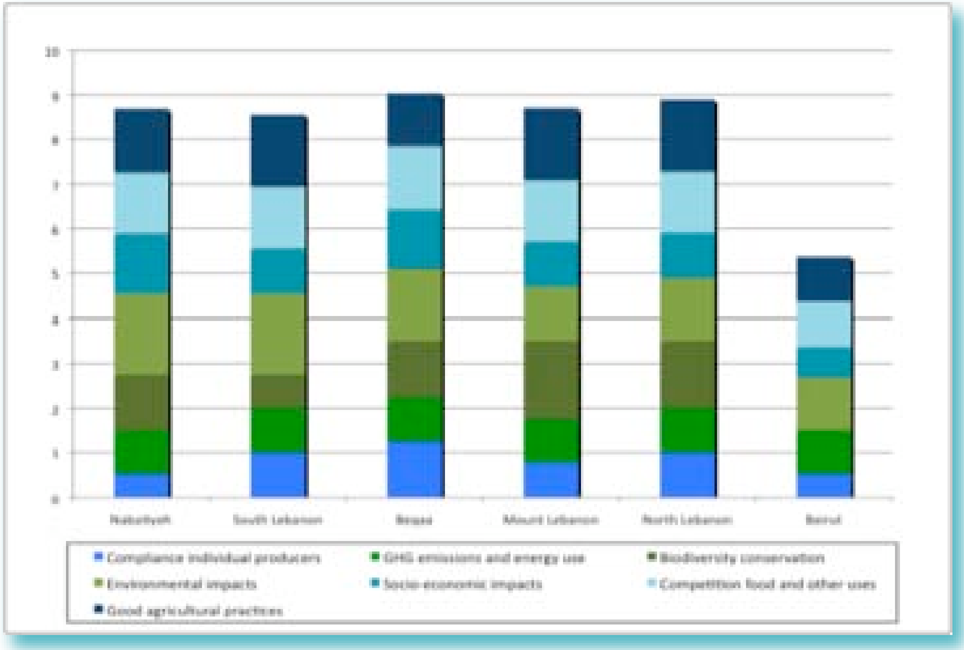
The analysis on sustainability impacts is done with two different environmental and social levels of sustainability as references. The first sustainability level is based on the compliance with the current European Union obligations as defined under the EU Renewable Energy Directive. The second level includes the compliance with additional sustainability criteria currently under discussion for their adoption by the European Union.

The sustainability impact assesment follows a scorecard approach, which includes three different steps: i) a regional assessment, ii) a biomass resource assessment and iii) a final assessment, integrating the previous two steps into a final score.

Regional sustainability assessment

The regional assessment shows that differences in total sustainability performance are limited between the Mohafazats; all regions show some level of vulnerability to both environmental and socio-economic issues. For example: environmental impacts score higher (i.e., worse) in Nabatiyeh and South Lebanon than in Mount Lebanon. Also, North Lebanon scores double on biodiversity conservation impacts compared to South Lebanon. The figure below shows the sustainability impact performance for the various mohafazats.

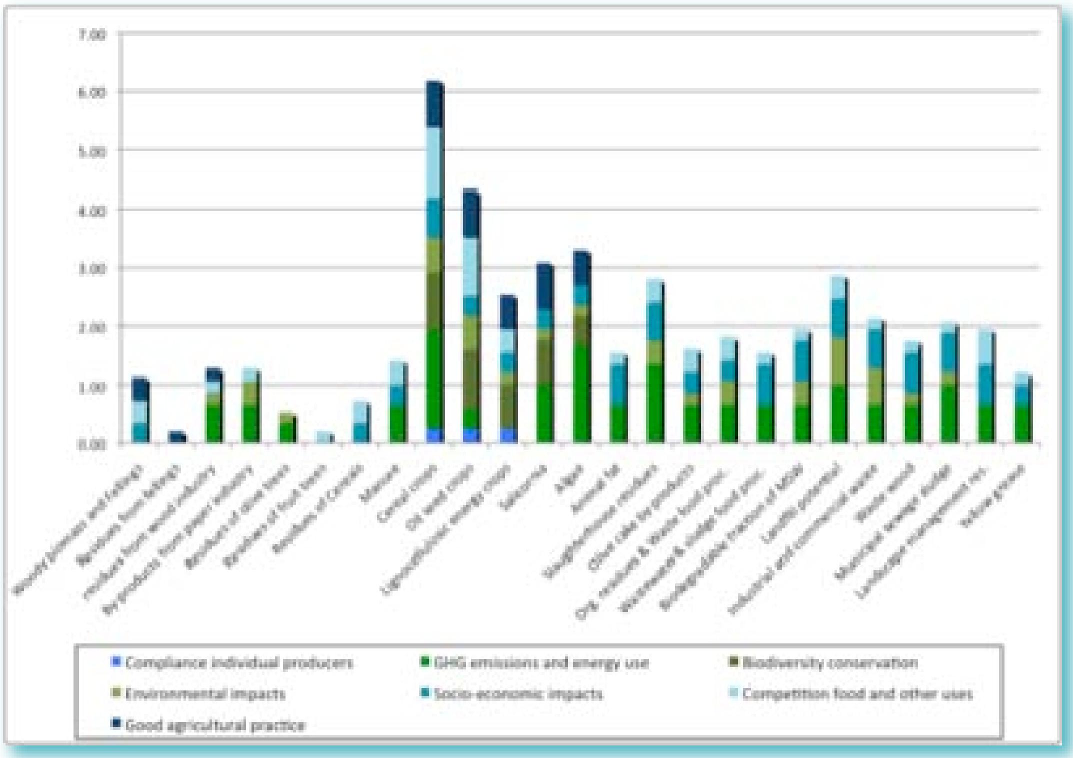
Regional sustainability impacts score for the different mohafazats



Resource sustainability assessment

A resource impacts assessment is conducted right after the regional assessments. Food crops for energy use clearly have a higher score compared to other biomass resources. Lignocellulosic energy crops are more sustainable than cereal crops and oil seed crops when harvested for energy uses. This is due to the use of fertilizers by instance, or due to the non-observation of best agricultural practices. Residues from agriculture and forestry produce the lowest impacts among all biomass streams. The figure below shows the sustainability impact performance for the various biomass streams considered.

Resource sustainability impacts score for the selected biomass resources.



Final sustainability impacts assessment

A final assessment is produced combining the results of the regional and resource assessments. This gives a final score which is a combination of the scores and their underlying assumptions. Based on this final score, the appropriate combinations of biomass resources – regions can be selected. For example, the deployment of yellow grease is an appropriate option for Beirut while less attractive for e.g. North Lebanon. Also, the development of landfill potentials for bioenergy seems more appropriate for Beirut than for other Mohafazats. The figure below shows the total score of the sustainability impact assessment for the combination of biomass streams and regions in Lebanon.

Results total score of the sustainability impacts assessment

Scoring card:	No risk		Medium risk			High risk
	< 1	1.0 - 1.5	1.51 - 2.0	2.01 - 3.0	3.01 - 4.0	4.01 - 5.0
	5.0 - 5.5	> 5.5		Not available		

	Beirut	N Lebanon	M Lebanon	Beqaa	S Lebanon	Nabatiyeh
Woody biomass and Fellings	1,00	1,62	1,49	1,88	1,59	1,63
Residues from fellings	0,53	0,95	0,83	1,12	0,83	0,87
residues from wood industry	1,33	2,05	1,83	2,22	1,83	1,97
By-products from paper industry	1,33	2,15	1,83	2,22	1,93	2,07
Residues of olive trees	0,87	1,38	1,16	1,45	1,26	1,30
Residues of fruit trees	0,53	0,95	0,83	1,12	0,83	0,87
Residues of Cereals	0,80	1,22	1,09	1,38	1,09	1,13
Manure	1,30	1,72	1,59	1,88	1,59	1,63
Cereal crops	3,68	6,32	6,40	6,38	5,99	6,31
Oil seed crops	2,62	5,15	5,25	5,19	4,83	5,14
Lignocellulosic energy crops	1,48	3,44	3,54	3,51	3,14	3,46
Salicornia	1,57	3,75	3,63	3,57	3,23	3,52
Algae	2,07	3,58	3,45	3,82	3,28	3,57
Animal fat	1,17	1,88	1,66	2,05	1,66	1,80
Slaughterhouse residues	2,47	3,18	2,86	3,25	2,96	3,10
Olive cake by-products	1,40	2,22	1,89	2,28	1,99	2,13
Org. residues & Waste food proc.	1,70	2,52	2,19	2,58	2,29	2,43
Wastewater& sludge food proc	1,17	1,88	1,66	2,05	1,66	1,80
Biodegradable fraction of MSW	1,67	2,38	2,06	2,45	2,16	2,30
Landfill potential	2,70	3,32	3,09	3,38	3,19	3,23
Industrial and commercial waste	1,97	2,68	2,36	2,75	2,46	2,60
Waste wood	1,47	2,18	1,96	2,35	1,96	2,10
Municipal sewage sludge	1,80	2,42	2,19	2,58	2,19	2,33
Landscape management res.	1,47	2,18	1,96	2,35	1,96	2,10
Yellow grease	1,00	1,72	1,49	1,88	1,49	1,63

Mitigation and opportunities

The risk on certain impacts can be avoided through the selection of appropriate mitigation measures. Positive benefits from bioenergy production can be further explored through highlighting these opportunities. The individual impact assessment performed in this study proposes for every impact a set of mitigation measures and opportunities to minimize the potential negative impacts and to promote positive ones.

Based on the outcomes of the scenario assessment and the sustainability impact assessment, the following conclusions can be made:

- The region (Beirut) has the lowest expected impact in terms of sustainability yet this is because it also has the lowest potential in bioenergy development and deployment;
- The biomass resources with possibly the highest potential in terms of bioenergy production are food crops (cereal and oil seeds) and lignocellulosic crops. Between these two streams, food crops for energy use show the highest risk in terms of sustainability impacts; it is recommendable to develop bioenergy industry around lignocellulosic crops rather than around food crops. The full exploitation of available land for bioenergy production may be substantially smaller when all impacts are taken into consideration;
- Strict sustainability levels are only considered for Scenario I. Given the versatility of possible sustainability risks, this strict sustainability level is also recommended for other scenarios.

Several sustainability impacts included in the assessment are interrelated to each other. The improvement or deterioration of one impact can therefore highly affect the scoring of other sustainability impacts. Consequently, the linkage of bioenergy production with many relevant policy areas such as agriculture, energy, poverty reduction or forestry, enforces policy makers and the market to make clear choices in priorities.

Considering the versatility and vulnerability of the Lebanese regions in terms of environment and socio-economic situation, the development of a strict sustainability level for bioenergy projects is highly recommended. In all cases, good monitoring and enforcement of these requirements needs to be ensured. Lignocellulosic energy crops production for bioenergy, especially for liquid fuels, provides an interesting potential for Lebanon and may provide benefits to rural areas and poor communities. Key considerations are the water limitations and competition of land with food crops. The deployment of small-scale projects, with an appropriate selection of land use (marginal or degraded lands preferred) and crop, which allow time for learning and risk avoidance, is therefore highly recommended. In all cases, the deployment of bioenergy projects should consider the local variation in environmental and socio-economic aspects within Lebanon and within the Mohafazats. A full list of mitigation actions and opportunities for various environmental,social, and economic issues are developed and presented in this study.

Life cycle assessments of relevant bioenergy options in Lebanon

Finally, and in order to quantify some of the most important environmental advantages of Lebanon's bioenergy options, this study presents Life Cycle Assessment (LCA) including greenhouse gas balance and energy balances for various bioenergy options for Lebanon. The results presented are described in the Lebanese context, but specific projects in Lebanon may have different GHG balances, so a balance should be prepared for an individual project to adequately assess its impact.

Full LCA calculations have been elaborated for:

1. Bioheat and bioelectricity from forestry residues
2. Bioethanol from the lignocellulosic energy crop Giant Reed
3. Compressed natural gas from fruit tree residues

LCA literature results that are relevant to Lebanon are reported for:

1. Biodiesel from used cooking oil
2. Combustion of straw for electricity generation
3. Biogas from sewage treatment Sludge
4. Municipal Solid Waste
5. Co-digestion of organic waste streams

BARRIERS TO BIOENERGY DEVELOPMENT IN LEBANON

The barriers to bioenergy development in Lebanon touch the technological, logistical, legal, economic, financial and commercial spheres. Based on a SWOT analysis, the main barriers detected are further analysed to produce recommendations that can help to overcome them. A detailed analysis on the next five bioenergy options is made:

1. Combustion-CHP, with a feedstock of residues from forestry felling.
2. Anaerobic digestion with residues of olive and fruit trees.
3. Combustion boiler coming from residues of cereals.
4. Production of lignocellulosic bioethanol from energy crops (giant reed especially recommended) as feedstock.
5. Anaerobic co-digestion of olive oil cake and other organic wastes.

Barriers to the successful deployment of these bioenergy options are thoroughly discussed along with their mitigation actions in order to plan a solid infrastructure and market in Lebanon. This study focus on the following four main concerns:

1. Security of feedstock supplies.
2. Economies of scale and other logistic factors.
3. Public and non-governmental organisations acceptance
4. Competition with other renewable and non-renewable energy sources, as well as, competition with other current end uses.

Furthermore, an analysis of the regulatory framework is made, along with a benchmark of renewable energy supportive schemes in the world. The study recommends adopting a feed-in-tariffs (FIT) system in Lebanon. The arguments in favour of a FIT policy for Lebanon are primarily economic in nature. These include the ability to:

1. Offer a secure and stable market for investors;
2. Stimulate significant and quantifiable growth of local industry and job creation;
3. Only cost money if projects actually occur;
4. Provide lower transaction costs;
5. Distribute costs and development benefits equitably across geographic areas;
6. Settle uncertainties related to grid access and interconnection;
7. Enhance market access for investors and participants;
8. Tailor the policies using a range of design elements that will achieve a wide range of policy goals;
9. Encourage technologies at different stages of maturity, including emerging.

Due to the Lebanese local conditions, FIT is recognized as the most appropriate renewable policy that could mitigate the electricity problem. Non-economic barriers can significantly hamper the effectiveness of policies and drive up costs, irrespective of the type of incentive scheme. Hence, Lebanon has to set a well-designed FIT legislation that meet local objectives, social aspects and electricity sector characteristics of the country.

This study concludes by presenting several innovative financial mechanisms to provide support to the establishment of the bioenergy strategy implementation. Because Lebanon requires funding to enable solutions to climate change solutions, recommendations on adapted innovative financial mechanisms are also provided.

FINAL RECOMMENDATIONS

Lebanon has the opportunity to leapfrog the development of large scale fossil fuel generation capacity and demonstrate that economic growth and development can be decoupled from an exponential growth in greenhouse gases. This is achievable with the implementation of a strong policy supporting renewable energy deployment, and within this framework, a strong national bioenergy strategy. Final recommendations for this strategy are:

1.Waste-to-Energy plants have large potential for development in Lebanon. Sites and specifications for the constructions of plants in Beirut, Tripoli, Tyr and Baalbek should be defined and a master plan be put into action.

2.Investments for the production of electricity and heat with biomass should be supported by the Lebanese government. By instance, the combination of forest residues, short rotation coppices residues, and agricultural residues are very suitable for co-firing in power plants, for heat production in boilers, or for its combustion if CHP plants.

3.A national action plan for the development of liquid fuels production should be established in the country to reduce the dependence on imported fossil fuels and to develop the agricultural sector by creating permanent jobs. Lebanon could produce biofuels for transport uses amounting to 17% of current total fossil fuel consumption pertained to the transportation sector. Special attention should be given to the production of bioethanol from lignocellulosic resources. The international biofuels industry is currently obliged to do the transition from producing biofuels from food crops to a more sustainable production of biofuels either from lignocellulosic crops or residues and waste. This transition has a high reconversion economic cost that Lebanon would not have to pay. Energy crops bring other socio-economic benefits such as crop substitution when properly regulated (this is relevant for the fight against drug crops in the country).

4.Lebanon should give attention to the development of technologies for the production of ethanol from lignocellulosic crops that are in the stage of becoming fully commercial within five years; energy crops require the development of on-site experience and usually also specific on-site research to adapt correctly and sustainably the species to harvest. These two conditions give Lebanon the right opportunity to step into the market avoiding the costs of transition that other countries will have to affront.

5.Local production of biodiesesl from used cooking oil and animal fat is recommendable. All regions in Lebanon offer the availability of this resource

6.Stimulation of the deployment of bioenergy by new policies (including a proper tariffing system), legislation and incentives to the market (as assumed under Scenario I) is key to reach the deployment of bioenergy in Lebanon. Examples of the introduction of new legislation or policies to stimulate the deployment of bioenergy are enforcement of standards for industrial wastewater discharges; the development of wastewater treatment plans; national master plans favoring the valorization of sludge or forest management plan and additional legislative changes are developed that consider harvesting in sustainable conditions.

7.Financial incentives can include the restructuring of existing tariffs to eliminate the financial deficit in the electricity sector and to improve collection rates, the encouragement of public private partnerships and encouraging innovative financial mechanisms.

8.In all cases, it is important not to focus on one single biomass resource or region for the development and deployment of bioenergy in Lebanon. Solutions should be sought in the exploitation of a combination of biomass resources, deployed in various Mohafazats. Given the linkages of bioenergy with other sectors (agriculture, water, forestry) cooperation should be sought with these sectors in the further development of policies and market initiatives.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

CEDRO	Country Energy Efficiency and Renewable Energy Demonstration Project for the recovery of Lebanon
CDR	Council for Development & Reconstruction
FAO	Food & Agriculture Organisation
GDP	Gross Domestic Product
GIS	Geographic Information System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH or German technical cooperation
HHV	High Heating Value
TOE	Tons of oil equivalents
LARI	Lebanese Agricultural Research Institute
LHV	Low Heating Value
MoA	Ministry of Agriculture
MoE	Ministry of Environment
MoET	Ministry of Economy and Trade
O&M	Operation & Maintenance
OMSAR	Office of the Minister of State for Administrative Reform
UNDP	United Nations Development Program
UNIDO	United Nations Industrial Organisation
WtE	Waste to Energy
WWTP	Wastewater Treatment Plant

CHAPTER 1

BIOENERGY RESOURCE ASSESSMENT FOR LEBANON

INTRODUCTION

Lebanon has a difficult energy situation due to its external dependence on fossil fuels, growing energy needs, subsidized energy prices, and a high energy import bill. Lebanon has no known fossil fuel resources, although there may be potential natural gas finds off the Lebanese coast. Apart from relatively small hydroelectric resources and the import of 50-100 megawatts of electricity semi-annually from Syria, all energy needs are met with imports of petroleum products, which represent over 5 million TOEs (tons of oil equivalents) in the last few years.

The power sector accounts for about 50% of fuel imports (World Bank, 2008). Lebanon depends on natural gas imports from Egypt and Syria. Further development of domestic renewable energy sources is, therefore, a priority within Lebanese energy policy. Previous analysis has already identified a large potential for further growth. These resources include further expansion of hydropower, wind, solar and sustainable biomass and biofuels. Apart from increasing the security of supply, increasing the share of sustainable bioenergy will contribute to the other pillars of Lebanon's energy strategy: environmental protection and the affordability of energy for the various sectors of the Lebanese economy.

This chapter presents the evaluation and findings of the current overall and realistic potential of bioenergy in Lebanon.

For the evaluation of current potentials, the following sources have been used:

- Publicly available information such as studies, reports, files, statistics and remote sensing data from the National Council for Scientific Research Lebanon;
- Experience of the consortium;
- Published quantitative data procured from relevant ministries;
- Information collected with on-ground surveys and interviews of experts;
- Information collected through UN agencies such as the United Nations Industrial Organisation (UNIDO), FAO, etc…;
- Information received from the UNDP-CEDRO Project.

II.DEFINITION OF BIOMASS STREAMS STUDIED

An accurate definition of biomass is essential to avoid double counting of certain streams.
Table 1 gives a detailed definition of each bioenergy stream considered for this study

Table 1: Definition and characterization of biomass streams

	Biomass resources	Definition
Forestry	Woody biomass and fellings	Trees, shrubs, bushes, or products derived from woody plants
	Residues from fellings	Forest residue, chips or logs from final fellings (tops, branches, bark), thinnings (whole tree chips), delimbed small-sized trees (stem chips) or stumps
Wood and paper industry	Wood residues from sawmilling, wood-working, furniture industry	Chemically untreated wood fractions from mechanical wood processing industry, i.e. sawdust, bark and chips
	By-products from paper industry	Black liquor, sludge, pulp and wood residues
Agriculture	Residues of olive trees	Olive tree clippings and straw
	Residues of fruit trees	Fruit tree clippings and straw
	Residues of cereals	Agriculture crop residues include wheat straw, barley straw
	Manure	Animal and poultry manures
Energy crops	Cereals for biofuels	Wheat, barley, and other cereals dedicated to biofuels
	Lignocellulosic energy crops	Woody energy crops: short rotation coppice (e.g. willow, poplar) and Herbaceous Energy Crops: energy grasses (e.g. reed canary grass, miscanthus)
	Oilseed crops	Such as sunflower, soybean, palm fruit, cotton seed
Food processing industry	Animal fat	Remaining animal fat after industrial processing
	Cake by-products	Remaining after olive oil extraction or oil seed extraction
	Slaughterhouse residues	Fat residues, meat unfit for human consumption, blood, viscera
	Organic residues and waste from food processing industry	Fruit and vegetable wastes such as peel, pulp, grape marc, pulp and fibre from sugar and starch extraction, filter sludge, food that does not meet quality control standards
	Wastewater and sludge from food processing industry	Liquid waste and sludge generated by washing meat, fruit and vegetables, blanching fruit and vegetables, pre-cooking meats, poultry and fish, cleaning and processing operations as well as wine making and sludge from wastewater treatment plants
Municipal solid waste and non-hazardous industrial waste	Biodegradable fraction of municipal solid waste	Residential and institutional post-consumer waste containing a significant proportion organic material (e.g. food waste, waste paper, cardboard, wood waste and yard wastes)
	Landfill potential	Methane gas extraction from existing landfills
	Industrial and Commercial waste	Waste paper, cardboard and wood pallets, organic residues Waste from commercial, supermarkets, restaurants
	Waste wood	Chemically treated industrial wood residues (no heavy metals or halogenated organic compounds), construction and demolition wood
	Municipal sewage sludge	Sludge from municipal wastewater treatment
	Landscape management residues	Urban wood waste consists of lawn and tree trimmings, whole tree trunks
	Yellow grease	Used cooking oil collected from restaurants and grease pits

The definitions proposed in this section will thus lead to clear counting of resources.

III. FULL CHARACTERIZATION OF ANALYSED BIOMASS STREAMS

A full characterization of all bioenergy streams considered in this study is given in the Volume "Annexes" of this study, Chapter 1, Annex I "Bioenergy streams factsheets." The characterisation of bioenergy streams includes the following information, when available:

- Production rate: Quantities produced by relevant unit
- Volume ratios: for streams based on by-products, waste or residues of industrial or agricultural production, expressed as % of production
- Seasonality: Existence or not of seasonal variations
- Calorific Value: expresses the energy potential in MJ/kg
- Moisture content: water content in %
- Methane production potential: expressed in Nm3 CH4 per unit of dry matter
- Transformation and valorisation technologies: possible families of technologies applicable to the stream
- Transportation requirements and issues: issues to be considered in the analysis of the stream reflecting collection and logistics, taken into account for feasibility and sustainability
- Economic barriers for realising the potential

IV. DIVISION OF THE NATIONAL TERRITORY IN RELEVANT AREAS OF INFLUENCE

Several aspects impact the availability and feasibility of use of the bioenergy streams in the short and long term. The most important aspects impacting availability are the qualification of protected areas or natural reserves, general weather conditions, soil conditions influencing yield levels, soil type (carbon stock), geography, and transportation infrastructure. Weather and soil type have direct impact on the yield performance and on the sustainability of the bioenergy chains.

Lebanon is a diversified country in terms of population, superficies, climate, agricultural production, and biodiversity. Thus, from one region to the other, bioenergy streams selected will not necessarily be the same.

The division of the country in mohafazat complies with the natural division of the country and is quite adequate to the assessment of the bioenergy streams. Therefore, to be effective and anticipate limitations, Lebanon's six mohafazats have been kept as areas of study[1]. Collection of data has been made for those six mohafazats and for cazas when available and reliable at this level.

IV.1 COUNTRY OVERVIEW

Administratively, the country is divided into six regions, called mohafazats, which are further subdivided into 26 districts, called cazas, including the capital, Beirut. Each caza and mohafazat has an administrative centre, which is most often one of the largest cities in the region. Table 2 shows all administrative divisions and subdivisions in Lebanon.

Lebanon comprises five distinct geomorphologic regions, namely:

- The coastal zone, including the shoreline and the continental shelf, the coastal plain, and the foothills of Mount Lebanon, rises to an altitude of 250 meters. It constitutes 13% of the country's total surface;
- The Mount Lebanon chain, including middle and high-elevation zones, rises from Akkar in the north and extends south to the hills of Jabal Amel. The highest peak is Qornet el-Sawda (3,087 meters). Mount Sannine (2,624 meters) is the second highest peak in the region. It constitutes 47% of the country's total surface;
- The Beqaa Valley, a fertile land corridor separating the Mount Lebanon and Anti-Lebanon chains, is drained to the north by the Aassi River and to the South by the Litani River. The central part of the valley was occupied by lakes and seasonally-flooded marshes until it was drained for agriculture during the 19th century. The only large natural wetland that survived conversion is the Ammiq swamp, a small remnant swamp along the Litani River that all but dries up by the end of September. It constitutes 14% of the country's total surface;
- The Anti-Lebanon chain, which extends across the Lebanese-Syrian borders along the eastern part of the country and includes, at its Southern terminus, Jabal el Cheikh (Mt. Hermon, 2,814 meters), which distributes rainfall and

[1] The number of mohafazat in Lebanon may be subject to official change by the Lebanese Government in the near future.

snowmelt into at least three main watersheds across Lebanon, and its neighbouring states. It constitutes 19% of the country's total surface;

- South Lebanon, an elevated plateau that extends a short distance inland from the western shores of South Lebanon to the Mount Hermon foothills in the East. Seasonal streams flowing from east to west into the Mediterranean Sea intersect this region. It constitutes 7% of the country's total surface.

Table 2: Administrative divisions and subdivisions

Mohafazat	Cazas
Beirut	Beirut
Mount Lebanon	Aaley
	Baabda
	Chouf
	Jbayl
	Kesrouane
	Matn
North Lebanon	Batroun
	Bcharreh
	Koura
	Minieh – Danniyeh
	Trablous
	Zgharta
	Aakkar
Beqaa	West Beqaa
	Rachaiya
	Zahleh
	Baalbek
	Hermel
South Lebanon	Tyr
	Jezzine
	Saida
Nabatiyeh	Bent Jbayl
	Hasbaiya
	Marjaayoun
	Nabatiyeh

IV.2 CLIMATE

The climate in Lebanon is subject to considerable variations due to altitude and location. Most of Lebanon has a Mediterranean climate, with warm dry summers, cool wet winters with snow in the mountains.

Precipitation in Lebanon is unevenly distributed between locations and seasons. Up to 90% of total precipitation falls between November and April. Several parts of the country experience zero rainfall during the remaining six months. Apart from North Beqaa, precipitation is heavy throughout the country with regional or local nuances depending on several factors: altitude, latitude and continental character;

- Coastal areas experience 600-1000 mm annual rainfall.
- This amount increases to over 1000 mm in the North of Beirut and to between 1000-1400 mm in the neighbouring mountain areas.
- The inland areas experience precipitation going down to 200 mm annually in the North, east of the massif Makmel, 600 mm in the central regions and between 600-1000 mm in the South.
- In the Beqaa region, rainfall decreases inversely with the elevation of the western chain and also from south to north. The southern stations generally receive over 700 mm annually (Makké Traboulsi, 2010). Figure 1 below shows the precipitation levels in Lebanon.

The relative humidity on the coast is largely constant and oscillates around 70%. Humidity variations in the mountains vary between 60 to 80% in the winter and 40 to 60% in the summer. On the other hand, the Beqaa Valley has a relatively high humidity (60 to 80%) during winter that decreases sharply during the summer to become extremely dry (near 40% in Northern Beqaa).

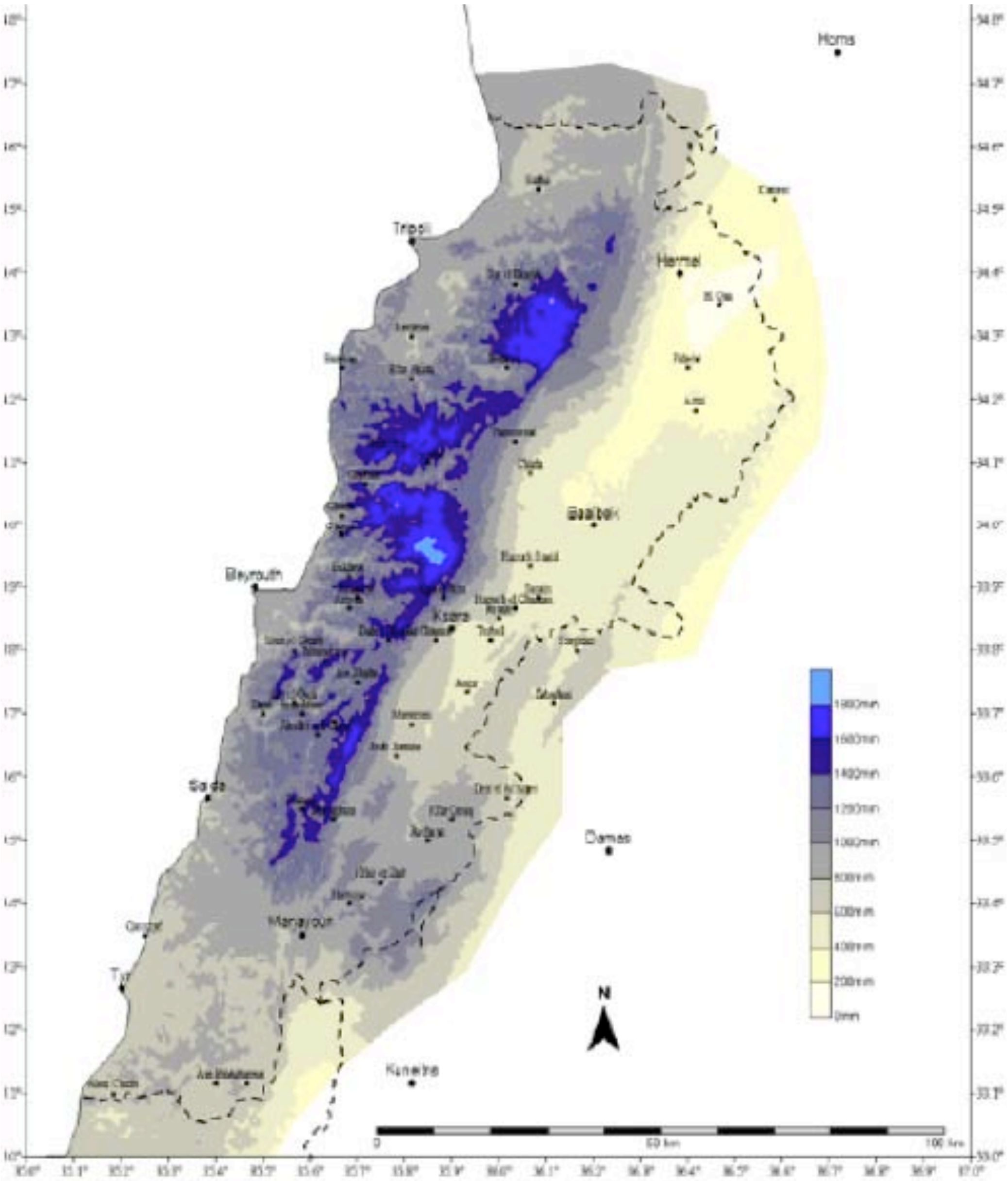
Regarding temperature levels, the coastal plain is considered as subtropical, with a mean temperature in Beirut of 27°C in summer and 14°C in winter. In the mountains, temperatures are found to decrease with elevation, while in the Beqaa Valley and the Anti-Lebanon Mountains the temperatures are relatively high in the summer and drop drastically in the winter.

IV.3 GEOLOGY

Lebanon's geology consists almost exclusively of fractured and cavernous limestone. Most are of Cretaceous origin, but with Jurassic limestone principally in the south and basaltic rocks particularly in the North.

Figure1. National precipitation map

(Makké Traboulsi, 2010)

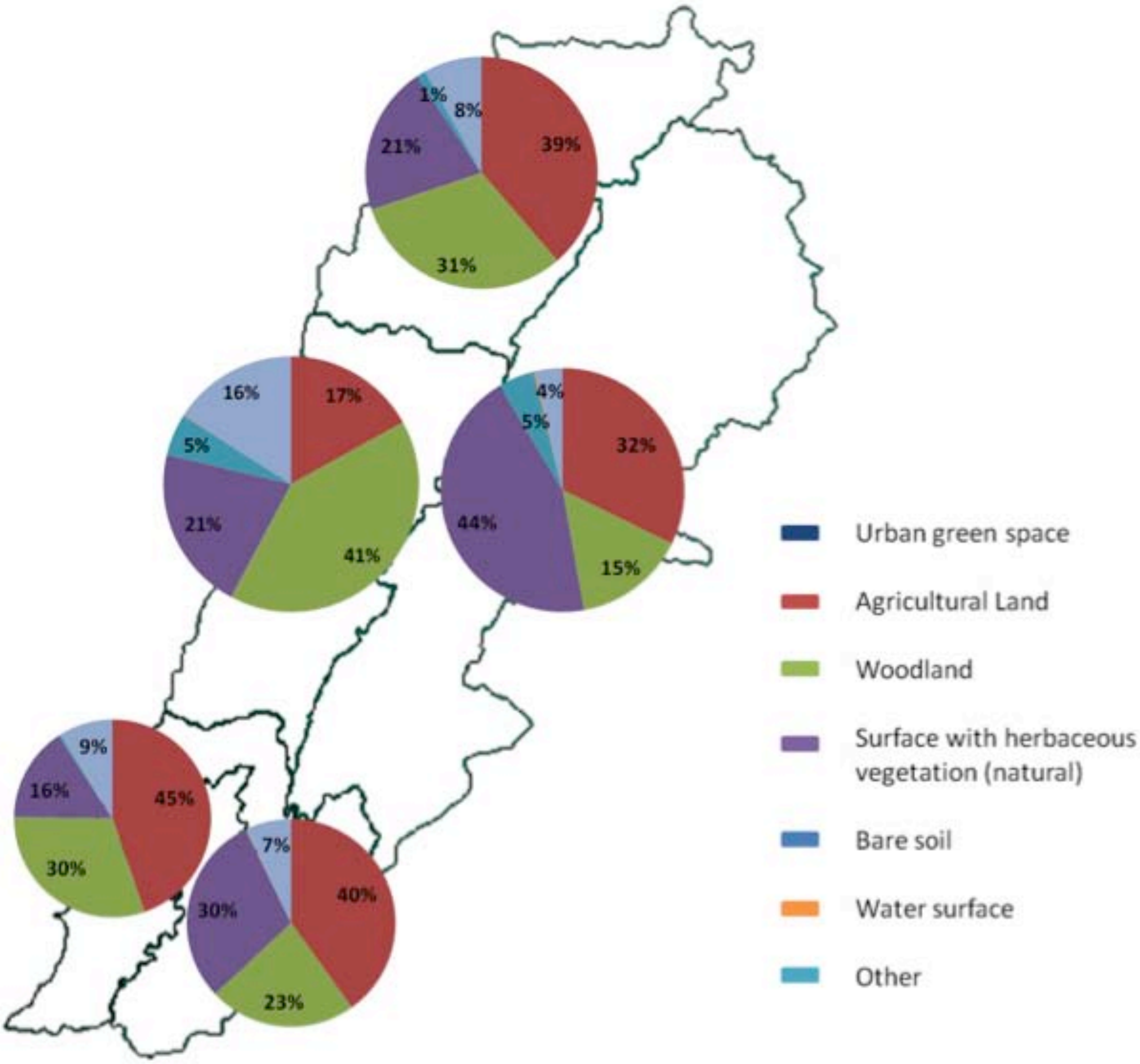


The fertile soils of the coastal plain are alluvial, while the soils at higher elevations and in the Beqaa are a typical example of the Mediterranean terra rossa. Geological processes include weathering, mass movements and erosion. In the semi-arid and dry sub humid climatic conditions of Lebanon where rainfall is often torrential, erosion is strongly linked to flash floods with devastating effects. An analysis of such events over the last three decades shows they are frequent[2], recurrent and widespread and have significantly contributed to land degradation. Mass movements[3] are very common in Lebanon, and the process is considered a significant aspect of superficial instability contributing to land degradation.

IV.4 LAND USE PER MOHAFAZAT AND CAZAS

An analysis of national GIS data provides an understanding of land use in each mohafazat and caza as shown in Figure 2 and Figure 3.

Figure 2 Land use per mohafazat (except Beirut)[4]

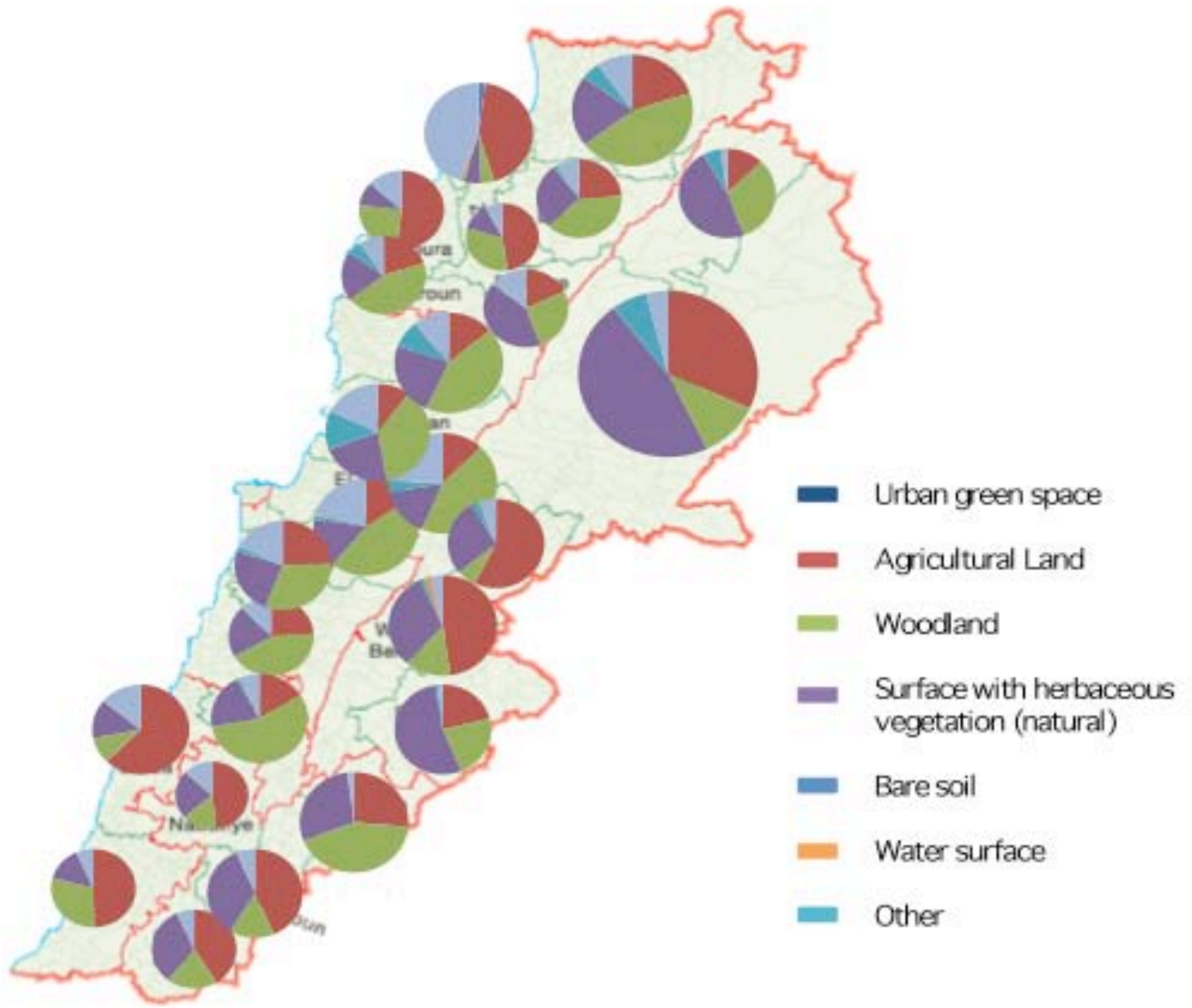


[2] According to UNDP's Flood Risk Management and Water harvesting for Livelihood Recovery in Baalback-Hermel project Report, repetitive flash floods have occured in the past years: in 1987, in the periods May-June and Autumn, then in 1994, 1999, 2001, twice in 2004 and more recently in 2007. It appears that these occurences are more frequent in recent years, with soil erosion impacts extending to tens of kilometers, leading, along with other factors, to higher risks of land degradation.

[3] Mass movement, also known as mass wasting or slope movement, is the geomorphic process by which soil, regolith, and rock move down slope under the force of gravity. Types of mass movement include creep, slides, flow, topple and falls, each with its own characteristic features, and taking place over timescales from seconds to years.

[4] Other' represents artificial areas (urban areas, Activity area, Non built-up artificial area, and artificial non-agricultural vegetated areas), unproductive area (beaches, rocks) and Wetland.

Figure 3: Land use per cazas (except Beirut)



V.5 AGRICULTURE IN LEBANON

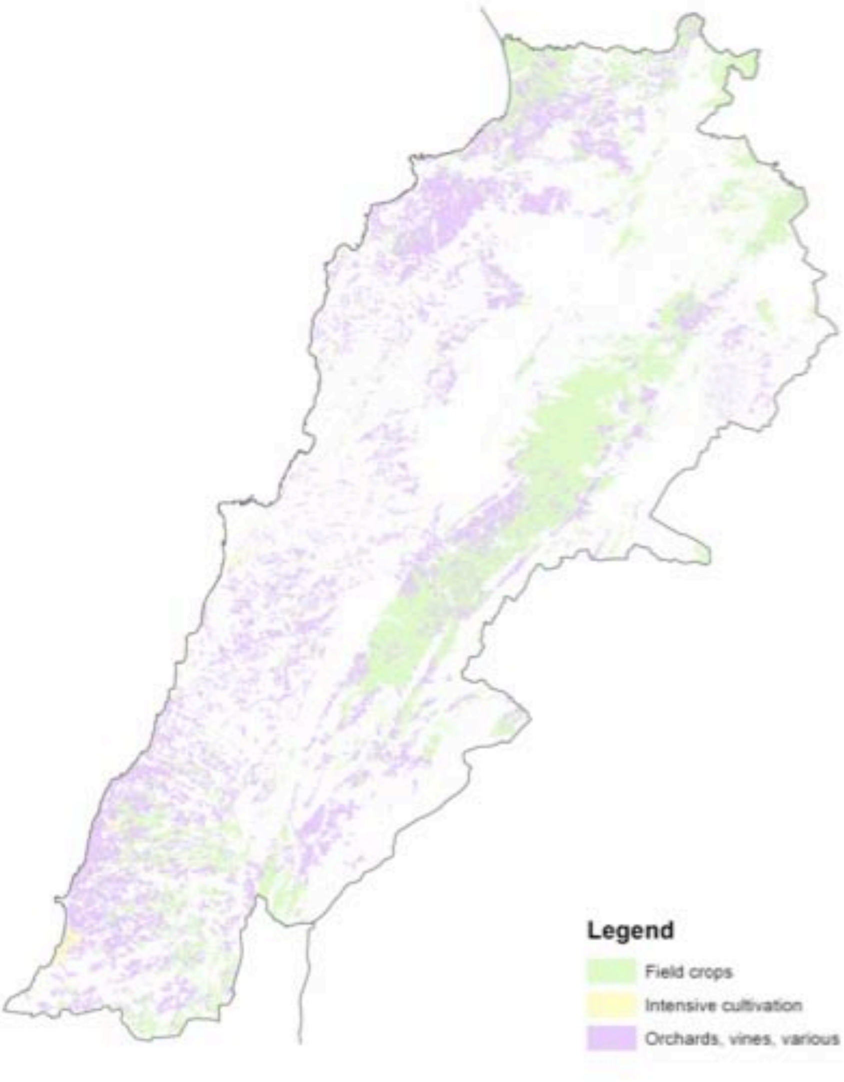
Agriculture in Lebanon is labour intensive and in need of modernization, yet it is an important economic sector that contributes directly to the country's exports and the local food industry. Lebanon offers a very wide and diverse range of cultivations, due to the differing landforms and the variability of crops. The agricultural regions can be divided into the coastal zone, the western slopes of Mount Lebanon, the Beqaa valley, the anti-Lebanon and Hermon mountains, and the southern hills. Current use of agricultural land is shown in Figure 4.

The coastal zone is cultivated with subtropical crops (bananas, oranges, avocado, etc.) with higher agriculture intensity in the south, along with wheat and a variety of irrigated crops and vegetables concentrated in the northern coastal plain of Akkar.

The western slopes of Mount Lebanon are mainly cultivated with permanent crops that include olives, fruit trees, and vineyards that blend with existing wooded lands. Agricultural activities intensify in the Beqaa valley and include mainly irrigated cultivation of cereals, fruit trees, as well as annual and biannual crops in the south and central Beqaa. The northern part of Beqaa allows for dry farming and some vine growing. On the other hand, the Anti-Lebanon and Hermon Mountain only allow for scattered agriculture due to the harsh topography, dry climate, and low population.

Finally, the southern hills support the cultivation of olive trees, grapes, fig trees and tobacco *(Source: FAO)*.

Figure 4: Current use of agricultural lands
(DAR – IAURIF, 2003)



IV.6 WATER

Water is one of Lebanon's most precious resources. However, despite the abundance of this resource, the country is expected to experience a water deficit within 10-15 years, unless sound and radical water management policies are developed and implemented. Human activities exert strong pressures on both the quantity (water extraction) and the quality (water pollution) of water resources. In addition, many other factors affect the water cycle (deforestation, dams, irrigation, drainage canals), altering the conditions for water replenishment. Continued soil erosion and loss of plant cover (including forests), will lead to scarcer water resources and poorer water quality. It is estimated that precipitation results in an average yearly flow of 8,600 million cubic meters. This flow gives rise to 40 major streams and rivers, and more than 2,000 springs. Lebanon has no navigable rivers or major natural lakes; however springs in the Beqaa feed two important rivers: the Litani and the Assi. Major springs can be found along the western slopes of the Lebanon Mountain chain. Many streams that flow throughout the country run only during the winter season. It is also estimated that groundwater quantity available for exploitation ranges between 400 and 1,000 Mm3/year.

V.ASSESSMENT OF BIOENERGY STREAMS WITH MOST INTERESTING POTENTIAL

V.1 METHODOLOGY

To select the bioenergy streams with the most interesting potential for Lebanon, a three steps approach has been used:

Step 1: Collection of remote sensing data and relevant literature available to characterize the bioenergy potential resource availability at a national level.

Step 2: Initial assessment of the accessibility, collectability and convertibility of each bioenergy stream. This allows the definition of the production areas, the potential volumes of residues and waste, and the identification the bioenergy streams that have the best potential for development in Lebanon.

Step 3: Study and in-depth assessment of shortlisted bioenergy streams where information was available at the mohafazat and cazas level. On-ground surveys have been conducted to collect information not readily available, refine first estimates and verify/confirm the results and conclusions.

The following table summarizes the quantity and the energy potential of each biomass resources. The ten most promising biomass streams have been ranked with the following criteria:

- Quantity
- Energy potential
- Competition with other uses
- Accessibility of the resource
- Current Legal framework

ON-GROUND SURVEYS

On-ground surveys and interviews with key private and public entities representatives have been either performed through telephone calls, emails, or face to face interviews.

A full report describing the results of ground surveys and interviews is presented in the volume "Annexes" of this study, chapter 1, annex II "Ground-surveys and interviews."

Data collected from these ground-surveys has been processed and analysed for each region. A quantitative assessment, as well as ratios and methodology retained for calculation of the potential in terms of primary energy for each bioenergy stream, is presented in the following sections.

The following sections show the results of the assessment made for all bioenergy streams.

V.2 WOODY BIOMASS AND FELLINGS

The forests of Lebanon are very rich in their variation and characteristics. They represent a unique feature in the arid environment of the Eastern Mediterranean. Until June 2006, they covered around 13.2% of the overall area of Lebanon. According to key experts, forest is showing a trend towards growth and an increase of surfaces. Ownership of forest is split between the state (27.3%), municipalities (10.1%), and private owners accounting for the rest (FAO, 2005). They represent a very important potential of biomass although geographical distribution will induce some limitations (exploitable state-owned forest are notably located in Akkar and in Hasbaya whereas exploitation in Hermel is more challenging given that forests are privately-owned). Many forests are also used as pasture grounds, giving rise to potential competition.

A 2005 study carried out by the Forestry Department of Food and Agriculture Organisation (FAO) of the United Nations estimated the living biomass of forest and wooded land as shown in Table 3.

Table 3: Forest and wooded lands in Lebanon (FAO, 2005)

Land Use	Above Ground Biomass (Million Tons (MT))	Below Ground Biomass (Million Tons (MT))	Total Living Biomass (Million Tons (MT))
Forest	2.793	0.797	3.59
Other wooded Lands	0.325	0.082	0.407

The following definitions were adopted in this national study:

Category	Definition
Forest	Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.
Other wooded land	Land not classified as "Forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.
Above-ground biomass	All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.
Below-ground biomass	All living biomass of live roots. Fine roots of less than 2mm diameter are excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead wood biomass	All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

With a wide variety of climatic and geologic conditions, there are numerous forest types and tree species in Lebanon.

Forest Types

Cedar, Fir and Juniper forests

These three forest types are found together as mixed evergreen forests in some parts of the country, but pure, or nearly pure, strands of each type are also found. Both cedar (Cedrus libani) and fir (Abies cilicica) are generally found between altitudes of 1,300 to 2,000 meters. Junipers (Juniperus excelsa and Juniperus oxycedrus) are found growing with fir and cedar starting at altitude of 1,500 meters. Occasionally, between altitudes of 2,000 meters and the timberline (about 2400 meters), pure stands of junipers are found, becoming increasingly scrubby as altitude increases.

The remaining cedar forests, which once covered the mountainous Oro-mediterranean zone (see Vegetation Zones, Section 2.2.2), are now found only as mosaic patches, occupying approximately 2,200 hectares on the western slopes of the Mount Lebanon chain. These forests are located on the western slopes of the Mount Lebanon range, in the following localities from north to south: Qamou'a, Dinnieh, Bsharre, Ehden, Sweisse, Hadeth-tannourine, Jaj, Bmohray, Ain-Zhalta, Barouk and Maasser al-Shouf.

Mixed forests of fir and cedar are found in Qamou'a, and in Ehden, where it grows at a lower density mixed with cedar and other tree species. Sparse Grecian Juniper forests, covering an area of 9,000 ha, grow in patches on the eastern slopes of the Mount Lebanon chain and in the Caza of Hermel. All these forests have suffered from deforestation and severely eroded soils for a long time, leading to severe deterioration in their natural habitats and invasion by degraded guarrigue.

Pine forests

Stone pine (Pinus pinea) forests occupy an area of 17,000 ha with nearly half of this managed for the production of pine nuts. These forests are found on the western slopes of the Mountain Lebanon chain at altitudes ranging from 800 m to 1500 m above sea level, specifically on the sandy soils of Metn and Jezzine. The area covered by these forests has decreased primarily as a result of war, forest fires, and urban development. The other pine forests types - Calabrian pine (Pinus brutia) and Allepo pine (Pinus halepensis) - grow between altitudes of 500 m and 1,300/1,500 m on the western slopes of the Mount Lebanon chain. Calabrian pine forests occupy a large area in the North, while Aleppo pines cover an area of 400-500 ha in the southern part of the country in the Cazas of Marjaoun and Hasbaya.

Oak forests

The kermes oak (Quercus calliprinos) forests cover 10 percent (40,000 ha) of the land area, and their dominance in the lower altitude of the western slopes of the Mount Lebanon range is an indicator of habitat degradation (USAID, 2009). The oak coppices found on the eastern slopes of Mount Lebanon extend in a very discontinuous manner in the low elevation zone between Yammouneh and Hermel and on the slopes of Jabal Barouk/Niha. On the western slopes of the Anti-Lebanon chain, only a few diminutive oak stands persist, mainly east of Baalbeck, Masnaa and around Rachaya. In the South, a few degraded and overgrazed oak coppices can be found on the hills of Jabal Amel. These forests have been subject to severe cutting for charcoal production and to overgrazing, which has led to their deterioration and their replacement by highly degraded garrigue. Additionally, sporadic trees of Turkey oak (Q. cerris) are found in Qamou'a and Ehden, Cedar Oak (Q. cedrorum) and Lebanon oak (Q. libani) in Ehden, pennatifid oak (Q. pinnatifida) in Ehden, Hadeth-Tannourine and Bsharre, and brant's oak (Q. brantii ssp. look) in Ain Zhalta and Barouk. Cyprus oak (Q. infectoria) is found in cedar and fir forests.

Evergreen Cypress

The only remaining forest patch of cypress (Cupressus sempervirens) is found in Akkar on hard limestone. Other species in this patch include Mediterranean buckhorn, Kermes oak (Q. infectoria var. boissieri), and the oriental strawberry tree (Arbutus andrachne). The mesic nature of this patch is indicated by the presence in this association of maple (Acer spp), whitethorn (Crataegus monogyna), false senna (Coronilla emeroides), hop-hornbeam (Ostrya carpinifolia) and others. In the Northern part of the Mount Lebanon chain, sporadic cypress tree populations are found in Calabrian pine forests, in Karm-Sadet and Aito villages.

Table 4, Table 5 and Table 6 indicate wooded lands and forests in Lebanon and their distribution type.

Table 4: Forest types breakdown*

Forest types	GS1 (Million m³)	%
Cedar and Juniper forest	1,01	18%
Pine forests	2,92	52%
Oak forests	1,45	26%
Others	0,22	4%
Total	5,60	

Table5: Forest species in Lebanon and its distribution* (FAO, 2005)

Species	GS (million m³)	AGB1 (million tonnes)	BGB2 (million tonnes)
Quercus cerris	0.96	0.78	0.21
Pinus pinea	1.55	0.62	0.22
Pinus brutia	1.3	0.68	0.18
Cedrus libani	0.31	0.16	0.04
Juniperus excelsa	0.29	0.15	0.04
Juniperus drupacea	0.09	0.05	0.01
Quercus infectoria	0.186	0.15	0.04
Quercus calliprinos	0.177	0.14	0.04
Ostrya carpinifolia	0.016	0.01	0.003
Platanus orientalis	0.019	0.013	0.004
Other species	0.06	0.04	0.001
Total	**4.967**	**2.793**	**0.797**

Table 6: Other wooded lands in Lebanon and its distribution* (FAO, 2005)

Species	GS (million m³)	AGB (million tonnes)	BGB (million tonnes)
Juniperus excelsa	0.32	0.17	0.04
Quercus calliprinos	0.1	0.08	0.02
Pinus brutia	0.05	0.03	0.01
Pinus pinea	0.02	0.01	0.003
Pyrus syriaca	0.01	0.01	0.002
Populus alba	0.01	0.005	0.001
Quercus infectoria	0.01	0.008	0.002
Prunus amygdalis	0.006	0.004	0.001
Prunus ursina	0.006	0.001	0.001
Other species	0.12	0.007	0.002
Total	**0.544**	**0.325**	**0.082**

* GS: Growing Stock. Volume over bark of all living trees more than 10 cm in diameter at breast height (or above buttress if these are higher). It includes the stem from ground level or stump height up to top of bole.

* AGB: Above-ground biomass. All living biomass above the soil including stem, stump, branches, bark seeds, and foliage.

* BGB: Below-ground biomass. All living biomass of live roots. Fine roots of less than 2mm diameter are excluded because these often cannot be distinguished empirically from soil organic matter or litter.

Potential assessment

Today, harvesting forests is not allowed in Lebanon except for broad leave species such as Infectoria and Calliprinos for charcoal production and for broad leave species and Pine species from the conifers family for wood fuel production. Law enforcement is weak; hence it is very difficult to assess the cutting permit volumes and geographic distribution for broad leave species. According to the interview with Nabil Assaf, Forest Engineer at the Ministry of Environment, 60% of wood cutting activities are not recorded. This percentage differs depending on the caza, geographical specificities and consequently on the type of trees.

Nevertheless the potential can be estimated considering that forests can be harvested in a sustainable way, and sustainability in this context means linking harvest volumes with the forest regeneration cycle. Considering that cedar and juniper forests are either protected or located in difficult harvesting areas, estimation is made only with pine forests and broadleaves forests, meaning with 82% of total forests.

The times needed for the regeneration of the broadleaved forests are the followings[5]:

- Time of regeneration for Mount Lebanon: 15 years
- Time of regeneration for Beqaa: 25 years
- Time of regeneration for others areas: 20 years

It is assumed that:

- Lower Heating Value[6] of forest wood is between 14.0 (low assumption) and 18.0 (high assumption) MJ/Kg.
- Average moisture content for forest wood is 20%.

[5] Interview with Jean Stephan, Forest Engineer at the Ministry of Agriculture

[6] Heating Value is defined as the amount of energy released when a fuel is burned completely in a steady-flow process and the products are returned to the state of the reactants. The heating value is dependent on the phase of water/steam in the combustion products. If H2O is in liquid form, heating value is called HHV (higher Heating Value). When H2O is in vapor form, heating value is called LHV (Lower Heating Value).

The methodology used to breakdown the living biomass per caza is to calculate a weight production potential by caza, while taking into account the surface area of forests and the density of the forests.

As shown during on-ground survey interviews, the density of dense forest is 65% and the density of sparse forest and shrubs is 10%.
These figures are applied to each caza. Table 7 shows all living biomass per caza.

Table 7: Living biomass per caza

	Calculation of region weight regarding biomass				
	Dense forest	Sparse Forest	Shrubs	Total with density	Weight
Beirut	**0**	**0**	**12**	**1**	**0,00%**
Baabda	3 135	3 959	1 659	2 599	4,94%
El Metn	3 498	4 354	3 459	3 055	5,80%
Chouf	3 931	6 245	9 457	4 125	7,84%
Aaley	1 749	2 925	3 355	1 765	3,35%
Keserwan	4 240	4 362	3 647	3 557	6,76%
Jbeil	3 550	6 814	7 828	3 772	7,16%
Mount Lebanon	**20 102**	**28 660**	**29 405**	**18 873**	**35,85%**
Tripoli	0	18	87	10	0,02%
Koura	661	1 101	2 503	790	1,50%
Zgharta	2 243	1 836	1 401	1 781	3,38%
Batroun	3 559	4 104	4 628	3 187	6,05%
Akkar	6 053	9 062	5 567	5 397	10,25%
Bcharre	2 144	1 155	997	1 608	3,05%
Menieh Daniyeh	3 379	4 970	5 454	3 239	6,15%
North Lebanon	**18 039**	**22 245**	**20 637**	**16 013**	**30,41%**
Zahlé	75	386	2 309	318	0,60%
West Bakaa	199	1 416	4 019	673	1,28%
Baalback	1 660	10 785	13 110	3 469	6,59%
Rachaiya	50	1 071	11 246	1 264	2,40%
Hermel	375	8 834	7 611	1 888	3,59%
Beqaa	**2 358**	**22 492**	**38 294**	**7 611**	**14,46%**
Saida	83	340	2 069	295	0,56%
Sour	1 023	3 306	7 506	1 746	3,32%
Jezzine	4 328	3 110	5 258	3 650	6,93%
South Lebanon	**5 434**	**6 756**	**14 833**	**5 691**	**10,81%**
Nabatiyeh	868	742	2 985	937	1,78%
Bent Jbeil	496	915	3 694	783	1,49%
Marjeyoun	738	583	2 492	787	1,49%
Hasbaiya	1 536	2 311	7 246	1 954	3,71%
Nabatiyeh	**3 637**	**4 550**	**16 418**	**4 461**	**8,47%**
Lebanon	**49 570**	**84 703**	**119 599**	**52 651**	**100,00%**

Table 7 enables the calculation of the energy potential from forest harvesting for Lebanon per caza, using the formula: *Energy potential* = Quantity of biomass available (below + above ground biomass) * 82% (excluding cedar and Juniper because they are either protected or located in difficult harvesting area) / (Years necessary to respect forest regeneration) * (1- moisture content) * heating value of forest wood.

Example for Baadba: Energy potential (low assumption) is (1448 113 + 44 434)*82%/15*(1-20%)*14.0 = 117,839 GJ. Table 8 indicates the energy potential estimated for living biomass per caza.

Table 8: Energy potential estimate for living biomass per caza

	Weighted biomass		Forest regeneration (years)	Potential estimate (GJ)	
	Above ground	Below ground		Low	High
Beirut	**68**	**20**	**20**	**41**	**52**
Baabda	148 113	44 434	15	117 839	151 507
El Metn	174 059	52 218	15	138 481	178 047
Chouf	235 054	70 516	15	187 009	240 440
Aaley	100 550	30 165	15	79 997	102 854
Keserwan	202 667	60 800	15	161 242	207 311
Jbeil	214 926	64 478	15	170 995	219 851
Mount Lebanon	**1 075 368**	**322 610**	**15**	**855 563**	**1 100 009**
Tripoli	596	179	20	356	458
Koura	45 031	13 509	20	26 870	34 547
Zgharta	101 504	30 451	20	60 568	77 873
Batroun	181 565	54 470	20	108 340	139 294
Akkar	307 522	92 257	20	183 499	235 927
Bcharre	91 648	27 494	20	54 686	70 311
Menieh Daniyeh	184 550	55 365	20	110 121	141 584
North Lebanon	**912 417**	**273 725**	**20**	**544 439**	**699 993**
Zahlé	18 130	5 439	25	8 654	11 127
West Bakaa	38 320	11 496	25	18 292	23 519
Baalback	197 653	59 296	25	94 352	121 309
Rachaiya	72 018	21 605	25	34 378	44 201
Hermel	107 575	32 272	25	51 352	66 024
Beqaa	**433 695**	**130 108**	25	**207 029**	**266 180**
Saida	16 801	5 040	20	10 025	12 890
Sour	99 477	29 843	20	59 358	76 317
Jezzine	207 981	62 394	20	124 102	159 560
South Lebanon	**324 259**	**97 278**	**20**	**193 485**	**248 767**
Nabatiyeh	53 382	16 015	20	31 853	40 954
Bent Jbeil	44 630	13 389	20	26 631	34 239
Marjeyoun	44 840	13 452	20	26 756	34 401
Hasbaiya	111 341	33 402	20	66 437	85 420
Nabatiyeh	**254 193**	**76 258**	**20**	**151 677**	**195 013**
Lebanon	**3 000 000**	**900 000**		**1 952 234**	**2 510 015**

WOODY BIOMASS AVAILABILITY

Wood harvesting is forbidden currently in Lebanon except for charcoal and fuel wood production from broad leave species and from Pine species from the conifers family. Current policies are about reforestation, biodiversity protection, species protection, unauthorized harvesting prevention, and fire protection.

Only through a forest management plan considering sustainable harvesting would all the above objectives be met, in addition to providing a resource for bioenergy production. For this biomass stream to become available, such a 'sustainable harvesting plan' and the needed legislative changes are required.

CONCLUSION

Forest wood biomass stream presents an interesting theoretical potential. However, this potential is difficult to develop for several reasons: forests are located in the mountains where the first preoccupations are reforestation and biodiversity protection. "Sustainable harvesting" is difficult to establish as there is weak law enforcement in terms of cutting permit volumes and geographic distribution for broad leave species.

The total primary energy potential of woody biomass and fellings ranges between 1952 and 2510 TJ/year, which is a relatively significant amount. Forestry legislation will be reviewed for 2010-2020 with the implementation of the national forest plan. At this stage, Law 85 prohibits cutting in all conifer forests, including juniper forests, which in majority, are state forests, easily exploitable for bioenergy production. Efforts are currently deployed by NGOs, in collaboration with the Ministry of Agriculture to reactivating management rights in public land. Exclusions are allowed for urbanization, public works, public danger and insects' breakouts, even on privately owned land.

V.3 RESIDUES FROM FELLINGS

Sustainable forestry management through maintenance of the forest can provide a regular stream of biomass for energy. Pruning of trees, extraction of residues and shrubs, and fire risk management practices can generate biomass. The assessment of such a stream is based on assumptions of volumes produced and pruning frequencies. Considering that cedar and juniper forests are either protected or located in difficult harvesting areas, estimation is made only with pine forests and broadleaves forests, meaning with 82% of forests that can be gathered.

Moreover assuming a four years frequency for pruning in Lebanese forests, and considering that residues represent 20% of the total tree volume (FAO, 1990), the energy potential for residues from fellings can be estimated per caza as indicated in Table 9.

Table 9: Energy potential estimate for residues from fellings per caza

	Weighted Above Ground biomass	Potential Estimate (GJ)	
		Low	High
Beirut	**68**	**0**	**0**
Baabda	148 113	68 014	87 446
El Metn	174 059	79 928	102 764
Chouf	235 054	107 937	138 776
Aaley	100 550	46 172	59 365
Keserwan	202 667	93 065	119 655
Jbeil	214 926	98 694	126 892
Mount Lebanon	**1 075 368**	**493 809**	**634 897**
Tripoli	596	274	352
Koura	45 031	20 678	26 587
Zgharta	101 504	46 611	59 928
Batroun	181 565	83 375	107 196
Akkar	307 522	141 214	181 561
Bcharre	91 648	42 085	54 109
Menieh Daniyeh	184 550	84 745	108 958
North Lebanon	**912 417**	**418 982**	**538 691**
Zahlé	18 130	8 325	10 704
West Bakaa	38 320	17 596	22 624
Baalback	197 653	90 762	116 694
Rachaiya	72 018	33 071	42 519
Hermel	107 575	49 398	63 512
Beqaa	**433 695**	**199 153**	**256 054**
Saida	16 801	7 715	9 919
Sour	99 477	45 680	58 731
Jezzine	207 981	95 505	122 792
South Lebanon	**324 259**	**148 900**	**191 443**
Nabatiyeh	53 382	24 513	31 517
Bent Jbeil	44 630	20 494	26 349
Marjeyoun	44 840	20 591	26 474
Hasbaiya	111 341	51 128	65 736
Nabatiyeh	**254 193**	**116 725**	**150 076**
Lebanon	**3 000 000**	**1 377 600**	**1 771 200**

Sustainable forest management and extraction of fellings from the forest has other benefits such as limiting forest fire risks. As stated in the document "State of Lebanon's Forest 2007", the main threats to the Lebanese forests include fires, insects and diseases, urban expansion and changes in land use, quarries, wars, among other factors. The combination of all these threats, in addition to natural environmental conditions, is resulting in overall forest degradation. Forest fires are considered as the main factor in the decline of the Lebanese forests. The lack of management of the forests and other wooded lands, mainly in the regions susceptible to fire, increases the risk of occurrence and spread of the fires. Annually, an area of 1500 to 2000 ha is burned. Exceptionally, more than 3,700 ha of forested lands were burned in the year 2006-2007.

RESIDUES FROM FELLINGS AVAILABILITY

Pruning of forest is allowed, but is not yet developed. Furthermore, the overall potential evaluated in Table 9 cannot be achieved fully given that parts of the forest are in areas where pruning or extraction of residues is uneasy due to difficult access and steep slopes for conventional logging machinery. However extracting methods such as the cable logging method can be implemented as a remedy in areas where access is difficult.

CONCLUSION

The wood residue stream from thinning operations and final felling are an interesting bioenergy potential that ranges from 1378 to 1771 TJ/year of primary energy. Its development, in areas where it is possible, would also provide a powerful mean for the fight against forest fires. The assessment shows that forest residues constitute a significant and untapped biomass resource that could be exploited for energy purposes and is therefore ranked first out of the ten identified streams.

V.4 WOOD RESIDUES FROM SAWMILLING, WOOD-WORKING, FURNITURE INDUSTRY

There is a very limited sawmilling industry in Lebanon partially due to the fact that wood harvesting is strongly limited. The Lebanese wood industry, which works in the field of woodcutting and furniture making, is one of the most traditional industries in the country. However its' plants are small and very scattered geographically. The industry is very fragmented.

Consequently, the wood residues from wood transformation industries in Lebanon are currently too limited in volume and too dispersed geographically to consider an economically viable collection of the residues for bioenergy production.

To this end, this stream has been excluded from the analysis.

V.5 BY-PRODUCTS FROM PAPER INDUSTRY

According to the Climate Change Country Report (MoE, 1999), the paper industry is one of the major industries in Lebanon.

Amongst the residues or by-products from this industry that are typically considered for bioenergy, none are generated by the structure and facilities of the industry in Lebanon:

- Dried pulp is imported from abroad. Consequently Lebanon does not produce wood residues from pulp processing.
- The manufacturing process of Lebanese paper industry does not produce black liquor.
- The waste fibres contained in wastewater are removed and reused up to five times through Dissolved Air Flotation units installed on the industrial sites. Wastewater meets national standard requirements to be discharged into water courses and rivers (Mimosa Sanitary Paper Co. Paper & Cardboard Facility, June 2006).

Based on this information, by-products from paper industry have not been retained as a potential bioenergy stream for Lebanon.

V.6 RESIDUES FROM OLIVE TREES

Agriculture contributes 5.8% of GDP in Lebanon (MoET, 2002) and employs about 6.7% of the total labour force (Kasparian, 2003), 57% of which are olive growers.

Olive trees cover 58.6 thousand hectares of the Lebanese territory (FAO, 2008) producing 76.2 thousand tons of olives per year (FAO, 2008). The areas where olive is cultivated sustain a growth rate of 3% annually (SRI, 2004). Table 10 indicates an estimate of the olive trees surface per caza.

Olive harvesting in Deir Mimes in the South of Lebanon

Table 10: Olive trees surface estimate per caza

	Olive trees surface area (ha) - (GIS, 1998)	Weight	Olive trees surface area (ha) - (FAO, 2008)
Beirut	**0**	**0,00%**	**0**
Baabda	538	0,86%	502
El Metn	358	0,57%	334
Chouf	3 957	6,30%	3 689
Aaley	2 785	4,43%	2 597
Keserwan	99	0,16%	92
Jbeil	1 122	1,79%	1 046
Mount Lebanon	**8 859**	**14,09%**	**8 259**
Tripoli	779	1,24%	727
Koura	6 840	10,88%	6 377
Zgharta	5 168	8,22%	4 818
Batroun	2 139	3,40%	1 994
Akkar	4 014	6,39%	3 742
Bcharre	146	0,23%	136
Menieh Daniyeh	2 411	3,84%	2 248
North Lebanon	**21 498**	**34,20%**	**20 042**
Zahlé	4	0,01%	4
West Bakaa	1 323	2,11%	1 234
Baalback	31	0,05%	29
Rachaiya	2 495	3,97%	2 326
Hermel	16	0,03%	15
Beqaa	**3 870**	**6,16%**	**3 608**
Saida	3 955	6,29%	3 687
Sour	6 977	11,10%	6 504
Jezzine	1 481	2,36%	1 380
South Lebanon	**12 413**	**19,75%**	**11 572**
Nabatiyeh	4 975	7,91%	4 638
Bent Jbeil	3 664	5,83%	3 416
Marjeyoun	3 044	4,84%	2 838
Hasbaiya	4 534	7,21%	4 227
Nabatiyeh	**16 217**	**25,80%**	**15 119**
Total	**62 856**		**58 600**

The geographical distribution of olive trees in the country is given by GIS in 1998. This distribution is applied to the 2008 FAO data to evaluate the total and geographical distribution of olive trees surface. Although there have been major changes and events in Lebanon since 1998, no significant changes in long-term production of olives have been noticed, thus the assumption that the geographical distribution of olive trees has remained constant can be made, except in the war-zone of South Lebanon. For the latter, data was not available to be updated.

The key assumptions used are:

- The density of olive trees in Lebanon is between 200 and 230 trees per ha (source: on-ground survey interview);
- On average, one pruning every 2 years that provide 18 Kg/tree of residues (H.Unal & K.Alibas, 2007);
- The heating value of olive tree wood is 13.3 MJ/Kg of dry matter (H.Unal & K.Alibas, 2007);
- Average moisture content for olive tree wood is 40% (H.Unal & K.Alibas, 2007)

With these assumptions, the estimate of the potential are calculated in Table 11.

Table 11: Energy potential estimate for olive trees residues per caza

	Quantities of residues (KT)		Energy potential Estimation (GJ)	
	Low	High	Low	High
Beirut	**0**	**0**	**0**	**0**
Baabda	1	1	7205	8286
El Metn	1	1	4790	5509
Chouf	7	8	52993	60942
Aaley	5	5	37299	42894
Keserwan	0	0	1323	1521
Jbeil	2	2	15029	17284
Mount Lebanon	**15**	**17**	**118639**	**136435**
Tripoli	1	2	10436	12002
Koura	11	13	91596	105335
Zgharta	9	10	69205	79586
Batroun	4	4	28648	32945
Akkar	7	8	53748	61810
Bcharre	0	0	1957	2251
Menieh Daniyeh	4	5	32292	37136
North Lebanon	**36**	**41**	**287882**	**331065**
Zahlé	0	0	57	66
West Bakaa	2	3	17723	20382
Baalback	0	0	412	474
Rachaiya	4	5	33412	38423
Hermel	0	0	215	247
Beqaa	**6**	**7**	**51819**	**59592**
Saida	7	8	52966	60911
Sour	12	13	93430	107445
Jezzine	2	3	19828	22802
South Lebanon	**21**	**24**	**166225**	**191158**
Nabatiyeh	8	10	66621	76614
Bent Jbeil	6	7	49065	56424
Marjeyoun	5	6	40766	46881
Hasbaiya	8	9	607140	69821
Nabatiyeh	**27**	**31**	**217165**	**249740**
Total	**105**	**121**	**841 730**	**967 990**

RESIDUES FROM OLIVE TREES STREAM AVAILABILITY

Estimates for residues from olive trees are calculated assuming that all residues are collected for energy generation purposes. Today's practices include leaving part of the residues on the ground and burning the light (yearly) pruning to keep the soil fertile[7]. The "Olio del Libano" hosted by the Ministry of Agriculture provided shredders to farmers to facilitate mixing residues with the soil to improve organic matter levels in soils. The remainder of the residues is used as fuel wood for heating, following heavy pruning (every 2 years or more).

Part of the energy generation potential of this stream is thus already achieved. Collection can be structured and can be extended to all olive trees fields.

CONCLUSION

Residues from olive trees stream have an interesting bioenergy potential ranging between 848 to 968 TJ/year of primary energy. Furthermore, and trees residues collection can be easily implemented.

Part of the resource is already used but not efficiently. Thus, the use of residues from olive trees stream is one of the bioenergy streams that can be easily developed in Lebanon by structuring the collection and modifying some of the cultivation practices.

V.7 RESIDUES FROM FRUIT TREES

Fruit trees cover 70.8 thousand hectares of the Lebanese territory (FAO, 2008) producing 950 thousand tons of fruit per year (FAO, 2008).

The main fruits cultivated in Lebanon, the surfaces that they cover and energy potential estimate are shown Table 12 to Table 15.

[7] Interview with Youssef Farres, General Manager of Olivetrade

Table 12: Fruit trees areas estimates per species

Fruit trees surface areas (FAOSTAT, 2008)		
Wineyards	13 200	18,6%
Citrus trees	16 150	22,8%
Orange	10 350	14,6%
Lemon	4 100	5,8%
Tangerines	1 700	2,4%
Fruit trees	33 200	46,9%
Apple	10 100	14,3%
Cheeries	8 100	11,4%
Apricots	6 400	9,0%
Peachs	3 550	5,0%
Pears	3 050	4,3%
Plums	2 000	2,8%
Bananas	3 000	4,2%
Total Lebanon	70 800	100,0%

Orange Plantation in Sarafand of South Lebanon

Table 13: The geographical distribution of fruit trees in the country (GIS, 1998)

	Fruit trees surface area (ha) (GIS, 1998)				Weight				Fruit trees surface area (ha) (FAO, 2008)			
	Vineyards	Fruit trees	Citrus trees	Banana trees	Vineyards	Fruit trees	Citrus trees	Banana trees	Vineyards	Fruit trees	Citrus trees	Banana trees
Beirut	0	0	0	0	0,0%	0,0%	0,0%	0,0%	0	0	0	0
Baabda	521	1 004	177	0	2,7%	2,1%	1,3%	0,0%	360	710	215	0
El Metn	542	1 141	184	9	2,8%	2,4%	1,4%	0,2%	374	807	223	7
Chouf	588	3 932	345	303	3,1%	8,4%	2,6%	8,6%	405	2 781	418	257
Aaley	649	1 191	300	0	3,4%	2,5%	2,3%	0,0%	448	842	364	0
Keserwan	343	1 577	78	21	1,8%	3,4%	0,6%	0,6%	237	1 115	95	18
Jbeil	188	2 129	17	115	1,0%	4,5%	0,1%	3,3%	130	1 506	21	98
Mount Lebanon	**2 832**	**10 974**	**1 101**	**449**	**14,8%**	**23,4%**	**8,3%**	**12,7%**	**1 953**	**7 761**	**1 336**	**380**
Tripoli	0	2	294	0	0,0%	0,0%	2,2%	0,0%	0	2	357	0
Koura	134	63	116	0	0,7%	0,1%	0,9%	0,0%	92	44	141	0
Zgharta	125	916	839	0	0,7%	2,0%	6,3%	0,0%	86	648	1 019	0
Batroun	141	1 262	129	0	0,7%	2,7%	1,0%	0,0%	97	892	157	0
Akkar	1 109	6 103	2 057	0	5,8%	13,0%	15,5%	0,0%	765	4 316	2 497	0
Bcharre	430	1 752	0	0	2,2%	3,7%	0,0%	0,0%	297	1 239	0	0
Menieh Daniyeh	110	3 553	1 054	0	0,6%	7,6%	7,9%	0,0%	76	2 513	1 279	0
North Lebanon	**2 049**	**13 650**	**4 490**	**0**	**10,7%**	**29,1%**	**33,7%**	**0,0%**	**1 414**	**9 654**	**5 450**	**0**
Zahlé	3 414	6 240	0	0	17,8%	13,3%	0,0%	0,0%	2 355	4 413	0	0
West Bakaa	2 057	2 189	0	0	10,8%	4,7%	0,0%	0,0%	1 419	1 548	0	0
Baalback	5 294	10 494	0	0	27,7%	22,4%	0,0%	0,0%	3 652	7 422	0	0
Rachaiya	1 562	576	0	0	8,2%	1,2%	0,0%	0,0%	1 078	407	0	0
Hermel	12	836	0	0	0,1%	1,8%	0,0%	0,0%	9	591	0	0
Beqaa	**12 340**	**20 334**	**0**	**0**	**64,5%**	**43,3%**	**0,0%**	**0,0%**	**8 513**	**14 382**	**0**	**0**
Saida	336	633	4 225	1 289	1,8%	1,3%	31,8%	36,4%	232	448	5 129	1 093
Sour	102	74	2 834	1 801	0,5%	0,2%	21,3%	50,9%	70	52	3 440	1 526
Jezzine	508	361	186	0	2,7%	0,8%	1,4%	0,0%	351	255	226	0
South Lebanon	**946**	**1 068**	**7 244**	**3 090**	**4,9%**	**2,3%**	**54,5%**	**87,3%**	**653**	**755**	**8 794**	**2 620**
Nabatiyeh	41	243	339	0	0,2%	0,5%	2,5%	0,0%	28	172	412	0
Bent Jbeil	302	174	5	0	1,6%	0,4%	0,0%	0,0%	208	123	6	0
Marjeyoun	363	70	1	0	1,9%	0,1%	0,0%	0,0%	250	49	1	0
Hasbaiya	262	429	125	0	1,4%	0,9%	0,9%	0,0%	181	303	151	0
Nabatiyeh	**967**	**916**	**469**	**0**	**5,1%**	**2,0%**	**3,5%**	**0,0%**	**667**	**648**	**570**	**0**
Total	**19 135**	**46 941**	**13 305**	**3 539**	**100%**	**100%**	**100%**	**100%**	**13200**	**33 200**	**16150**	**3 000**

Assuming that this distribution is still valid in percentage, it is applied to new fruit trees surfaces areas provided by FAO surveys (FAO, 2008).

Table 14: Key assumptions for fruit trees surface estimates (FAO, 2008)

	Density trees/ha	Kg/tree/year
Vineyards	400	4
Citrus trees	200	22,44
Orange	200	21
Lemon	200	25
Tangerines	200	25
Fruit trees	200	22,59
Apple	200	35
Cheeries	200	26
Apricots	200	13
Peachs	200	11
Pears	200	15
Plums	200	9
Bananas	200	1

Table 15: Estimate of the potential of biomass from fruit trees per caza

	Residue Quantities (KT)				Potential estimation (TJ)									
					Low					High				
	Vineyards	Fruit trees	Citrus trees	Banana trees	Vineyards	Fruit trees	Citrus trees	Banana trees	Total	Vineyards	Fruit trees	Citrus trees	Banana trees	Total
Beirut	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Baabda	0,6	3,2	1,0	0,0	4,4	24,2	7,3	0,0	35,9	5,0	27,7	8,3	0,0	41,0
El Metn	0,6	3,6	1,0	0,0	4,5	27,6	7,6	0,0	39,7	5,2	31,5	8,6	0,0	45,3
Chouf	0,6	12,6	1,9	0,1	4,9	95,0	14,2	0,4	114,5	5,6	108,6	16,2	0,4	130,9
Aaley	0,7	3,8	1,6	0,0	5,4	28,8	12,3	0,0	46,5	6,2	32,9	14,1	0,0	53,2
Keserwan	0,4	5,0	0,4	0,0	2,9	38,1	3,2	0,0	44,2	3,3	43,6	3,7	0,0	50,5
Jbeil	0,2	6,8	0,1	0,0	1,6	51,4	0,7	0,1	53,9	1,8	58,8	0,8	0,2	61,6
Mount Lebanon	**3,1**	**35,1**	**6,0**	**0,1**	**23,6**	**265,1**	**45,3**	**0,6**	**334,7**	**27,0**	**303,0**	**51,8**	**0,7**	**382,5**
Tripoli	0,0	0,0	1,6	0,0	0,0	0,1	12,1	0,0	12,2	0,0	0,1	13,8	0,0	13,9
Koura	0,1	0,2	0,6	0,0	1,1	1,5	4,8	0,0	7,4	1,3	1,7	5,5	0,0	8,5
Zgharta	0,1	2,9	4,6	0,0	1,0	22,1	34,6	0,0	57,7	1,2	25,3	39,5	0,0	66,0
Batroun	0,2	4,0	0,7	0,0	1,2	30,5	5,3	0,0	37,0	1,3	34,8	6,1	0,0	42,3
Akkar	1,2	19,5	11,2	0,0	9,3	147,4	84,7	0,0	241,4	10,6	168,5	96,8	0,0	275,9
Becharre	0,5	5,6	0,0	0,0	3,6	42,3	0,0	0,0	45,9	4,1	48,4	0,0	0,0	52,5
Menieh Daniyeh	0,1	11,4	5,7	0,0	0,9	85,8	43,4	0,0	130,2	1,0	98,1	49,6	0,0	148,8
North Lebanon	**2,3**	**43,6**	**24,5**	**0,0**	**17,1**	**329,8**	**184,9**	**0,0**	**531,8**	**19,5**	**376,9**	**211,3**	**0,0**	**607,8**
Zahlé	3,8	19,9	0,0	0,0	28,5	150,8	0,0	0,0	179,2	32,6	172,3	0,0	0,0	204,9
West Bakaa	2,3	7,0	0,0	0,0	17,2	52,9	0,0	0,0	70,0	19,6	60,4	0,0	0,0	80,1
Baalback	5,8	33,5	0,0	0,0	44,2	253,5	0,0	0,0	297,7	50,5	289,8	0,0	0,0	340,2
Rachaiya	1,7	1,8	0,0	0,0	13,0	13,9	0,0	0,0	26,9	14,9	15,9	0,0	0,0	30,8
Hermel	0,0	2,7	0,0	0,0	0,1	20,2	0,0	0,0	20,3	0,1	23,1	0,0	0,0	23,2
Beqaa	**13,6**	**65,0**	**0,0**	**0,0**	**103,0**	**491,3**	**0,0**	**0,0**	**594,3**	**117,7**	**561,5**	**0,0**	**0,0**	**679,2**
Saïda	0,4	2,0	23,0	0,2	2,8	15,3	174,0	1,7	193,7	3,2	17,5	198,8	1,9	221,4
Sour	0,1	0,2	15,4	0,3	0,8	1,8	116,7	2,3	121,6	1,0	2,0	133,4	2,6	139,0
Jezzine	0,6	1,2	1,0	0,0	4,2	8,7	7,7	0,0	20,6	4,8	10,0	8,7	0,0	23,6
South Lebanon	**1,0**	**3,4**	**39,5**	**0,5**	**7,9**	**25,8**	**298,3**	**4,0**	**336,0**	**9,0**	**29,5**	**340,9**	**4,5**	**384,0**
Nabatiyeh	0,0	0,8	1,8	0,0	0,3	5,9	14,0	0,0	20,2	0,4	6,7	16,0	0,0	23,1
Bent Jbeil	0,3	0,6	0,0	0,0	2,5	4,2	0,2	0,0	6,9	2,9	4,8	0,2	0,0	7,9
Marjeyoun	0,4	0,2	0,0	0,0	3,0	1,7	0,0	0,0	4,7	3,5	1,9	0,0	0,0	5,4
Hasbaiya	0,3	1,4	0,7	0,0	2,2	10,4	5,1	0,0	17,7	2,5	11,8	5,9	0,0	20,2
Nabatiyeh	**1,1**	**2,9**	**2,6**	**0,0**	**8,1**	**22,1**	**19,3**	**0,0**	**49,5**	**9,2**	**25,3**	**22,1**	**0,0**	**56,6**
Total	21,1	150,0	72,5	0,6	159,7	1 134,2	547,9	4,5	1 846,2	182,5	1 296,2	626,1	5,2	2 110,0

RESIDUES FROM FRUIT TREES STREAM AVAILABILITY

There is almost no data available regarding the use of residues from fruit trees. For example, there is no mention of use for soil regeneration or heating. Small scale collection for personal use is reported without quantification and characterization of these uses. The assumption is made that, similarly to olive trees, residues are already being used but not efficiently.

Thus, the estimate of the bioenergy potential of residues from fruit trees is calculated assuming, as for olive trees, that all residues are collected for energy generation purposes. Collection of these residues can be implemented relatively easily.

CONCLUSION

Residues from fruit trees stream present have a very interesting bioenergy potential estimated to be approximately 2110 TJ/year of primary energy. Furthermore, fruit trees residues removal can be implemented without difficulty.

Part of the resource is already used but not efficiently. Thus, the use of residues from fruit trees is one of the bioenergy streams to be developed in Lebanon if the collection is structured.

V.8 RESIDUES FROM CEREALS

Agriculture in Lebanon is the third most important sector in the country after the tertiary and industrial sectors. The main crops include cereals (mainly wheat and barley), fruits and vegetables, olives, grapes, and tobacco, as well as sheep and goat herding. Table 16 and Table 17 show the cereal production in Lebanon estimated by two different sources.

Table 16: Cereal production in Lebanon. Source (MoA, 2006)

Prod (KT) (MoA, 2006)	
Wheat	140
Barley	29
Oats	0,3
Total	169,3

Table 17: Cereal production in Lebanon (FAOSTAT, 2008)

Prod (KT) (FAOSTAT 2008)	
Wheat	143,7
Barley	29
Corn	3,4
Sorghum	1
Oats	0,3
Total	177,4

FAOSTAT figures are consistent with the Ministry of Agriculture figures. They are therefore used to evaluate total production in each area. The Ministry of Agriculture and FAOSTAT report a wheat production of approximately 140,000 tons per year while Rabih Kabalan, expert on wheat at the Lebanese Agriculture Research Institute (LARI), reports that wheat production is lower and varies between 70,000 and 80,000 tonnes per year. Table 19 represents the surface estimate of the cereals production and Table 20 shows the cereal distribution breakdown per Mohafazat.

Table 18: Surface estimate for cereals production in Lebanon (FAOSTAT 2008)

Area (ha) (FAOSTAT, 2008)	
Wheat	49 900
Barley	14 500
Corn	900
Sorghum	600
Oats	250
Total	66 150

Table 19: Cereal distribution breakdown per mohafazat (MoA, 2003)

Distribution of areas by governorates	Wheat		Barley		Others	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Mount Lebanon	288	0,7%	11	0,1%	15	0,9%
North	10422	26,3%	725	6,9%	891	51,6%
Bekka	19823	50,0%	9322	89,3%	629	36,4%
South	3523	8,9%	152	1,5%	89	5,2%
Nabatiyé	5615	14,2%	233	2,2%	104	6,0%
TOTAL	39671		10443		1728	

It is assumed that this distribution is still relevant and it is applied to the figures from FAOSTAT 2008 in order to evaluate the current breakdown of surface areas per mohafazat as indicated in Table 20.

Table 20: Cereals surface estimates per mohafazat

Applied to surface areas of 2008	Wheat	Barley	Corn	Sorghum	Oats
Mount Lebanon	362	15	8	5	2
North	13 109	1 007	464	309	129
Beqaa	24 934	12 944	328	218	91
South	4 431	211	46	31	13
Nabatiyé	7 063	324	54	36	15
TOTAL	49 900	14 500	900	600	250

There are 2 methodologies to estimate the energy potential from cereals:

1. Ratio of residues produced per unit of crop, and
2. Residues produced per unit of land

1.Residues to crop ratio method:

Table 21 demonstrates the assumptions for the residues to crop ratio for wheat and barley.

Table 21: Assumptions residues to crop ratio for wheat and barley (Source: MoA; Turkey survey)

	Residue (T/ha)	Moisture content
Wheat	2,82	17,00%
Barley	2,30	17,00%
Corn	5,41	60,00%
Sorghum	NA	NA
Oats	2,57	17,00%

Table 22 shows the cereal residues quantities per mohafazat.

Table 22: Cereal residues quantities per mohafazat (crop ratio method)

Residues quantity wet basis (T) - From ratio	Wheat	Barley	Corn	Sorghum	Oats
Mount Lebanon	1 356	37	38	na	3
North	49 077	2 416	2 279	na	201
Bekka	93 346	31 064	1 609	na	142
South	16 590	507	228	na	20
Nabatiyé	26 441	776	266	na	23
TOTAL	186 810	34 800	4 420	na	390

Table 23: Energy potentials (GJ) from cereals per mohafazat (crop ratio method)

Energy potential (GJ) - from ratio	Wheat	Barley	Corn	Sorghum	Oats	Total
Mount Lebanon	16 209	0	0	N.A.	0	16 210
North	586 568	29	13	N.A.	2	586 613
Baqua	1 115 673	371	9	N.A.	2	1 116 055
South	198 281	6	1	N.A.	0	198 288
Nabatiyé	316 022	9	2	N.A.	0	316 033
TOTAL	2 232 753	416	25	N.A.	5	2 233 199

2.Residue yields method

Table 24, Table 25 and Table 26 demonstrate the residue yields method.

Table 24: Assumptions Residue yields method (H. Unal & K. Alibas, 2007)

	Residue (T/ha)	Moisture content
Wheat	2,82	17,00%
Barley	2,30	17,00%
Corn	5,41	60,00%
Sorghum	NA	NA
Oats	2,57	17,00%

Table 25: Cereal residue quantities per mohafazat (yield method)

Residues quantity wet basis (T) - From yields	Wheat	Barley	Corn	Sorghum	Oats
Mount Lebanon	1 022	35	42	na	6
North	36 968	2 315	2 511	na	331
Bekka	70 315	29 770	1 772	na	234
South	12 497	485	251	na	33
Nabatiyé	19 917	744	293	na	39
TOTAL	140 718	33 350	4 869	na	643

Table 26: Energy potentials from cereals per mohafazat (residue yield method)

Energy potential (GJ) - from yields	Wheat	Barley	Corn	Sorghum	Oats	Total
Mount Lebanon	12 210	420	243	N.A.	67	12 940
North	441 843	27 673	14 461	N.A.	3 960	487 936
Bekka	840 401	355 812	10 209	N.A.	2 795	1 209 216
South	149 358	5 802	1 444	N.A.	396	157 000
Nabatiyé	238 049	8 893	1 688	N.A.	462	249 093
TOTAL	1 681 862	398 599	28 045	N.A.	7 679	2 116 185

The application of the 2 methodologies, lead to an overall energy potential result from residues of cereals (mainly straw) comprised between 2,116,000 and 2,233,000 GJ.

RESIDUE FROM CEREALS STREAM AVAILABILITY

According to Rabih Kabalan, approximately two third of the harvest represents non grain portion (straw) that is mostly collected and sold for animal feeding. A small portion, estimated at 5 percent, is left on the soil for animal grazing.

If cereals residues were to be used for energy purposes, farmers would have to find an alternative for animal breeding that is economically viable.

CONCLUSION

Residues from cereals stream presents have one of the most interesting bioenergy potential for Lebanon ranging between 2 116 to 2233 TJ/year of primary energy. The possibilities of energy production (electricity and heat) and second generation production make this stream a valuable one for the future of Lebanon's energy and transport sectors.

V.9 MANURE

Livestock in Lebanon includes cattle, sheep, goats, horses, asses and mules, pigs, and chicken. The production figures and the distribution per mohafazat are presented in Table 27. These figures have been confirmed by on-ground surveys.

Table 27: Livestock heads in Lebanon (MoA, 2010)

Livestocks (Head) (MoA,2010)	Mount Lebanon	North Lebanon	Beqaa	South Lebanon	Nabatiyeh	Total
Cattle	12 300	26 000	27 200	5 600	5 800	76 900
Ovine	17 900	35 200	264 100	5 600	14 500	337 300
Goats	48 100	51 500	272 500	40 400	82 200	494 700
Poultry	3 120 000	27 196 000	7 800 000	N.A.	N.A.	78 000 000
Pigs	N.A.	N.A.	N.A.	N.A.	N.A.	10 000

Manure can be used as a bioenergy stream by the production of biogas generated through an anaerobic digestion process. The energy potential of manure has been assessed in terms of both primary energy and methane potential. Each unit of animal produces a quantity of manure and each type of manure has a net calorific value and a methane production potential. Thus the biogas production potential can be evaluated.

Manure is difficult to characterise since it is a very heterogeneous, depending if it is mixed with wood chips or straw, or not.

A theoretical potential from animal manure can be estimated using the assumptions detailed in Table 28.

Cattle farm in the South of Lebanon

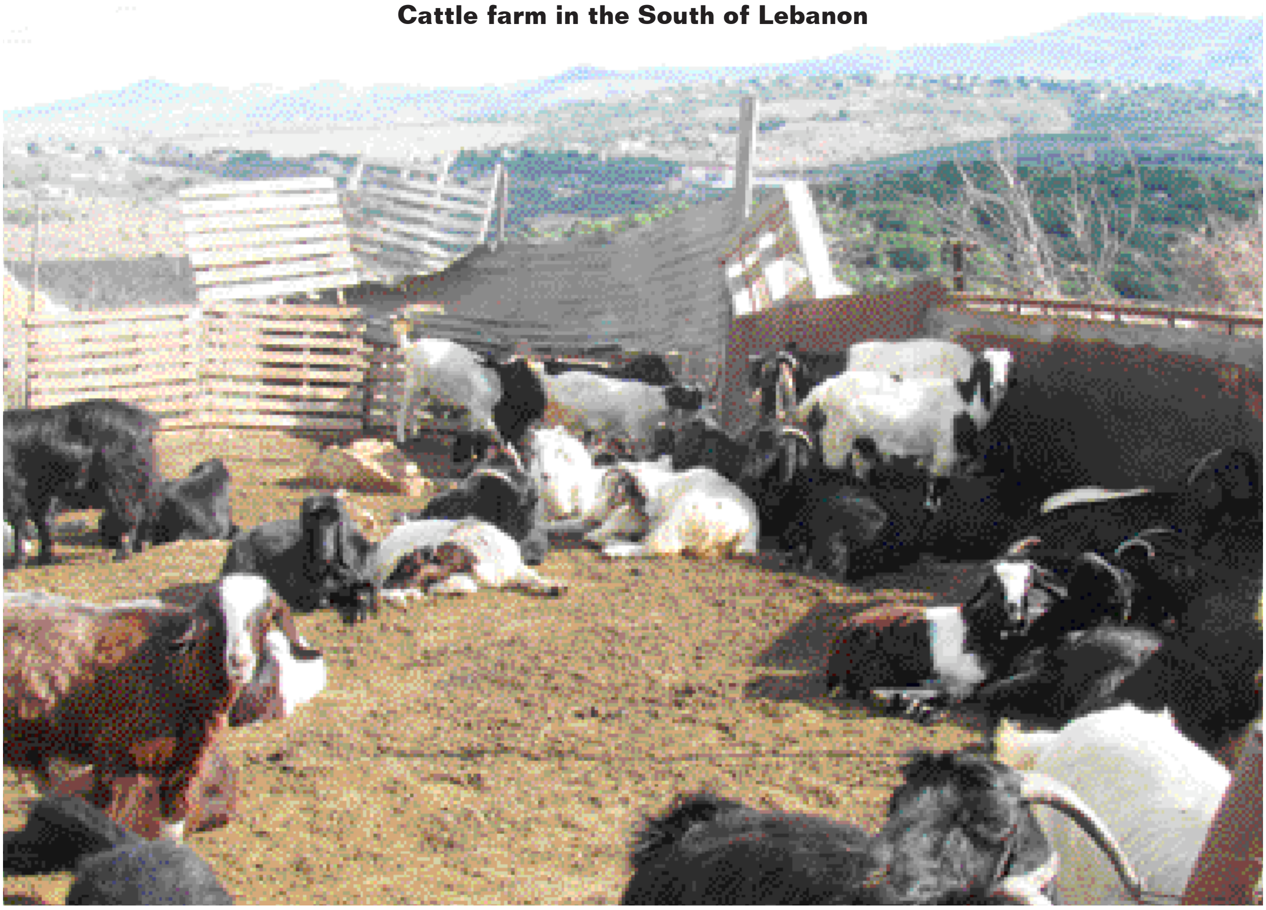


Table 28: Assumptions for theoretical biogas production potential from animal manure

Assumptions (Verástegui and Matero, 1979 and Amane Energy estimate)	Livestocks (Heads)	Manure quantities (Kg/year/Unit)	Moisture content (%)	Manure quantities (Tons/year)	Manure quantities (tons of Dry Matter/year)	Calorific value (MJ/KgDM)	Methane potential (m³/tRM)
Cattle	76 900	6000	92%	461 400	36 912	17,5	15
Horses	23 000	5000	72%	115 000	32 200	16,2	19
Sheep/Goats	832 000	800	72,5%	665 600	183 040	11,08	16
Pigs	10 000	3000	94,0%	30 000	1 800	14,5	14
Chickens	78 000 000	25	89,7%	1 950 000	200 850	15	18

The assumptions in Table 29 lead to the theoretical potential described in Table 30.

Table 29: Primary energy and methane potential from manure in Lebanon

Energy potential estimate	Primary energy potential (GJ)	Methane potential (GWh)
Cattle	645 960	61,9
Horses	521 640	19,5
Sheeps/goats	848 108	95,3
Pigs	26 100	3,8
Chickens	3 012 750	314,0

MANURE STREAM AVAILABILITY

The collection of on-farm manure throughout the country is considered difficult and cumbersome[8]. On the one hand, although farms are regionally located, these remain small in terms of number of heads and thus the collection of daily quantities will not be efficient to ensure good process performance. On the other hand, given that the 50 percent of chicken breeding facilities are concentrated and limited to 4 major players, i.e. Hawa Chicken, Tanmia, Wilco and Shuman, collection of chicken manure mix is easier and is therefore the primary manure stream to be considered.

According to interviews conducted during the on-ground survey, chicken manure is generally collected with wood chips representing the chicken bed. The manure represents generally 5-10 percent of total manure mix and is not separated. The mix is generally used as a fertilizer by farmers.

Chicken manure generated in the 4 main poultry slaughterhouses has an energy potential of 1,500,000 GJ. In terms of methane potential it equals at 157GWh.

CONCLUSION

Manure stream could theoretically show a large potential estimated in 1 500 TJ/year of primary energy, but in reality this potential can only be achieved partially for manure from chicken, pigs and part of the cattle herd, that is to say, where animals are raised in closed facilities allowing the collection of the manure. Moreover, energy recovery from manure occurs through anaerobic digestion and requires to be mixed with other by-products. Finally, the practice of mixing woodchips with chicken manure does not favour an anaerobic digestion process. Manure should be considered as part of biogas generation projects mix with other co-products such as residues from cereals harvesting, i.e., straw.

V.10 ENERGY CROPS

METHODOLOGY

The methodology aims to identify the most suitable energy crops for different regions as an extra indication

[12] Interview with expert from the Ministry of Agriculture

for national planners and project developers. This selection is not only based on soil and water conditions suitability, but it is also based on the amount of greenhouse gases emissions that are coupled with crop production. Land use availability assumptions made for energy crops are the following:

Energy crops can be grown on:

- Current energy cropland
- Abandoned agricultural land
- Grassland

Availability assumptions:

- On former energy cropland 100% can be used, there is no competition.
- On abandoned cropland it is estimated that between 50% and 60% can be used, due to competition with other land use options (infrastructure, forestry) and with nature reserves.
- On grassland it is estimated that between 5 to 20% can be used, due to competition with current uses, e.g. for grazing/fodder.

UNUSED LAND SURFACE AREA ESTIMATE

Current energy crop land

This study has not identified any current energy crop land used in Lebanon.

Grassland

According to the "Land Cover – Land Use Map of Lebanon: Technical Report" (2003), grasslands are characterized as lands dominated by grasses rather than large shrubs or trees. Grasslands occur in areas where cropping is not possible either due to the presence of shallow, stony soils or steep slopes. These native pastures are sometimes referred to as marginal lands because there is no alternative use to grazing. They are overgrazed by sheep and goats and frequently suffer from nutrient deficiency and severe soil erosion. They are either managed by local communities or held as government-owned land. This category has been further divided into dense grassland and clear grassland.

Figure 5 illustrates, for example, dense grassland as found in Zghorta, North Lebanon.

According to the 1998 GIS data base, grassland represents a total surface area of 317,000 hectares distributed between dense grassland (103,000 hectares) and clear grassland (215,000 hectares).

The GIS data base lists the entire surface concerned by grassland per mohafazat and per caza.

Table 30 summarizes dense and clear grassland surface area per mohafazat.

Figure 5: Dense grassland (Zghorta, North Lebanon)

Table 30: Grassland surface per mohafazat in Lebanon (GIS, 1998)

Grassland surface area per Mohafazat (ha) (GIS, 1998)	Beirut	Mount Lebanon	North Lebanon	Beqaa	South Lebanon	Nabatiyeh	Total
Grassland - Total	12	41 302	40 953	188 162	14 451	32 721	317 601
Dense grassland	12	18 858	21 214	26 031	10 746	26 240	103 101
Clear grassland	0	22 444	19 739	162 131	3 705	6 481	214 500

It appears that the Beqaa Valley has the most important area of grassland with 188,000 hectares followed by Mount Lebanon and North Lebanon regions with 41,000 hectares each.
However, the Beqaa Valley grassland is mainly constituted of clear grassland (162,000 hectares when dense grassland represents only 26,000 hectares). In Mount Lebanon and North Lebanon grassland is distributed in the equivalent proportions between dense and clear grassland.
In South Lebanon, grasslands represent 14,000 hectares mainly constituted of dense grassland with over 10,000 hectares.
Table 31 to Table 35 summarize grassland surface area distribution per caza.

Table 31: Grassland surface area in Beqaa per caza (GIS, 1998)

Grassland surface area in Beqaa (ha) (GIS, 1998)	Zahlé	West Bakaa	Baalback	Rachaiya	Hermel
Grassland - Total	12 071	13 436	108 206	29 499	24 949
Dense grassland	4 128	4 414	4 733	8 178	4 578
Clear grassland	7 943	9 022	103 473	21 321	20 372

Around 57% of the Beqaa total grassland areas is located in caza of Baalback.

Table 32: Grassland surface area in Mount Lebanon per caza (GIS, 1998)

Grassland surface area in Mount Lebanon (ha) (GIS, 1998)	Baabda	El Metn	Chouf	Aaley	Keserwan	Jbeil
Grassland - Total	3 169	4 099	10 270	6 301	7 502	9 962
Dense grassland	1 719	2 643	6 506	3 412	1 121	3 458
Clear grassland	1 451	1 456	3 764	2 888	6 381	6 504

Table 33: Grassland surface area in North Lebanon per caza (GIS, 1998)

Grassland surface area in South Lebanon (ha) (GIS, 1998)	Saïda	Sour	Jezzine
Grassland - Total	3 870	5 739	4 842
Dense grassland	3 576	4 189	2 981
Clear grassland	294	1 550	1 861

Table 34: Grassland surface area in Nabatiyeh per caza (GIS, 1998)

Grassland surface area in Nabatiyeh (ha) (GIS, 1998)	Nabatiyeh	Bent Jbeil	Marjeyoun	Hasbaiya
Grassland - Total	7 057	8 834	9 201	7 629
Dense grassland	6 225	6 667	7 992	5 356
Clear grassland	832	2 167	1 209	2 272

Table 35: Grassland surface area in South Lebanon per caza (GIS, 1998)

Grassland surface area in South Lebanon (ha) (GIS, 1998)	Saida	Sour	Jezzine
Grassland - Total	3 870	5 739	4 842
Dense grassland	3 576	4 189	2 981
Clear grassland	294	1 550	1 861

Abandoned agricultural land

According to the Agriculture Overview Report based on the agriculture census dated 1999, permanent fallow land represents 53,137 hectares. The distribution per mohafazat is detailed in Table 36. The mohafazats of Beqaa, North Lebanon and Nabatiyeh are those considered as the most suitable in terms of topography, climate and potential availability.

Table 36: Permanent fallow land in Lebanon per mohafazat (MoA, 1999)

Permanent fallow land (ha) (MoA, 1999)		
Permanent fallow land Total nationwide		53 137
Mount Lebanon	21%	11 159
Beqaa	36%	19 129
North Lebanon	16%	8 502
Nabatiyeh	19%	10 096
South Lebanon	8%	4 251

The most important surface area available is located in the Beqaa (app. 19,000 ha).

Moreover the report mentions a surface area of 472 900 hectares of uncultivated land. As reported by farmers in the Agricultural Overview Report it is estimated that 109,400 hectares of uncultivated land could be managed to become farmland. Unfortunately, distribution per mohafazat is not stated in this report. This information will be updated upon completion of the on-going agricultural census that would also present a breakdown per mohafazat. According to the MoA, the agriculture census should be finalized in 2011 but the data was not accessible at the date of this report.

Cannabis plantation surface area

Cannabis fields are located in part of North Beqaa, more precisely in Baalbeck – Hermel region with an approximate surface area harvested of 20,000 hectares. Cannabis is planted between February and April, and requires minimal irrigation, fertilizer, and maintenance. A farmer can earn between 8,000 and 12,000 US Dollars per average hectare cultivated .

To replace the illicit plantation, it is important to take into account not only the agronomic but also the economic aspects, particularly the source of livelihood for the local population.

It requires finding substitution crops that will allow farmers an easy adaptation to new agricultural practices and comparable revenues.

The Ministry of Agriculture and the UNDP launched a project aiming at introducing industrial hemp in the Beqaa as substitutes for hashish farmers in the context of the Sustainable Land Management Program for Livelihood Development in Lebanon. The objective of this project is to reach between 5,000 and 7,000 hectares.

Before the selection of industrial hemp, unsuccessful attempts to replace hashish occurred with the following crops (the reasons for the failures are given in bracket);

- Caper (needs a lot of labour for which there is an absence of market)
- Saffron (no market)
- Sunflower (irrigation needed, imported sunflower oil is cheaper)
- Colza (too much irrigation needed, economically not viable)

Other crops harvested in this part of the Beqaa are mainly wheat, barley, onions and potatoes.

Energy crops for substitution need to have similar requirements as cannabis crops, i.e. minimal irrigation, fertilizer needs and maintenance. Cannabis crops could be replaced by Jatropha or by special variety of hemp for energy production. In this case, the entire plant can be used as a solid fuel when compacted (Karus and Leson, 1995). It can be converted to other biofuels by a variety of conversion technologies. Hemp can be considered as a potentially important energy crop species. The oil of hemp can be used as biodiesel. Hemp's high total biomass means that productivity can be high as 18t/ha. Special oil hemp varieties can produce up to 600L /ha of oil. Biofuels such as biodiesel and alcohol fuel can be made from the oils in hemp seeds and stalks, and a fermentation of the plant as a whole, respectively. The energy from hemp may be high, based on acreage or weight, but can be low based on the volume of the lightweight harvested hemp. It does, however, produce more energy per hectare per year than corn, sugar or any other crop currently grown for ethanol or biodiesel (N. El Bassam, 2010).

Due to lack of experience in cultivation of energy crops in Middle East countries no reliable statistics on yields are available. Thus, international statistics are used.

SELECTED UNUSED LAND PER REGION:

Mountainous regions are excluded because of the poor accessibility of these regions.

Beqaa

Table 37 indicates the Beqaa surface availability assumptions.

Table 37: Beqaa surface availability assumptions

Surface availability assumptions - Beqaa Jatropha for cazas of Baalbak, Rachaiya and Hermel			
Grassland availability assumption	5%	to	20%
Potential grassland surface considered (ha)	8 133	to	32 531
Fallow land availability assumption	50%	to	60%
Potential fallow land surface considered (ha)	9 565	to	11 478
Total surface considered (ha)	17 697	to	44 008
Surface availability assumptions - Beqaa Miscanthus for cazas of Zahle and WestBeqaa			
Grassland availability assumption	5%	to	20%
Potential grassland surface considered (ha)	1 275	to	5 101

Beqaa is characterized by hot temperatures in the summer that drop drastically in the winter. The experts interviewed during on-ground survey recommended focusing on the following areas:

- Hermel: the area is highly unproductive and energy crops could be used to reduce erosion. Precipitation is low (between 250 and 300 mm/year)
- Baalbeck: productive area
- Rachaiya, West Bekka and Zahlé: Precipitation is quite high for the region: between 600 and 700mm
- Eastern slope of Anti-Lebanon: This area is not very populated and abandoned land is easily found.

North Lebanon: Table 38 indicates the surface availability assumptions in North Lebanon.

Table 38: North Lebanon surface availability assumptions

Surface availability assumptions - North Lebanon				
Grassland availability assumption		5%	to	20%
Potential grassland surface considered (ha)		723	to	2 893
Fallow land availability assumption		50%	to	60%
Potential fallow land surface considered (ha)		4 251	to	5 101
Total surface considered (ha)		4 974	to	7 994

Because of the medium fertility and the climate, the Akkar plain and the lower hills area are the most interesting ones. On the contrary, the mountainous part of Akkar is not suitable and will thus not be retained.

Nabatiyeh: The surface availability assumptions in Nabatiyeh are shown in Table 39.

Table 39: Nabatiyeh surface availability assumptions

Surface availability assumptions - Nabatiyeh Giant Reed for cazas of Marjeyoun and Hasbaiya			
Grassland availability assumption	5%	to	20%
Potential grassland surface considered (ha)	841	to	3 366
Fallow land availability assumption	50%	to	60%
Potential fallow land surface considered (ha)	5 048	to	6 058
Total surface considered (ha)	5 889	to	9 423
Surface availability assumptions - Nabatiyeh Eucalyptus for cazas of Nabatiyieh and Bent Jbeil			
Grassland availability assumption	5%	to	20%
Potential grassland surface considered (ha)	795	to	3 178

The experts interviewed during on-ground survey recommended focusing on Marjayoun and Hasbaiya Cazas because of the precipitation (between 600 and 1,000mm/year), the average annual temperature (between 18.5°C and 21°C). It is an agricultural area and the soil quality is considered fertile.

Mount Lebanon and South Lebanon

A certain amount of surface area is needed for energy crops. In both Mount Lebanon and South Lebanon the unused lands are highly scattered, and plots are small and belong to a multitude of owners. Moreover, these two regions have a high population density and are highly urbanized.

For these reasons, implementing energy crops in these regions is not recommended.

Forest near Chalboun Village, North Lebanon

SELECTED CROPS

Sunflower (Helianthus anuus L.) and Jatropha (Jatropha Curcas L.)

The cultivated species of sunflower (Helianthus anuus L.) is a native of America that was taken to Spain from Central America before the middle of the sixteenth century. The stem can grow as high as 3m and the flower head can reach 30cm in diameter with large seeds.

Sunflower is a well-adapted crop under various climatic and soil conditions. With its well-developed root system it is one of the most drought-resistant crops and considered suitable for semi-arid countries.

A satisfactory crop can be produced, without irrigation, even in winter rainfall regions with approximately 300 mm. Growth is satisfactory when temperature do not fall below 10°C, but it can resist far lower temperatures. Sunflower requires ample sunlight and is considered insensitive to day length.

Sunflower grows on a variety of soils ranging from sandy soils to clay. In low-fertility soil its performance is better than other crops such as corn, potato and wheat. The whole seed contains about 40% of oil.

In southern European Regions, sunflower has been considered as an energy crop for biodiesel production and is produced only under strong and continuous financial incentives.

Jatropha (Jatropha Curcas L.) is a crop that grows in regions around the equator. It grows as a bush of up to 6m in height and can live up to 50 years. After three years the first seeds can be harvested. Jatropha can grow in areas that are unsuitable for other plants, because they are too dry or too arid, or because they have been left by humans due to soil depletion after excessive agriculture. The plant is well adapted to drought (Heller, 1992) and grows well in arid region (Lutz, 1992) and is pests resistant. It requires very little water and can survive long periods of droughts by shedding most of its leaves in order to minimize the loss of water (Jones and Miller, 1991).

The plant requires very little fertilizer or pesticides. The oil from seeds can have a fuel application. Jatropha produces seeds with an oil content of 32%.

The current distribution shows that introduction has been most successful in the drier regions of the tropics with annual rainfall of 300-1000 mm. It occurs mainly at lower altitudes (0 to 500m) in areas with average annual temperatures above 20°C, but can grow at higher altitudes and tolerates slight frost. It grows on well-drained soils with good aeration and is well adapted to marginal soil with low nutrient content. The plants are cultivated as hedges to prevent erosion while enhancing soil productivity.

It is very difficult to estimate unequivocally the yield of a plant that is able to grow in very different conditions. Yield is a function of water, nutrients, heat, the age of the plant and other factors. Seed production ranges about 2 tons per hectare (non-irrigated) per year to over 12.5 tons per hectare per year (irrigated), after five years of growth.

The by-product can be used for energy production. The shells may be transformed into biogas in a digester. The press cake is used as organic fertilizer to improve the soil and stabilize the field crop yield without expensive chemicals. Press cake contained more nitrogen and organic matter than conventional mineral fertilizer (N.El Bassam, 2010).

Sunflower and jatropha have been selected as most promising crops for the production of biodiesel in Lebanon. Sunflower seems more suitable for the North of Lebanon (mild climate and the soil conditions are medium) and Jatropha as more suitable for the Beqaa region, e.g. cazas of Baalbeck, Hermel and Rachaiya (due to their precipitation comprised between 200 and 700mm and temperature conditions).

Miscanthus (Miscanthus spp.)

Miscanthus (Miscanthus spp.) is a genus of woody, perennial, tufted or creeping rhizomatous grasses that originated in East Asia. It is high in lignin and lignocelluloses fiber. Among all the 23 species in this genus there are 3 species that are of great interest for energy purpose: M. sacchariflorus, M. sinensis and M. x giganteus.

Overall, miscanthus is a group of highly resistant plants against disadvantageous ecological factors. It has evolved in regions of the world that have large temperature fluctuations between summer and winter. The plant is resistant to heat, frost, drought and flood. The crops prefer warm climates. No optimum growing temperature or range has been determined.

Miscanthus does not make many demands on the soil, a fact demonstrated by its ability to grow on many types of arable land.

Water plays a large role in crop yield. During the crop's growing season it is estimated that 600mm of precipitation would be necessary to produce 20 tons per ha dry matter yields. Greater yields become possible with increased irrigation.

The energy density of miscanthus is 18.2MJ/Kg. Miscanthus can be considered as one of the most important future energy crops due to its high yield potential under different climatic conditions, and can be converted to wide varieties of energy feedstocks for heat, electricity generation through combustion, gasification and liquefaction. Miscanthus biomass contains extremely low ash and nitrogen contents (El Bassam, 2010).

Miscanthus has been selected for the cazas of West Beqaa and Zahle in Beqaa region as the annual precipitation are higher than in the rest of Bekka, i.e. 600 to 700mm per annum.

Jojoba

Jojoba is another crop that could be of interest for the future; however it is disregarded at this stage due to high value of jojoba oil in the cosmetics industry.

Jojoba is cultivated mainly in Arizona, Northern Mexico, Argentina, Australia, Chile and India. The plant is evergreen, and the leaves are covered with wax to prevent excessive loss of water. The seed contain 47 to 62 percent of wax, which becomes liquid at 7°C. The plants often only reaches a height of 0.6 to 0.9 m. Jojoba can be grown at altitudes ranging from sea level to 1500m.

Jojoba tolerates drought and thrives under soil and moisture conditions that are not suitable for most other agri cultural crops. An annual rainfall of 250 mm is enough for the plant to survive. The first yields are obtained after 4 to 5 years, and full yields after 10 years. Jojoba bears for 100 to 200 years. Jojoba grows best in sandy or decomposed granite or rocky soil. Even if the fertility of the soil is marginal, jojoba is still able to produce well without the use of fertilizers. The high costs of collecting the small fruits may be a limiting factor.

Giant Reed (Arundo donax L.)

Giant Reed (Arundo donax L.) grows wild in Southern European regions (Greece, Italy, Spain, Southern France and Portugal) and other Mediterranean countries. Giant Reed has been cultivated throughout Asia, Southern Europe, Northern Africa and the Middle East for thousands of years.

Giant Reed has several attractive characteristics that make it the champion of biomass crops. Giant Reed is also an environment-friendly plant:

- It offers valuable protection against soil erosion on slopes and erosion-vulnerable soils
- It is an extremely pest resistant crop (disease, insect, weed), not requiring any of the chemical inputs (pesticides)
- It has the ability to remain undamaged if an accidental fire sweeps across a Giant Reed plantation
- It has the ability to adapt to saline soils and saline water
- It is less invasive than Miscanthus or sugar cane

Giant Reed is also considered to be one of the most cost effective energy crops because it is perennial and its annual input, after establishment, are very low. Only harvesting costs will occur. All these attributes make giant reed a very attractive and promising candidate species for biomass production.

The stems are up to 3.5 cm in diameter and up to 10m tall. In the warm Mediterranean regions, the above-ground giant reed parts remain viable during winter months. If plants are not cut, in the following spring new shoots emerge at the upper part of the stem from buds located at stem nods.

In its wild state, giant reed is usually found along river banks and creeks and on generally moist soils, where it exhibits its best growth. However, it is also found in relatively dry and infertile soils, at field borders, on fields' ridges or on roadsides where it grows successfully.

Giant Reed can be grown on almost any soil type from very light soils to very moist and compact soils without irrigation under semi-arid Southern European conditions. Giant Reed is one of the most pest-resistant plants. So far no diseases have been reported.

The effect of irrigation rates on fresh and dry matter biomass yields is insignificant. It was reported (Dalianis, 1995a) that fresh and dry matter biomass yields of giant reed, averaged over three years for autumn harvests, were respectively 59.8t/ha and 32.6t/ha for the high irrigation rate (700mm/year) and 55.4t/ha and 29.6t/ha for the low irrigation rate (300mm/year).

There are only few references to giant reed biomass yields in world literature. Giant reed biomass yield potential is 20 to 25 tons of dry matter/hectare (Matzke, 1988). These high yields are obtained from unimproved wild populations with almost no crop management. This indicates the significant biomass potential of this plant.

Giant reed has been selected for Nabatiyeh region (Cazas of Marjayoun and Hasbaiya) as it fits well with the soil condition and climate of the region. Indeed, Giant Reed requires a minimum of 300mm of rainfall per year and precipitation statistics for Nabatiyeh are comprised between 300mm and 1,000mm/year.

Eucalyptus (Eucalyptus spp.)

Eucalyptus (Eucalyptus spp.) is a fast-growing tropical tree species used as a biomass source of bioenergy, and for pulp and paper manufacturing. Eucalyptus species are native from Australia. During the last two centuries eucalyptus were spread from Australia to many regions of the world. E. Globulus is a dominant species in Spain and Portugal and E. Camaldulensis in Morocco and Spain. These two species are well adapted to Mediterranean countries. Eucalyptus is highly adaptive and grows rapidly in a wide range of climatic conditions. Sensitivity to low tempera tures is the most environmental factor limiting the regions over which eucalyptus can be planted.

E. Camaldulensis is able to produce acceptable yields on relatively poor soils with prolonged dry season, exhibits some frost resistance, and tolerates soil salinity. It is a drought-resistant species and grows in areas receiving 200mm rainfall per annum, though growth is better where annual rainfall exceeds 400 mm (Turnbull and Pryor, 1984).

In many countries E. Camaldulesis is used for fuel wood and charcoal. Its high density makes it a good fuel. It is considered as a drought-tolerant species suitable for arid or semi-arid regions. In south-western Spain it grows well with 465mm annual precipitation and about four months dry season.

Since Eucalyptus regenerates itself after each harvest operation, biomass accumulation can be generated over several growth cycles with only one initial cost of site preparation and planting. A number of Eucalyptus coppices regrow readily, sometimes up to six or seven times (Hillis, 1990).

Taking into account the large volume of biomass produced, eucalyptus are less nutrient depleting than many other agricultural crops. This is partly because the largest proportion of the biomass produced consists of lignocelluloses.

In Greece, both E. Camaldusensis and E. Globulus are being tested under various environmental soil conditions, very short rotation cycles and dense populations. Dry matter yields of two-year rotating E. camaldulsensis of up to 32t/ha/year have been obtained.

Biomass components of both E. Camaldusensis and E. Globulus have high heating value with an average for both species of 17,5MJ per Kg of dry matter (El Bassam, 2010).

Eucalyptus has been selected for the cazas of Nabatiyeh and Bent Jbeil in Nabatiyeh region as it fits well with the soil condition and climate of the region.

ENERGY POTENTIAL ESTIMATE

There is a large gap between the low estimate and the high estimate for the following reasons:

- It is difficult to estimate unequivocally the yield of plants that are able to grow in different conditions of water, nutrients, temperatures, precipitation and soil fertility. The ranges of yields are selected to fit with the local conditions. It is understood that trials have to be made to fine-tune those yields.
- The gap between the minimum and the maximum of surface area that could be of interest.

Beqaa

Energy potential estimate and assumptions for jatropha and miscanthus in Beqaa is indicated in Table 40.

Table 40: Energy potential estimation and assumptions for jatropha and miscanthus as energy crops in Beqaa

Assumptions		Low energy (no irrigation)	High energy (with irrigation)
Selected crops			Jatropha
Harvests per year			1
Nuts production [Non-irrigated/irrigated] (Kg/ha)		2 000	5 000
Volume ratio (Kg of oil/Ton of nuts)			350,00
Jatropha oil calorific value (MJ/Kg)			39,62
Energy potential estimation (GJ)			
Energy potential - Low estimate			490 819
Energy potential - High estimate			3 051 328
Assumptions			
Selected crops			Miscanthus
Harvests per year			1
Volume ratio (T of dry matter/ha/year)			20,00
Net calorific Value (MJ/Kg)			18,20
Energy potential estimation (GJ)			
Energy potential - Low estimate			464 236
Energy potential - High estimate			1 856 943

North Lebanon : Energy potential estimate and assumptions for sunflower in North Lebanon is indicated in Table 41.

Table 41: Energy potential estimation and assumptions for sunflower as energy crop in North Lebanon

Assumptions			High energy (with irrigation)
Selected crops			Sunflower
Harvests per year			1
Volume ratio (Kg/ha of biodiesel)			1 000
Biodiesel calorific value (MJ/Kg)			37,00
Energy potential Estimation (GJ)			
Energy potential - Low estimate			184 048
Energy potential - High estimate			295 793

Nabatiyeh

Table 42 indicates the energy potential estimation and assumptions for giant reed in Nabatiyeh.

Table 42: Energy potential estimation and assumptions for giant reed and eucalyptus as energy crops in Nabatiyeh

Assumptions			High energy (with irrigation)
Selected crops			Giant Reed
Harvests per year			1
Volume ratio (Tons of dry matter/ha/year)			22,50
Calorific value (MJ/Kg of dry matter)			15,00
Energy potential Estimation (GJ)			
Energy potential - Low estimate			1 987 697
Energy potential - High estimate			3 180 412
Assumptions			
Selected crops			Eucalyptus
Harvest			1 every 2 years
Volume ratio (T of dry matter/ha/year)			32,00
Net calorific Value (MJ/Kg)			17,50
Energy potential Estimation (GJ)			
Energy potential - Low estimate			444 965
Energy potential - High estimate			1 779 859

Total Lebanon: Table 43 shows the total energy potential from energy crops in Lebanon.

Table 43: Total energy potential from energy crops in Lebanon

Table 43: Total energy potential from energy crops in Lebanon

Energy potential estimation (GJ)			
Energy potential - Low estimate			3 571 764
Energy potential - High estimate			10 164 335

CONCLUSION

Energy crops represent the largest future bioenergy potential for Lebanon. The total potential could reach more than 10 000 TJ/year of primary energy, and therefore it could become of high interest for Lebanon. Moreover, it could help to reduce erosion and degradation of the soil. Energy crops can have many applications and uses; energy wise they can be combusted for the production of electricity and heat, and they can also be processed to convert them in second generation biofuels. This last possibility would help reducing Lebanon's dependence on oil.

Feasible large areas within the unused land selected in this section have to be identified. However, the availability of the land has to be verified on-ground before discussions and tests with the owners can begin.

V.11 SLAUGHTERHOUSES RESIDUES

Slaughterhouse residues are treated in the two following sections: slaughterhouse waste and animal fat. These bioenergy streams are treated in separate sections since animal fat is a highly valuable source for the production of biodiesel. On the other hand these two bioenergy streams can be treated together through anaerobic digestion. The best scenario is determined in chapter 3: Future scenarios for bioenergy Lebanon.

Slaughterhouse waste

Bovines, sheep, goat and swine slaughter occurs either in dedicated slaughterhouses or in butcheries, located in most cities and towns throughout the country. However, there are five main slaughterhouses in Lebanon. Three of them are along the Lebanese coastline (Tripoli, Beirut and Saida) while the other two (Zahle and Nabatiyeh) are inland. Wastes resulting from slaughterhouse activity are (except for the Beirut slaughterhouse) dumped in (more or less) uncontrolled landfills. Although reports stated that some slaughterhouse waste may be buried or burned on site at times and shredded and dumped to the sea or rivers at other times, the on-ground survey indicates that waste disposal occurs only in sanitary landfills and controlled dumps.

QUANTITY OF SLAUGHTERHOUSE WASTE

The slaughtering by-products have been estimated as follow (Amane Energy estimate):

- 50% of edible tissue (meat and bones)
- 8% of edible offal
- 3% of blood
- 9% of skin
- 4% of head, horns and hooves
- 11% of inedible offal
- 10% of gut content
- 5% of fat

Wastes considered in the calculation are contents of stomach, intestines, and blood, i.e., 24% of animal weight. The weight of skin and hides which are sold to tanneries are excluded as well as bones which are reused and cannot be treated in a methanisation unit. Dead stocks, i.e. the amount of animals that die from diseases are also excluded as biogas production would require specific sanitizing treatment that is very costly.

No accurate data is currently available on the amount of

Butcher in Nabatiyeh Slaughterhouse

slaughterhouse waste generated nationwide. Based on the on-ground survey, it appears that regional slaughterhouses do not maintain accurate log for slaughtering activities within the facilities. Head counts were recorded based on interviews with facilities' appointed veterinaries that provided estimates of the number of animals slaughtered on a weekly basis, accounting for increases in holiday seasons.
Based on interviews with environmental experts and key informants, the Beirut Slaughterhouse does maintain accurate data on the number of animals slaughtered. Nonetheless, this information could not be obtained despite contacts with the Municipality of Beirut and the Slaughterhouse staff.

Assumptions have been made by using both data on the import of live animals and data on the national meat production and average amounts of waste per animal slaughtered.
According to the document "Controlled management of Wastes from Slaughterhouses in Lebanon: A Business Plan for a Rendering Facility" dated 2005, live animals increase in weight by 20% from the time of entry to Lebanon until the time for slaughtering and around 95% of the imported animals are slaughtered.
Table 44 summarizes the import of live animals to Lebanon between 2006 and 2009 and the average estimated quantity of animals slaughtered.

Table 44: Import of live animals to Lebanon

Net Import (Tons/year) (www.customs.gov.lb and MoE, 2005)	2006	2007	2008	2009	Yearly average
Live bovine animals	93 034	81 665	62 490	92 519	82 427
Live sheep and goats	8 212	7 591	6 406	15 298	9 377
Total	101 246	89 256	68 896	107 817	91 804
Percentage of imported live animals slaughtered	95%				
Live animals weight increase from the time of entry to Lebanon until the time for slaughtering	20%				
Total imported animals slaughtered (tons/year)	115 420	101 752	78 541	122 911	**104 656**

The amount of live imported animals slaughtered per year is approximately 105,000 tons.

With regards to the national meat production, no recent data is available. Consequently data used is issued from a report of the Ministry of Agriculture named "Controlled Management of Wastes from Slaughterhouses in Lebanon - A Business Plan for a Rendering Facility", which records 27,600 tons per year of live animals slaughtered nationally in 2002 as shown in Table 45.

Table 45: Total meat production in Lebanon (MoA, 2005)

National production (Tons/year)	2002
Bovine	14 300
Sheep	6 500
Goats	4 900
Pork	1 900
Total	27 600

Adding the imported sources of live animals and the local source of live animals would lead to a total amount of 132,000 tons of animals slaughtered within slaughterhouses or butcheries in Lebanon.
The amount of waste resulting from slaughtering is estimated at 24% of the live animal weight, excluding the weight of the fat, skin and hides. Therefore, the quantity of slaughterhouse waste generated nationwide is approximately 18,500 tons per year.
Interviews with supervising veterinaries during on-ground

survey provided an estimate of the amount of animals slaughtered in some of the main slaughterhouses. Table 46 shows the data collected through these interviews. Amounts of animals slaughtered are not recorded, therefore these data are estimates.

Table 46: Estimated waste from meat production generated in Lebanon (excludes poultry)

Slaughterhouse	Mohafazat	Quantity of cows slaughtered (Tons/year)	Goat (Tons/year)	Total	Estimated quantities of waste (tons/year)	Comments
Beirut	Beirut	NA	NA	NA	NA	Composting
Nabatiyeh	Nabatiyeh	3500	4 890	8 390	1 175	
Saida	South Lebanon	6500	9 750	16 250	2 275	
Sour	South Lebanon	1630	5 890	7 520	1 053	
Jezzine	South Lebanon	1300	9 750	11 050	1 547	
Zahleh	Beqaa	NA	NA	NA	NA	
Tripoli	North Lebanon	NA	NA	NA	NA	

SLAUGHTERHOUSE WASTE ENERGY POTENTIAL

The calorific value of slaughterhouse waste stands between 14.0 and 16.0 MJ per kg of raw matter with an average of 15.6 MJ per kg. The total energy potential of slaughterhouse and butcheries waste is therefore estimated at 495,000 GJ per year for the national territory. Assumptions retained are summarized in Table 47 below.

Table 47: Energy potential estimates from slaughterhouse waste (excludes poultry)

Assumptions	
Total animals slaughtered (tons/year)	132 256
Waste ratio	24,00%
Estimated quantity of slaughterhouse waste (tons/year)	31 742
Average calorific value (MJ/Kg RM)	15,60
Energy potential estimation (GJ)	
Beirut	N.A.
Nabatieh	31 412
Saida	17
Sour	28 155
Jezzine	41 371
Zahleh	N.A.
Tripoli	N.A.
TOTAL slaughterhouses	100 955
TOTAL national	495 167

Attention is drawn to the fact that three of the major slaughterhouses; namely Saïda, Sour and Jezzine, are located in the same mohafazat (South Lebanon) and located close to each other, allowing an easy collection and the implementation of a single treatment unit for the slaughterhouse waste.

POULTRY SLAUGHTERHOUSE

The only potential bioenergy production process applicable to poultry slaughterhouse wastes is anaerobic digestion. But there are no examples of full-scale anaerobic digester treating solid poultry slaughterhouse wastes only. Laboratory tests measuring biogas production potential of poultry slaughterhouse waste are not conclusive. Moreover, feathers, which consist mainly of keratin, present a very poor anaerobic degradability.

Animal fat

It should be noted that, in most cases, slaughterhouses and butcheries do not sort animal fat from the rest of the slaughterhouse waste.

Assumptions on the amount of animal slaughtered per year in Lebanon remain identical to those described in the previous section.

ANIMAL FAT QUANTITY

The amount of animal fat available after slaughtering is estimated at about 5% of the total waste. Therefore, the quantity of animal fat waste generated nationwide is approximately 6,600 tons per year.

ENERGY POTENTIAL EVALUATION

The calorific value of animal fat stands at an average of 39.0 MJ per kg. The total energy potential of animal fat from slaughterhouse and butcheries is therefore estimated at 258,000 GJ per year for the national territory.

Assumptions retained are summarized in Table 48 below.

Table 48: Energy potential estimates from animal fat waste

Energy potential estimate (GJ)	
Beirut	NA
Nabatieh	16 361
Saida	31 688
Sour	14 664
Jezzine	21 548
Zahleh	NA
Tripoli	NA
TOTAL Slaughterhouses	84 260
TOTAL National	257 900

AVAILABILITY OF SLAUGHTERHOUSE WASTE

With regards to the Beirut slaughterhouse, all of the waste is composted and turned into high grade organically certified fertilizer. Meat compost is mixed with 260 tons per year of landscape management residues from the parks and gardens of the municipality of Beirut, 400 tons per year of paper and cardboard collected from ten to twelve different sources (mainly supermarkets) and 72 tons per year of fish waste generated by the nearby fish market.

As for the rest of the country, there is no specific treatment or end uses. Often small private companies are collecting the waste from the butcheries and the disposal method occurs, more or less, in an uncontrolled manner. The resource is distributed nationwide even if the five main slaughterhouses concentrate the largest amount of waste.

CONCLUSION

Slaughterhouse waste and animal fat represent a medium bioenergy potential for Lebanon estimated to hold approximately 495 TJ/year of primary energy. In order to exploit this potential effectively, it is important to centralize the slaughtering that currently occurs in butcheries.

Except for Beirut, where a valorisation into high grade fertilizer has been established, there are no competitive end uses.

Animal fats are also interesting as they have a high calorific value. Their potential is more modest and it is estimated to be in the order of 258 TJ/year of primary energy. It is highly sought after for biodiesel production or can be mixed with other slaughterhouse waste and treated through anaerobic digestion.

Figure 6: National geographic distribution of olive mills (ELARD, 2008)

IV.12 OLIVE OIL CAKE BY-PRODUCT

The Lebanese territory produces 83.2 million tons of olives per year (MoA, 2003). The Ministry of Agriculture estimates that around 70% of the total olive production is transformed into olive oil. Olive oil production generates residues made of spent olives or pomace. The national production of olives is characterized by an important gap between the volumes of low production years and high production years. We have assessed the energy potential for these two extremes. Lebanon has 492 olive mills; the majority (45.73%) are located in North Lebanon, followed by Mount Lebanon (17.48%), South Lebanon (16.67%), Nabatiyeh (15.45%) and the Beqaa (4.67%) (ELARD, 2008).

Figure 6 shows the national geographic distribution of olive mills.

ESTIMATE OF THE ANNUAL QUANTITY OF OLIVE OIL CAKE BY-PRODUCT

All estimates of the annual quantity of olive oil cake by-product were calculated using the study: "Integrated Waste management for the olive oil pressing industries in Lebanon" (ELARD, 2008). Other information was collected during the on-ground surveys, particularly through interviewing three key representatives:

- Ms. Samar Khalil, Project Manager, Integrated Waste Management for the Olive Oil pressing industries in Lebanon, MoE
- Mr. Youssef Fares, General Manager Olivetrade
- Mr. Enrico Azzone, Ministry of Agriculture, team leader of the project Olio de Lebanon
- Mr. Jean-Pierre Sfeir, Solarnet

Assessing the energy potential of the olive oil cake by-products requires the estimate of the annual quantity of pomace generated compared to olive input for olive oil production. The average quantities of olive input for the low season years and high season years are 78,300 tons and 184,600 tons, respectively.

Olive oil cake formation in the South of Lebanon

Pomace generation ratio and moisture content is directly linked to the olive oil extraction method. In Lebanon, 87% of olive mills use the traditional oil extraction method, while 10% use the 3-phase decanters and 3% use 2-phase decanters.

- Traditional mills generate the lowest quantity of pomace compared to other technologies (38% to 50%, average: 44%) with the lowest moisture content (25% to 31%, average: 28%).
- The pomace generation rate from the 3-phase decanters is comprised between 55% and 60% (average: 58%) and characterized by a moisture content of 46% to 48% (average: 47%).
- 2-phase decanters generate the highest quantity of pomace (77%) characterized by a moisture content of 60%.

Therefore, the national olive oil industry produces a total of 36,000 tons of pomace during low production years and 85,000 tons during high production years. These estimates include pomace at different moisture content rates. Figures and results are summarized in Table 49 below. Quantities issued from the different extraction methods are:

- Traditional mills (pomace at 28% moist): Low season average: 30,300 tons; High season average: 71,500 tons;
- Three phase mills (pomace at 47% moist): Low season average: 4,500 tons; High season average: 10, 600 tons;
- Two phase mills (pomace at 60% moist): Low season average: 1,200 tons; High season average: 2,800 tons.

Table 49: Pomace generation at olive mills

Olive mills data (Integrated waste management for the olive oil pressing industries in Lebanon, Syria, Jordan, 2008)	Total	Tradition al mills	3-Phase mills	2 Phase mills
		88%	10%	2%
Olive input (Tons/year)				
High season average	184 600	162 448	18 460	3 692
Low season average	78 333	68 933	7 833	1 567
Pomace generation rate		44%	58%	77%
Pomace generation (Tons/year)				
High season average	84 934	71 477	10 615	2 843
Low season average	36 041	30 331	4 504	1 206
Moisture content		28%	47%	60%
%DM		72%	53%	40%
Dry matter (tons/year) - High season average		51 464	5 626	1 137
Dry matter (tons/year) - Low season average		21 838	2 387	483

In order to homogenize these quantities with the same moisture content and to be able to calculate the energy potential, Table 50 presents converted figures in tons at 90% dry matter.

Table 50: Pomace generation at olive mills per season

Pomace generation @90% dry matter (Tons)	Total	Traditional ills	3-Phase mills	2 Phase mills
High Season average	64 696	57 182	6 251	1 263
Low season average	27 453	24 264	2 652	536

Based on the national distribution of pomace generated from olive mills, Table 51 shows the quantities of dry matter at 90 percent generated per Mohafazat.

Table 51: National distribution of pomace generated from olive mills

National distribution of pomace generated from olive mills (Integrated waste management for the olive oil pressing industries in Lebanon, Syria, Jordan, 2008)	%	Tons of pomace @90%DM - Low season	Tons of pomace @90%DM - High season
Beirut	0,0%	0	0
Mount Lebanon	25,8%	7 083	16 692
North Lebanon	36,3%	9 965	23 485
Beqaa	2,7%	741	1 747
South Lebanon	10,7%	2 937	6 922
Nabatiyeh	24,5%	6 726	15 851
TOTAL	100,0%	27 453	64 696

ENERGY POTENTIAL ESTIMATE

The calorific value of the pomace with 90 percent of dry matter content is comprised between 13.0 and 17.0 MJ per Kg of raw matter[9]. The calorific value observed in Lebanon is 16.74MJ/kg (4.65 kWh/kg). The total energy potential of the olive oil cake by-product is calculated at between 460,000 and 1,083,000 GJ per year for the national territory.

Table 53 shows these results and presents the details of the energy potential per mohafazat. North Lebanon, Mount Lebanon and Nabatiyeh mohafazat show the highest potential.

Table 52: Energy potential estimation from olive pomace

Energy potential Estimation (GJ)	Low	High
Beirut	0	0
Mount Lebanon	118 567	279 417
North Lebanon	166 822	393 133
Beqaa	12 408	29 241
South Lebanon	49 173	115 882
Nabatiyeh	112 593	265 337
TOTAL	459 564	1 083 010

The analysis of mill locations indicates that the most interesting production centres are:

- North Lebanon: the coastal part of the following cazas: Batroun, Khoura, Tripoli, Zgharta and the southern part of the caza of Akkar;
- Mount Lebanon: the southern part of the mohafazat, i.e. caza of Aley and caza of Chouf;
- Nabatiyeh: cazas of Nabatiyeh, Hasbaya and Marjaayoun.

AVALABILITY OF THE RESOURCE

According to the ELARD (2008), the pomace end uses/disposal methods are the followings:

- Sent to Syria for extraction of oil from pomace to use it in soap manufacturing: 30.91%
- Selling: 1.82%
- Refining: 1.45%
- Pressing to form blocks for heating: 17.45%
- Heating: 31.64%
- Composting: 3.27%
- Soil conditioner: 3.27%
- Drying: 0.36%
- Coal: 9.82%

In 49% of the cases, dried pomace is used as heating fuel during winter. The industry lacks drying processes and pomace is dried under solar evaporation and/or compressed before being used as heating fuel. Farmers frequently get the husk back and use it for personal and entourage consumption. Pomace as an energy source is not exploited in an efficient manner. The second principal end use is the extraction of oil from pomace in soap manufacturing that also occurs in Syria (31%).

As stated by the experts interviewed during the on-ground survey, pomace is sold at different prices depending on the extraction method:

- Traditional process: USD 80$ per ton
- Three phase and two phase processes: USD 20$ per ton

CONCLUSION

Olive oil cake by-products present have a very interesting bioenergy potential for Lebanon, ranging from 460 to 1083 TJ/year of primary energy. Furthermore, the majority of the production is centralized in three different parts of the country, i.e. North Lebanon, Mount Lebanon and Nabatiyeh.

Most of the resource is already used (exported in Syria for soap production, energy purposes…) but not efficiently. Thus, pomace is one of the bioenergy streams that can be developed in Lebanon if collection is structured. There is currently one actor on the Lebanese market using "bulk pomace" in stoves[10].

IV.13 ORGANIC WASTE FROM THE FOOD PROCESSING INDUSTRY

DISTRIBUTION OF FOOD AND BEVERAGE INDUSTRIES ACROSS LEBANON

According to data from the Central Administration for Statistics (CAS, 2004), the Food and Beverage industries are

[9] Interview with J.P. Sfeir, an energy expert who conducted a study related to olive residues in the energy sector

[10] Interview with J.P. Sfeir, see Annexes; Chapter 1, Part II, "Ground Surveys and Interviews".

mainly located in Mount Lebanon and North Lebanon with 2,870 and 1,568 firms, respectively, followed by the greater Beirut Area, the Beqaa, South Lebanon and Nabatiyeh – as shown in Table 53.

Table 53: Distribution of food and beverage industry across mohafazat (CAS, 2004)

Distribution of food and beverage industry across mohafazah	
Beirut	893
Mount Lebanon	2 870
North Lebanon	1 568
South Labanon	1 074
Beqaa	1 153
Nabatiyeh	716
Total	**8 274**

MAIN INDUSTRIES

Main food and beverage industries in Lebanon are beer, wine, cake & biscuits, bread and green beans. The yearly productions are presented in Table 54.

Table 54: Production from main food and beverage industries in Lebanon

Main industries production (MoE, 2006)	
Beer (hL/year)	158 740
Wine (hL/year)	43 356
Cake & biscuits (tons/year)	772 862
Bread (tons/year)	177 758
Green beans (tons/year)	16 818

SOLID WASTE QUANTITY ESTIMATES AND ENERGY POTENTIAL

It is difficult to produce reliable industrial solid waste estimates since a comprehensive waste survey, and/or industrial production statistics are missing, and given that no landfills are dedicated solely for such waste streams. The METAP/Tebodin study (1998) estimates the organic waste from food and beverage industry at 17,820 Tons per year. This figure must be higher taking into consideration the industrial growth production since 1998.

Beer industry:

Almaza/Heineken is the main beer producer in Lebanon[11]. Its beer processing plant is located in Daoura, greater Beirut Area. For the year 2010, Almaza produced 210,000 hectoliters (hL) of beer with projections of 7% projected growth annually.

Beer processing generates mainly 2 types of solid waste, namely spent grains and kieselguhr (ferment). Almaza/Heineken produces approx. 2,720 tons per year of spent grains that are sold at the price of USD 20 per ton for animal feeding and a negligible quantity of kieselguhr. Spent grains present an interesting methane potential, i.e. a net calorific value of 18.64 MJ/Kg of dry matter (Russ, Mörtel and Meyer-Pittroff, 2005) with a moisture content of 77 percent (Okamoto H., Kitagawa Y., Minowa T., Ogi T., 1999) corresponding to an average of 70 Nm3 of methane gas (Amane Energy estimate) per ton of raw matter. The total annual energy potential of Almaza/Heineken by-product is 11,660 GJ of primary energy and 1,703 MWh in terms of methane potential. Table 55 summarizes the assumptions adopted and subsequent results.

[11] Another small industry is currently trying to tap into the market but production quantities are still very small.

Table 55: Energy potential estimation from waste from beer industry

Spent grains - Assumption	
Moisture content (%)	77,0%
Net calorific value (MJ/Kg of DM)	18,64
Methane production potential (Nm3/t raw matter)	70,00
Energy potential Estimation	
Primary energy from spent grains (MWh)	3 239,22
Methane potential (MWh)	1 703,32

The potential is rather low and the stream has not been retained in comparison to others. But an opportunity should be taken to develop a biogas production project with Almaza Heineken using the residues from the site and exploring the use of other residues located within a reasonable distance.

Wine industry

Based on interviews with major producers, the organic waste of the wine making industry appears to be totally recycled. Grape stems are often given to farmers for animal feeding upon request. Otherwise, these are mixed with residual grape skins and seeds are left to ferment before being deposited back onto vineyards as fertilizer. Some producers are reported providing confectionary industries with the grape sinks as flavor additives.

The percentage of grapes used for animal feeding varies among producers but the fact remains that the organic waste generated is totally recycled.

Cake & biscuits

Production of cake & biscuits is significant in Lebanon with 772,862 tons (MoE, 2006). The energy potential of waste and by-products generated by this industry is rather high and the methane production potential is estimated to be between 220 to 320 m3 per ton, depending on the type of waste. Data about organic waste quantities and end uses are not available but assumptions can be made that Cakes & Biscuits Industry and Bakeries Industry have the same percentage of waste residues, i.e. 3-5%. As a result the total amount of waste residues is approximately 24,000 tons per year. This quantity is rather low and therefore the stream has not been retained but can be considered as a source of supply of a biogas generation project mixed with other co-products.

Bakeries

The Bakeries Industry present a high methane potential; between 260 and 430 m3 methane gas per ton of waste generated.

According to the on-ground surveys, an average of 3-5% waste residues (returns and production defects) applies to the production volumes. Taking into account a production of 177,758 tons (MoE, 2006), the total amount of waste residues is comprised between 5,340 and 8,890 tons per year. This total amount of residues is rather low. Moreover the production is highly scattered. Therefore the Bakeries stream is excluded.

Green beans (fruits and vegetables canned foods)

The national production is not high enough to generate sufficient by-products especially considering that the energy potential of green beans processing residues is low (an average of 25 m3 of methane gas per ton of raw matter). Therefore the green beans stream is excluded.

CONCLUSION

Despite repetitive research and interviews, it was very difficult to find relevant and tangible information. Contacts with major industries in the cake and biscuits industry and in the bakeries did not allow any estimates of waste quantities generated. Production quantities, reused by-products and/or waste generated were not disclosed by the industries.

Wine and green beans industries are not interesting in terms of energy potential for Lebanon.

Residues from beer processing, cakes & biscuits and bakeries industries present an interesting methane potential, however the quantities of waste residues generated are too low and, except for the beer industry, the facilities are scattered and collection of very small quantities of residues is not economically viable.

Therefore organic waste from food processing Industry stream is not retained as interesting bioenergy stream in this study, but it can be considered as part of a biogas generation projects when mixed with other co-products.

IV.14 WASTEWATER AND SLUDGE FROM THE FOOD PROCESSING INDUSTRY

Only a few agro-food industries sites have a preliminary wastewater treatment (screening equipment). Nearly all wastewater from the food processing industry are released with very limited treatment into water courses or co-disposed in the domestic wastewater system collection network. As an example, a major dairy producer acknowledged the disposal of manure directly to the river while wastewater is treated in large aeration tanks before discharge.

To develop this stream in Lebanon, it is necessary to impose standards for industrial wastewater discharges with the first objective of protecting the environment. As a result, industries are obliged to treat their wastewater effluent. Municipal wastewater treatment plants could support small to medium industries in the treatment of their wastewater. Subsidies for the production of biogas from wastewater sludge and organic waste will encourage the treatment of sludge by anaerobic digestion and the production of energy from biogas, hence meeting two objectives: protecting the environment and developing renewable energy sources.

IV.15 BIODEGRADABLE FRACTION OF MUNICIPAL SOLID WASTE

This section reviews the energy potential of the biodegradable fraction of municipal solid waste. First, relevant literature is used to provide a first assessment of the available and accessible volumes. Second, during the on-ground survey, interviews with MoE and CDR officials and/or solid waste experts verified and adjusted the first assumptions.

QUANTITY OF BIODEGRADABLE FRACTION OF MUNICIPAL SOLID WASTE

The available biodegradable fraction of municipal solid waste is quantified herein. Commercial organic waste is included as it is not separately collected. Biodegradable fraction of solid waste represents 55% of total municipal solid waste[12]. Table 56 shows the quantities of municipal solid waste generation per mohafazat and Table 57 shows the calculated quantities of organic fraction.

Table 56: Municipal solid waste generation per mohafazat (MoE, 2010)

Municipal solid waste generation	Tons of raw matter/day	Tons of raw matter/year
Beirut	900	328 500
Mount Lebanon	1600	584 000
North Lebanon	700	255 500
Beqaa	450	164 250
South Lebanon	300	109 500
Nabatiyeh	350	127 750
Total	4 300	1 569 500

Table 57: Organic waste generation per mohafazat

Organic waste generation	Tons of raw matter/day	Tons of raw matter/year
Beirut	495	180 675
Mount Lebanon	880	321 200
North Lebanon	385	140 525
Beqaa	248	90 338
South Lebanon	165	60 225
Nabatiyeh	193	70 263
Total	2 365	863 225

[12] Interview with Bassam Sabbagh, Head of Urban Environment Pollution Control Department, Ministry of Environment

It is estimated that approximately 863,000 tons per year of biodegradable waste are generated. The greater Beirut area and Mount Lebanon account for almost 60% of the total.

ENERGY POTENTIAL FROM BIODEGRADABLE FRACTION OF MUNICIPAL SOLID WASTE

Biodegradable fraction of municipal solid waste has a net calorific value of 6.2 MJ/Kg of dry matter and a methane potential of 36m^3 of methane per ton of raw matter on average. Moisture content is between 40% and 60%, with an average of 50%. The energy potential of biodegradable fraction of municipal solid waste has been estimated both in terms of primary energy and methane potential. The total energy potential of the bioenergy stream is estimated at 2,676,000 GJ (743 GWh) nationwide and the methane potential is estimated at 278 GWh. Mohafazat of Beirut and Mount Lebanon generate the highest amount of waste and consequently are the most interesting regions in terms of potential energy production. Table 58 summarizes the assumptions adopted.

Table 58: Energy potential estimation from MSW per mohafazat

Energy potential estimation		Primary energy (GJ)	Methane potential (GWh)
Beirut		560 093	58,19
Mount Lebanon		995 720	103,44
North Lebanon		435 628	45,26
Beqaa		280 046	29,09
South Lebanon		186 698	19,40
Nabatiyeh		217 814	22,63
Total		2 675 998	278,01

BIODEGRADABLE FRACTION OF MUNICIPAL SOLID WASTE AVAILABILITY

According the Ministry of Environment (2010), 9% of the organic fraction of municipal solid waste is currently composted. Table 60 reports all the composting units operating or near operation and their respective capacity. The latest planned unit will be in operation in 2012.

Based on these data, it is estimated that approximately 214,000 tons of organic waste will be composted. Composting is a competitive end use and affects the availability of this bioenergy resource. The energy potential has been calculated without taking into account these composted amounts of organic waste. Table 59 and Table 60 summarize the net potential per mohafazat and nationwide.

Table 59: Composting capacity in Lebanon

Composting units (Expert)	Mohafazat	Status	Composted (Tons/day)	Composted (Tons/year)	Comments
Bourj Hammoud	Mount Lebanon	Operational	300	109 500	Under O&M tendering.
Shouf Swayjani	Mount Lebanon	Under construction	15	5 475	1.5 years to operation.
Jbeil	Mount Lebanon	Under construction	40	14 600	
Ansar	Nabatiyeh	Operational	6	2 190	Not operational and there is no timeframe for the beginning of operations.
Khiam	Nabatiyeh	Operational	10	3 650	
Khirbit Silim	Nabatiyeh	Operational	10	3 650	To be completed by end 2010. Directly operational.
Taybe	Nabatiyeh	Operational	10	3 650	To be completed by June 2011. Directly operational.
Bent Jbeil	Nabatiyeh	Under construction	NA	NA	Not initiated yet. The location of the plant is not decided yet and seems problematic.
Aytaroun	Nabatiyeh	Operational	NA	NA	Waste is currently dumped at the Kayal dump.
Tyr	South Lebanon	Under construction	100	36 500	
Minieh	North Lebanon	Under construction	45	16 425	Expected completion in July 2011.

Table 60: Energy potential estimate from the organic fraction of MSW

Energy potential estimation		Primary energy (GJ)	Methane potential (GWh)
Beirut		560 093	58,19
Mount Lebanon		594 038	61,71
North Lebanon		377 921	39,26
Beqaa		229 129	23,80
South Lebanon		73 548	7,64
Nabatiyeh		177 080	18,40
Total		**2 011 807**	**209,00**

The total primary energy potential is estimated to be 2,011,000 GJ (558 GWh), while the methane potential is 209 GWh. It appears that the largest potential are concentrated in the greater Beirut Area and Mount Lebanon (57%) areas followed by North Lebanon (19%). Waste generated in these two areas is landfilled without energy recovery of the landfill gas. The lost opportunities over the ten last years in term of energy generation from landfilled waste are estimated in the next section.

Outside the greater Beirut Area, it is estimated that 74% of the waste are more or less discarded in uncontrolled landfills. However, according to the latest solid waste management plan developed by the CDR and Ministry of Environment (CDR and MoE, March 2010), four incinerators with energy recovery are planned to receive unsorted municipal waste of major urban areas (Beirut, Tripoli, Tyr and Baalbek). The sites and specifications of the incinerators have not been laid out at this stage and are currently subject to study by external consultants. Preliminary information indicates that the capacity of each incinerator should not be less than 1,000 to 1,500 tons per day in order to be efficient. The organic fraction will be dried and then incinerated. Ashes will be sent to the landfills. The availability of this bioenergy stream is linked to the waste management master plan.

CONCLUSION

This stream is very interesting in terms of energy potential estimated at 2 011 TJ/year of primary energy. Furthermore, part of it could be recovered in existing landfills. An estimate of the lost opportunities over the ten last years is assessed in the next section.

However energy recovery from solid waste is already planned in the Solid Waste Master Plan for the major urban areas with the implementation of four Waste-to-Energy (WTE) plants. It is envisaged that these Waste-to-Energy units will treat, according to the interview of the expert, the majority of waste generated nationwide.

IV.16 LANDFILL GAS POTENTIAL

The waste deposited in a landfill gets subjected, over a period of time, to anaerobic conditions. Its organic fraction is slowly decomposed and leads to the production of landfill gas containing about 45 to 55% of methane. Methane can be recovered through a network of gas collection pipes and utilized as a source of energy either for direct thermal applications or for power generation.

Naameh Landfill

Production of landfill gas starts within a few months of the disposal of the wastes and generally lasts for about ten years (or more depending on the composition of the waste and its moisture content).
This section reviews the current potential of methane gas that can be recovered in the existing landfills and takes into account the waste disposed during the last ten years. First, methane gas that can be recovered from the main landfills and controlled open dumps have been assessed. Second, information collected through the on-ground survey allowed to verify and to adjust the first assumptions.

SUITABLE LANDFILLS FOR ENERGY RECOVERY

Landfills in Lebanon do not have landfill gas collection systems.
The implementation of landfill gas collection systems requires a critical size above which it will generate enough landfill gas to be economically viable. As a consequence, the sites considered suitable for energy recovery are those having over one million tons of waste in place, a majority of which should be less than ten years old.
Table 61 summarizes the information gathered concerning the existing landfills.

Table 61: Operational landfill capacity in Lebanon per mohafazat

Operational landfill capacity (Expert)	Mohafazat	Year of starting operation	Tons/ year	Max capacity (Tons)	Observati ons	Comments
Tripoli (controlled dumping)	North Lebanon	1999	110 000	1 500 000	Landfill gas flared	
Naameh (Laceco, 2010)	Mount Lebanon	1998	820 000	8 500 000	Planned for closure in 2010 but is still operational for the next 3 years; Landfill gas flared.	
Bsalim (Laceco, 2010)	Mount Lebanon		22 000	420 000	Inert material	Not suitable for energy recovery: inert material)
Zahleh (AESA Misiones S.A) for a 10 years period)	Beqaa	2002	39 992	N.A.	Landfill gas flared	Not suitable for energy recovery: Not large enough
Hbaline	Mount Lebanon	2005	Approx. 15 000	N.A.	UNDP report executed in 2009	Not suitable for energy recovery: Not large enough

The Naameh sanitary landfill and the controlled dump of Tripoli have been retained to assess their respective potential. The landfills of Bsalim, Zahleh and Hbaline are not suitable for the following reasons;

- Bsalim landfill: Disposal of inert material only
- Zahleh landfill: Not large enough for energy recovery to be economically sustainable.
- Hbaline landfill: According to Bassam Sabbagh, Head of

Urban Environment Pollution Control Department, Ministry of Environment, a UNDP report about gas flaring at the Hbaline landfill executed in 2009 stated that the landfill is not large enough for energy recovery to be economically sustainable.

ESTIMATION METHODOLOGY

The potential of landfill gas that can be produced and collected from any landfill site depends upon several factors, including the amount of waste in place and its characteristics.

To assess the potential, we assume that each ton of waste will produce 6 m3 of landfill gas per year.

This ratio reflects the average landfill gas production observed in diverse energy recovery projects in operation in developing countries, and may not accurately account for the quality of waste, climate, and other characteristics present at a specific landfill.

This production rate can be sustained for 5 to 15 years, depending on the site. Regarding the characteristics of the country waste (i.e., organic content of 55% and moisture content of 40-60%), it is assumed that a ton of waste will produce landfill gas during ten years[18].

This method only requires knowing how much waste is in place in the landfill. The waste tonnage should be less than ten years old. This is a conservative estimate of gas recovery. It may vary but it has the advantage of providing a reliable estimate of the current situation.

A reasonable assumption for the landfill gas collection efficiency is 70 to 85% and a methane gas content of 45 to 55%. Furthermore, in order to estimate the waste tonnage disposed since the opening of the landfills, waste generation growth rate of 1.65% per year is assumed, as reported by MoE (2010). Table 62 summarizes the assumptions retained to assess the energy potential of existing landfills.

Table 62: Assumption for the calculation of energy potential from landfills

Assumptions		
Percentage of waste generation growth per year		1,65%
Landfill gas production potential (m^3/year during 10 years)		6
Landfill gas recovery (% of landfill gas generated)		70%
Fraction of methane in landfill gas(%)		45%
Calorific value of methane gas (KWh/m3)		9,94

Table 63 and Table 64 summarize the calculated amount of waste disposed each year since the beginning of operation in the Naameh sanitary landfill and Tripoli controlled open dump, respectively, - based on the amount of waste disposed in 2010.

The rate and volume of landfill gas produced at a specific site as well as the period over which waste produces gas depend on the characteristics of the waste (e.g., composition and age of the refuse) and a number of environmental factors (e.g., the presence of oxygen in the landfill, moisture content, and temperature). Waste composition: The more organic the waste present in a landfill is, the more landfill gas (e.g., carbon dioxide, methane, nitrogen, and hydrogen sulfide) is produced by the bacteria during decomposition. Moisture content: The presence of moisture (unsaturated conditions) in a landfill increases gas production because it encourages bacterial decomposition. Moisture may also promote chemical reactions that produce gases. Age of Refuse: More recently buried waste will produce more gas than older waste. Landfills usually produce appreciable amounts of gas within 1 to 3 years. Peak gas production usually occurs 5 to 7 years after wastes are dumped.

Table 63: Waste disposed at Naameh landfill

Naameh	Tons/year
1998	673 791
1999	684 909
2000	696 210
2001	707 697
2002	719 374
2003	731 244
2004	743 309
2005	755 574
2006	768 041
2007	780 714
2008	793 595
2009	806 690

Table 64: Waste disposed at Tripoli landfill

Tripoli	Tons/year
1999	91 878
2000	93 394
2001	94 935
2002	96 501
2003	98 094
2004	99 712
2005	101 357
2006	103 030
2007	104 730
2008	106 458
2009	108 214
2010	110 000

ENERGY RECOVERY POTENTIAL

Taking into account the above assumptions, the potential of the landfills (if landfill gas were captured with energy recovery) for 2010 is as follows;

• For the Naameh sanitary landfill, a potential methane gas recovery of 14 400 000 Nm3, equivalent to 143 GWh for 2010.

• For the Tripoli controlled open dump, a potential methane gas recovery of 1 900 000 Nm3, equivalent to 19 GWh for 2010.

Table 65 summarizes the landfill gas generated in both landfills, the landfill gas that could potentially be recovered, the potential methane gas recovery and its' equivalent in terms of energy.

Table 65: Methane recovered and energy potential estimation from landfills

Potential amount of methane gas recovered	
Naameh	
Landfill gas generated in 2010 (m3)	45 757 424
Landfill gas potential recovery in 2010 (m3)	32 030 197
Methane potential production in 2010 (m3)	**14 413 589**
Tripoli	
Landfill gas generated in 2010 (m3)	6 138 191
Landfill gas potential recovery in 2010 (m3)	4 296 734
Methane potential production in 2010 (m3)	**1 933 530**
Energy potential estimation	
Naameh (GWh)	143,3
Tripoli (GWh)	19,2
Total (GWh)	162,5
Total (GJ)	585 000,0

Lost opportunities

Lebanon has lost and is losing a significant opportunity in terms of energy production from methane recovery in landfills. Given that the waste amount disposed in a landfill has to be over one million tons of waste in place to be economically viable, a majority of which should be less than ten years old, the following assumptions have been made:

- Energy recovery could have started in year 2000 in the Naameh Sanitary Landfill;
- Energy recovery could have started in 2008 in the Tripoli controlled open dump

Consequently, the opportunity lost in term of bioenergy from methane recovery is estimated at:

- 1,128 GWh since 2000 for Naameh
- 57 GWh since 2008 in Tripoli.
- A total of 162.5GWh (585,000 GJ)

CONCLUSION

The opportunity lost in term of energy potential at the Naameh sanitary landfill is substantial (estimated at 585 TJ/year of primary energy). The Naameh landfill was planned to close this year yet its lifetime was extended for three more years, pending the possible execution of newly planned incinerators.

IV.17 INDUSTRIAL AND COMMERCIAL WASTE

Industrial and commercial waste, i.e., waste paper, cardboard and wood pellets, organic residues from commercial supermarkets and restaurants, usually are disposed in curbside waste containers and are collected with the municipal solid waste stream. Wood pellets are included in the waste wood bioenergy stream and other organic industrial and commercial wastes are included in the biodegradable fraction of municipal solid waste sections.

Draft decrees on industrial waste management, namely the licensing and permitting for industrial facilities to dispose of industrial and hazardous waste, and the classification and management of industrial and hazardous waste are as of yet not approved. One of the consequences is the poor documentation of waste composition, most interestingly that of non-hazardous waste for bioenergy generation.

According to this information, industrial and commercial waste has not been kept as interesting bioenergy stream for Lebanon.

IV.18 WASTE WOOD

This section reviews the energy potential of waste wood. First, relevant literature provides a first assessment of the available and accessible volumes. Second, during the on-ground survey, an interview with the head of Urban Environment Pollution Control Department at the Ministry of Environment provided figures fine-tuning and confirming the first assumptions.

QUANTITY OF WASTE WOOD

All bulky waste wood is collected together; hence the estimates below include industrial, commercial and municipal

waste wood volumes. According to the Ministry of Environment, waste wood represents 2% of the municipal solid waste volumes in urban areas and 4% in rural areas. The mohafazat of Beirut, Mount Lebanon and North Lebanon are considered as urban areas. The mohafazat of Beqaa, South Lebanon and Nabatiyeh are predominantly rural.
Table 66 presents estimates of the quantities of wood waste per mohafazat based on the quantities of municipal solid waste generation per mohafazat (Table 58). Taking into account the waste wood ratios, it is estimated that approximately 39,500 tons per year of waste wood is generated. The greater Beirut and Mount Lebanon area account for more than 45% of the total.

Table 66: Waste wood generation

Waste wood generation	Tons/day	Tons/year
Beirut	18	6 570
Mount Lebanon	32	11 680
North Lebanon	28	5 110
Beqaa	18	6 570
South Lebanon	12	4 380
Nabatiyeh	14	5 110
Total	**122**	**39 420**

The Lebanon Climate Change Report (MoE, 2006) refers to a proportion of 2.6% of wood waste contained in the municipal solid waste - nationally. This information confirms the above estimates.

ENERGY POTENTIAL OF WOOD WASTE

Calorific value of waste wood is comprised between 17.0 and 20.0 MJ per Kg of dry matter with an average of 18.5 MJ per Kg of dry matter. The estimate of the total energy potential of waste wood for the national territory is therefore approximately 583,416 GJ. The mohafazats of Beirut and Mount Lebanon generate the highest waste wood quantity and consequently are the most interesting regions in terms of potential bioenergy production.
Table 67 summarizes the assumptions retained in the calculation.

Table 67: Energy potential estimates from wood waste in Lebanon

Assumptions	
Moisture content	20,00%
Average calorific value (MJ/Kg dry matter)	18,50
Energy potential estimation (GJ)	
Beirut	97 236
Mount Lebanon	172 864
North Lebanon	75 628
Beqaa	97 236
South Lebanon	64 824
Nabatiyeh	75 628
Total	**583 416**

WASTE WOOD AVAILABILITY

There is an absence of wood recycling in Lebanon. Waste wood generated in the greater Beirut Area and Mount Lebanon are sent with all bulky items to the inert landfill of Bsalim (except quantities where they are sorted and sold to clients as reported in Laceco reports). This waste stream is recorded separately once sorted. A considerable part of the shredded waste wood is then collected by scavengers who are reselling it for heating purpose.
Based on the August 2010 monthly report of the Bsalim landfill (LACECO, 2010) the waste wood received anually at the landfill is approximately 13,920 tons. Beirut

and Mount Lebanon together generated 18,250 tons of waste wood per year (Table 67). Consequently 4,330 tons per year are already sold corresponding to an energy potential of 64,000 GJ. Regarding the rest of the country, no reliable information is available on waste wood end uses and it is not possible to estimate which proportion is currently used for heating purposes.

CONCLUSION

Waste wood bioenergy stream have an interesting bioenergy potential estimated at 583 TJ/year of primary energy. Collection and sorting of waste wood already exists in Lebanon. In terms of availability, except a small part that is currently sold for heating, there are no other competitive end uses. There are no waste wood recycling activities and consequently it is sent to landfill. Much of the waste wood (45%) is generated in Beirut and Mount Lebanon, sorted at the landfill and sent to a unique location. Thus, waste wood stream is one of the bioenergy streams that offer interesting potential in Lebanon.

IV.19 MUNICIPAL SEWAGE SLUDGE

MUNICIPAL SEWAGE SLUDGE QUANTITY

The energy potential of municipal sewage sludge generated from the 120 WWTPs planned by CDR and MoE is estimated using data from the study conducted by Tecsult International Limited and KREDO Consulting Engineers, entitled "Etude du plan directeur pour la valorisation ou l'élimination des boues d'épuration" (2002). More recent data is currently unavailable.

The report indicates that the 120 wastewater treatment plants would generate 328.9 tons of dry matter per day in 2010. Table 68 summarizes the distribution of sludge production per mohafazat. It is to be noted that:

- 52 percent of the national sludge production is generated in Greater Beirut Area and Mount Lebanon, from which 40 percent will be produced by the Beirut wastewater treatment plants of Ghadir and Daoura.
- 60 percent of the national sludge production is generated in the five largest wastewater treatment plants (Daoura, Ghadir, Tripoli, Zahleh and Keserwan wastewater treatment plants);
- 74 percent of the national sludge production is generated in the ten largest wastewater treatment plants (in addition to the five plants mentioned above: Saïda, Sour, Nabatiyeh, Timnine and Tahta and El Marj).

Table 68: Municipal sewage sludge generation in Lebanon (CDR, 2002)

Location	2010 Horizon (ton dm/day)	2020 Horizon (ton dm/day)
Mount Lebanon	36.2	52.5
Beirut	135.8	168.4
Beqaa	57.9	78.0
North Lebanon	62.7	79.8
South Lebanon	36.3	46.9
Total	328.9	425.6

Table 69: Municipal sewage sludge generation for ten largest plants in Lebanon

2010 Sludge production (2002 estimate) (CDR, 2002)			
Tons of dry matter per day		328.9	
Tons of dry matter per year		120 049	
Sludge quantity assumptions		**@ 15% dry matter**	**@ 40% dry matter**
Sludge generated (tons/year)		800 323	300 121
Sludge production from the 10 largest plants (tons/year)	74%	592 239	222 090
Sludge production from the 5 largest plants (tons/year)	60%	480 194	180 073
Sludge production for Beirut and Mount Lebanon (tons/year)	52%	416 168	156 063

Waste wood

Based on these figures, the amount of raw sludge generated per year has been assessed nation-wide, for the 10 largest WWTPs, for the 5 largest WWTPs and for Greater Beirut and Mount Lebanon Areas as shown in Table 69.

ENERGY POTENTIAL FROM MUNICIPAL SEWAGE SLUDGE

Energy potential from municipal sewage sludge is calculated both in terms of primary energy and methane potential. The net calorific value of sewage sludge at 40 percent of dry matter is estimated at 3.0MJ/Kg (Layman, 2008). Table 70 summarizes the assumptions retained and the assessment of primary energy from sludge both on a nation-wide scale and for the largest treatment plants in the country.

Table 70: Primary energy estimate from wastewater treatment sludge

Assumptions - Primary energy from sludge	
Sludge net calorific value (MJ/Kg of sludge @40% DM)	3,00
Energy potential estimation	
Energy potential - Total (GJ)	900 364
Energy potential - 10 largest plants (GJ)	666 269
Energy potential - 5 largest plants (GJ)	540 218
Energy potential - Beirut + Mount Lebanon (GJ)	468 189

Methane production potential of municipal sewage sludge depends on the organic content and can vary from 12 to 23m3 of methane gas per ton of raw sludge at 15% of dry matter, with an average of 17.5m3. This is a realistic assumption to be considered for a developing country.

Table 71 summarizes the assumptions adopted, and the assessment of energy potential from sludge both on a nation-wide scale and for the largest wastewater treatment plants in the country.

It is not economically viable to install sludge digestion units with energy recovery on small size wastewater treatment plant sites that have a sludge production below 1 ton of dry matter per day (approximately 80 sites out of the 120). The methane potential of the municipal sewage sludge that could be generated at the ten largest plants of the country, i.e., 92 GWh equivalent to 666,230 GJ, is promising. However the assessment of the energy potential for the following 30 WWTP in term of sludge production requires further investigation to determine for each site the opportunity to implement sludge digestion.

Table 71: Methane potential estimation from municipal sewage sludge

Assumptions	
Methane production potential (m3/t raw matter)	17,50
Energy potential estimation	
Energy potential - Total (GWh)	125,29
Energy potential - 10 largest plants (GWh)	92,72
Energy potential - 5 largest plants (GWh)	75,18
Energy potential - Beirut + Mount Lebanon (GWh)	65,15

AVAILABILITY OF THE RESOURCE

According to inventory of wastewater treatment plants by the German Technical Cooperation (GTZ, 2009), the process characteristics and status of the 10 largest wastewater treatment plants are as follows;

- Daoura: Biological treatment and sludge stabilization; Commissioning in 2011
- Ghadir: Preliminary treatment and sea outfall; Commissioning in 1997, no upgrading planned
- Tripoli: Sludge digestion with energy recovery (cogeneration); Commissioning in 2009 (Degrémont)
- Zahleh: Sludge thickening, drying and disposal; Commissioning in 2010 (Degrémont)
- Kesrouane: Biological treatment and sludge stabilization; Commissioning in 2012
- Saïda: Preliminary treatment and sea outfall; (Commissioned 2006) extension of collector planned
- Sour: Biological treatment and sludge stabilization; Commissioning in 2013
- Nabatiyeh: Biological treatment, sludge stabilization; Construction completed, main collector pending
- Timnine Tahta: Biological treatment and sludge stabilization; construction completed and commissioning in 2011
- El Marj: Biological treatment and sludge stabilization – Commissioning in 2012

Regarding the status of the ten largest wastewater treatment plant, all sludge produced currently or in a near future seem to be available except:

- Sludge from Tripoli wastewater treatment plant from which energy is already recovered
- Sludge from Zahleh wastewater treatment plant which is used as soil amendment.

CONCLUSION

The energy production potential from the ten largest plants in Lebanon is promising and estimated to be approximately 666 TJ/year of primary energy.

The possibility of energy recovery from sludge for the following 30 WWTPs in term of sludge production quantity requires further investigation and needs to be studied site by site.

IV.20 LANDSCAPE MANAGEMENT RESIDUES

To assess the energy potential of landscape management residues, the knowledge of the areas where urban green spaces are managed needs to be estimated, along with the annual quantities of residues resulting from the maintenance of these gardens and parks.

LANDSCAPE MANAGEMENT AREAS

According to measurements applied through GIS in 1998, only the cities of Beirut and Tripoli present managed urban green spaces areas, with surface areas of 43 and 55 hectares, respectively[13]. According to the interview with Fadi Shayya (urban planner and editor of the book “At the Edge of the City: Reinhabiting Public Space toward the Recovery of Beirut’s Horsh Al-Sanawbar”), urban green space in Beirut is estimated at 45.8 hectares. The GIS 1998 base does not allude to the presence of green spaces beyond these two cities and to our knowledge there are no other reliable data. Consequently, an estimate for the quantity of residues for the rest of the country is excluded. The landscape area in Lebanon is shown in Table 72.

Table 72: Landscape area in Lebanon

Landcape area (ha)	(GIS, 1998)	(F.Shayya)
Beirut	43,0	45,8
Tripoli	55,0	-

[13] The City of Saida presents a managed green space of 0.2ha, which is not significant.

VOLUME RATIOS OF RESIDUES AND ENERGY POTENTIAL ESTIMATE

According to the landscape management contractor of Beirut Municipality, Mahmoud Adada, maintenance of green spaces in Beirut generates 20 m3 of residues (equivalent to 1.5 tons per day), six days a week, which is equivalent to 10 tons per year per hectare.

From these figures, it is estimated that Beirut produces 468 tons/year and Tripoli 562 tons/year of landscape management residues. Landscape management residues present moisture content of approximately 20% and an average calorific value of 18.5 MJ/Kg of dry matter (Amane Energy estimates). Table 73 summarizes all the assumptions used to calculate the energy potential of this bioenergy stream for Lebanon.

Sanayeh Garden

Table 73: Landscape management residues in Lebanon

Assumptions			
Tons of residues in Beirut per day (6 days a week) Source: Fadi Shayya	1,50		
Tons of residues /ha/year	10,22		
Moisture content	20,0%		
Average Cicalorific value (MJ/Kg dry matter)	18,50		
Quantity of residues	**Tons of raw matter/year**	**Tons of dry matter/year**	**Comments**
Beirut	468,0	374,4	260 tons raw matter / year composted with the Beirut slaughterhouse waste. The remaining 208 Tons are shredded and used as soil fertilizer n the Chatila region)
Tripoli	562,0	449,6	A priori Included in the quantity of Biodegradable fraction of Municipal Solid Waste
Total	1030,0	824,0	

The energy potential estimate is calculated from the quantity of dry matter generated per year.

Energy potentials of 6,926 GJ and 8,318 GJ per year can be achieved for Beirut and Tripoli, respectively, as shown in Table 74.

Table 74: Energy potential estimate from landscape management residues

Energy potential estimate (GJ/year)	
Beirut	6 926
Tripoli	8 318
Total	**15 244**

AVAILABILITY OF THE RESOURCES

The Municipality of Beirut is in charge of the maintenance of the urban green spaces and of the collection of the residues. Currently, 260 tons of the Beirut landscape management residues are composted with the Beirut slaughterhouse waste. The remaining 208 tons are shredded and mixed with soil to be used as fertilizers, mostly in the Chatila region.

As for the landscape management residues in Tripoli, there is a lack of reliable data regarding the end uses/destination of the landscape management residues. The assumption adopted as is that landscape management residues are treated with Municipal Solid Waste.

CONCLUSION

Considering the small landscape surfaces concerned in Beirut and Tripoli, it was not considered appropriate to further investigate this bioenergy stream for the rest of the country. Given the lack of reliable data for the rest of the country, it is assumed that the rest of the country's residues are treated with municipal solid waste.

It can be concluded that landscape management residues present a very limited potential for Lebanon as the quantities are minimal and consequently the energy potential is negligible. This residue can be treated in composting units and used as soil fertilizer. To this end, this bioenergy stream was not considered further as of interest.

IV.21 YELLOW GREASE

To estimate the energy potential of yellow grease in Lebanon, the collectable quantities generated per year need to be evaluated.

Household consumption of waste oil is not taken into account as collection is too difficult to establish practically. Currently, household yellow greases are disposed of in sewers. Hence, only the collectable yellow grease (i.e. used cooking oil from restaurants and catering) is taken into account for this bioenergy stream.

Without reliable information on this bioenergy stream, two different routes to estimate the available quantities were applied.

First, international data sources and ratios are used to provide a first estimate of the available and accessible volumes. Second, during the on-ground survey, an interview of the representative of the only biodiesel producer in Lebanon, Biodiesel Lebanon, was carried out. The figures collected through this interview allowed the verification of the adopted international assumptions.

ESTIMATE OF THE ANNUAL QUANTITY OF COLLECTABLE YELLOW GREASE

Estimate based on international sources

The average volume of yellow grease per capita per year is 4 kg for urban populations (NREL, 1998). It was assumed that the Lebanese urban population represents approximately 3.5 million inhabitants[14]. The first rough estimate of the yellow grease generated in Lebanon is consequently 14,000 tons/year. Table 75 summarizes the assumptions and the results.

Table 75: Yellow grease quantities in Lebanon (estimation)

Yellow grease quantity rough estimate	
Average production rate (Kg of raw matter/ Inhabitants/year - urban population) (NREL, 1998)	4,00
Lebanese urban population	3 500 000
Yellow grease generation (Tons/year)	14 000,0

Confirmation of estimates with on-ground survey

According to Mr. Walid Ghazal, spokesperson of Lebanon Biodiesel, the company collects 20% of the collectable yellow grease, equivalent to 220 to 250 tons per month. These figures indicate that the volumes of collectable yellow grease per year on a national level stand at 13,200 to 15,000 tons. It is not possible to divide the estimate at a mohafazat level due to the lack of data as shown in Table 76 below.

Table 76: Yellow grease quantities in Lebanon (based on interviews)

Yellow grease quantity based on interview	Low estimate	High estimate
% of yellow grease collectable collected by biodiesel Lebanon	20%	
Yellow grease collected by biodiesel Lebanon (Tons/month)	220,0	250,0
Yellow grease collected by biodiesel Lebanon (Tons/year)	2 640,0	3 000,0
Yellow grease collectable at a national level (Tons/year)	13 200,0	15 000,0

ENERGY POTENTIAL ESTIMATE

The calorific value of yellow grease stands between 36.0 and 39.0 MJ per Kg of raw matter with an average calorific potential of 37.5 KJ per Kg. The total energy potential of the collectable yellow grease in Lebanon is therefore between 495,000 and 562,000 GJ per year, as shown in Table 77.

Table 77: Energy potential estimates from yellow grease

Energy potential estimate	Low estimate	High estimate
Average calorific value (MJ/Kg RM)	37,50	
Energy potential (GJ)	495 000	562 500

AVALABILITY OF THE RESOURCE

According to Mr. Walid Ghazal, only household cooking oils are dumped into sewers while all yellow greases from restaurants, chains and catering services are collected and sold at a price of approximately USD 250$ per ton and are subject to the laws of supply and demand.

Biodiesel Lebanon, the only biodiesel producer in Lebanon, collects approximately 20% of total yellow grease - i.e., approximately 200 tons per month or 2,400 tons per year - for its production. Biodiesel is sold to diesel distributors to

[14] The population is estimated at 4.2 million (source: Second national Communication of the MoE and population used in the calculation of the National Greenhouse Gas emission); 90 % living in urban areas (State of Lebanon Forests, 2007).

correct the poor quality and the composition of the diesel. This company is currently limiting its production due to limited storage capacity. The remaining 80 percent are apparently used in animal feeding, mixed with other by-products.
According to Mr. Chafic Estephan, Head of the field crops department at the Lebanese Agricultural Research Institute (LARI), who is currently working on a yellow grease project, it is not unusual that restaurants directly sell their yellow greases for direct use as fuel for vehicles (without any previous treatment).
In most countries in the world (developed countries as well as developing countries), collection of yellow grease is a sensitive subject because it is a very valuable by-product with very high energy content. Most of the time the accessibility to this by-product is difficult given that a few players only control the market, limit new entrants and set the market price. According to Mr. Walid Ghazal, this situation applies to the Lebanese market.

CONCLUSION

The yellow grease bioenergy stream has an interesting energy potential ranging from 495 to 562 TJ/year of primary energy. This potential is especially interesting for biodiesel production or mixed with other by-products within co-digestion biogas production units.
Collection systems are already in place. The problem resides in accessibility, as the market is controlled by a few players and the price is already very high. Prices fluctuate in response to supply and demand dynamics. According to biodiesel producers, the prices can go up as high as USD 320 per ton and in holiday seasons can drop to USD 150 per ton. An average price retained throughout the year is around USD 280.
Nonetheless, yellow grease bioenergy stream is one of the bioenergy streams that can be developed in Lebanon.

VI.RANKING OF MOST INTERESTING BIOENERGY STREAMS FOR LEBANON

A first ranking of the bioenergy streams, taking into account only the energy potential has been made. It allowed to exclude bioenergy streams with the lowest energy potential. Then bioenergy streams where major sustainability or accessibility issues exist have been excluded from the main ranking. This is the case of wood harvesting from forests as it may lead to deforestation, but not the case of forestry residues (sustainable forest management). This is also the case for animal manure and the biodegradable fraction of municipal solid waste given the difficultly in their collectability in the country.
In a few cases, when two streams are almost equal in ranking, a detailed comparison has been made, for example between wood waste and wastewater sludge. It is easier to collect 39,000 tons of wood than 590,000 tons of sludge. Therefore waste wood has been ranked higher than sewage sludge even if its total energy potential is lower.
Table 78 shows the quantity and energy potential of each biomass stream. Furthermore a ranking is made considering criteria such as energy potential, sustainability, other uses, accessibility and current legal framework. Each ranking criterion is assessed in term of high (green), medium (yellow) and low (red) potential.

As result, the ranking of the ten most promising bioenergy streams is:

1.Residues from forestry fellings
2.Residues from fruit and olive trees
3.Residues from cereals
4.Energy crops on currently unused land
5.Olive cake by-products
6.Waste wood
7.Municipal sewage sludge
8.Animal fat and slaughterhouse residues
9.Yellow grease
10.Landfill gas recovery (specifically Naameh landfill)

THE ISSUE OF MUNICIPAL SOLID WASTE

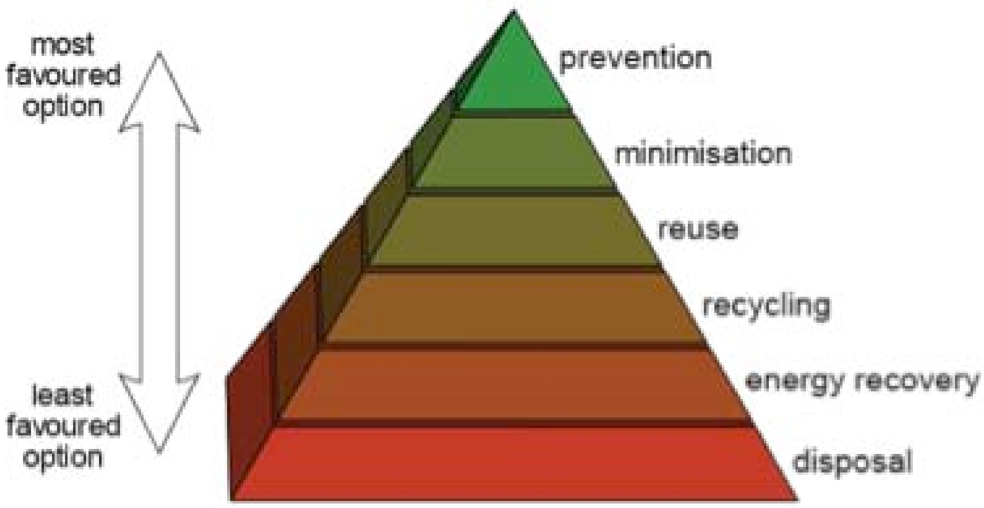
While landfill gas recovery is considered in the above ranking, the biodegradable fraction of municipal solid waste as feedstock for Waste-to-Energy plants is not considered in the above ranking as the strategy for this potential is dealt with separately by the Waste-to-Energy Plan issued under Decision 55 to promote Waste-to-Energy (WTE) technologies in large cities while renewing the commitment to the 2006 Solid Waste Master Plan in the rest of country. The 2010 plan suggests up to 4 Waste-to-Energy sites. Their location and technical specifications are still unknown as feasibility studies are currently under development. Discussions with experts suggest that the sites are most likely to be in Beirut and Mount Lebanon but that it is very difficult to predict changes in the quantity and composition of waste as a result of the implementation of the WTE Plan.

It is very important to note though that direct energy recovery in Waste-to-Energy plants is a better option than disposing municipal solid waste at landfills.

The waste hierarchy has taken many forms over the past decade, but the basic concept has remained the cornerstone of most waste minimisation strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

The options for treating waste follow common sense criterion of applying first the most favoured option: prevention of waste generation. Figure 7 shows the pyramid of options for waste treatment, with the most favoured options in the top, and the least favoured options in the bottom.

Figure 7: Pyramid of waste treatment options



In simple terms, the waste hierarchy refers to the "4 Rs" which are listed below in order of importance:

- Reduce
- Reuse
- Recycle, and
- Recover

An effective system of waste management may need an entirely new way of looking at waste. It involves efforts to reduce hazardous waste and other materials by modifying industrial production. The worst option for the treatment of waste is therefore the disposal of waste. Landfilling is the least favoured option as their environmental impacts on soil and underground water could be very significant. Energy recovery, for example through Waste-to-Energy plants, is better than landfilling and should be implemented only after the options of waste reuse and waste recycling have been exhausted.

The Ministry of Environment (MoE) and the Council for Development and Reconstruction (CDR) are mandated to reconcile and merge the 2006 and 2010 plans and coordinate the selection of technologies, contractors and supervision of implementation. Solid waste management strategies and changes to the current situation should be clearer by end of phase 1 of the newly commissioned study for devising the optimal options within the Lebanese context. The study will also incorporate projections of waste amounts and characteristics and recommendations for management up until 2025.

The outcome of the study could have significant impact on the bioenergy potential in Lebanon and should be incorporated upon completion.

Table 78: Quantity and energy potential of each biomass resources

	Biomass resources	Quantity* (Tons)	Primary energy potential (TJ)	Energy potential	Sustainability	Other uses	Accessibility	Legal framework	Selected streams	Ranking
Forestry	Woody biomass and fellings	210,000	1,952 - 2,510							Not ranked
	Residues from fellings	150,000	1,378 - 1,771							1
Wood and paper industries	Wood residues from sawmilling, wood-working, furniture industry	0	0							Not ranked
	By-products from paper industry	0	0							Not ranked
Agriculture	Residues of olive trees	100,000 - 120,000	842 - 968							2
	Residues of fruit trees	240,000 - 300,000	2,110							
	Residues of Cereals	180,000	2,116 - 2,233							3
	Manure	1,950,000	1,500							Not ranked
Energy crops	Jatropha		491 - 3,051							4
	Miscanthus		464 - 1,857							
	Eucalyptus		445 - 1,780							
	Sunflower		184 - 296							
	Giant Reed		1,990 - 3,180							
Food processing industry	Animal fat	6,600	258							8
	Slaughterhouse residues	31,500	495							
	Olive cake by-products	27,500 - 64,500	460 - 1,083							5
	Organic residues and waste from food processing industry	N.A.	N.A.							Not ranked
	Wastewater and sludge from food processing industry	Not treated	0							Not ranked

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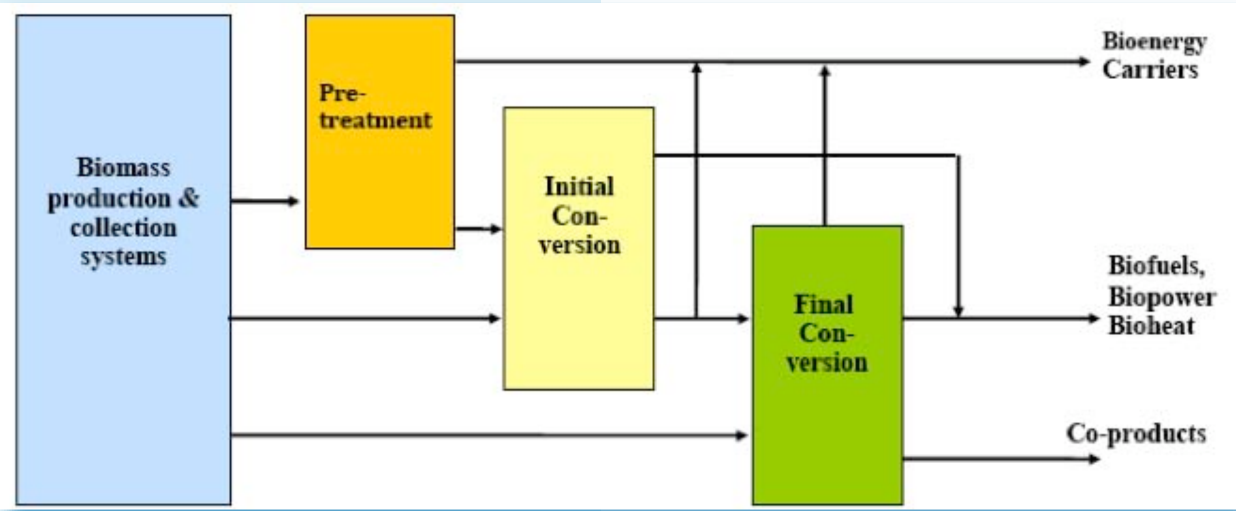
CHAPTER 2

BIOENERGY CONVERSION OPTIONS FOR LEBANON

INTRODUCTION

An up-to-date assessment of the state of the art in bioenergy conversion technologies is provided in this chapter. Subsequently, a proposal of the most suitable conversion options is developed and analysed for the most relevant bioenergy resources that have been identified in chapter 1. The level of maturity of these technologies, their associated costs (currently and in the near future), and the required technical know-how for operation and maintenance are provided in the format of fact-sheets per conversion path shown in the annex of this study. In addition, information about agricultural practices, collection, sorting, transport, storage, and different issues required by these processes with an estimation of their related costs are also presented.
The findings of this chapter are intended to support decision-making regarding future investments in the development of bioenergy business and industry in Lebanon, as well as to be of value to decision-making regarding the selection of case studies and demonstration projects. The information provided here is explorative and is by no means intended to replace dedicated feasibility studies.
According to the results from chapter 1, Lebanon has a relatively abundant availability of forest residues and agricultural residues from cereals, fruit trees and olive trees. Various waste streams such as sewage sludge, yellow grease or waste wood, show an interesting potential as well. Some biomass streams, such as woody biomass, may become interesting over time yet are currently limited or constrained due to restrictions in accessibility and/or in the current legal framework. Cultivation of energy crops for bioenergy production has not yet been established in Lebanon although potential land areas are available.
The most fertile areas are located along the coastal strip and in the Beqaa valley. The diversity of the Republic's topography and climate enables cultivation of a wide variety of vegetables, fruits, agro-industrial crops and cereals. Traditional use of biomass in the rural areas is intensive.
The value chain of bioenergy links the raw material after its collection with the final energy uses (see Figure 8). This chain is a multiple options combination of feedstock, processing technologies (possibly with several steps) and marketable end products such as other bioenergy carriers, liquid and gaseous biofuels, power and heat. Additionally, co-products that have value for other applications (e.g. glycerine from biodiesel production) can be produced in many of the bioenergy value chains.

Figure 8: General scheme of the bioenergy value chain

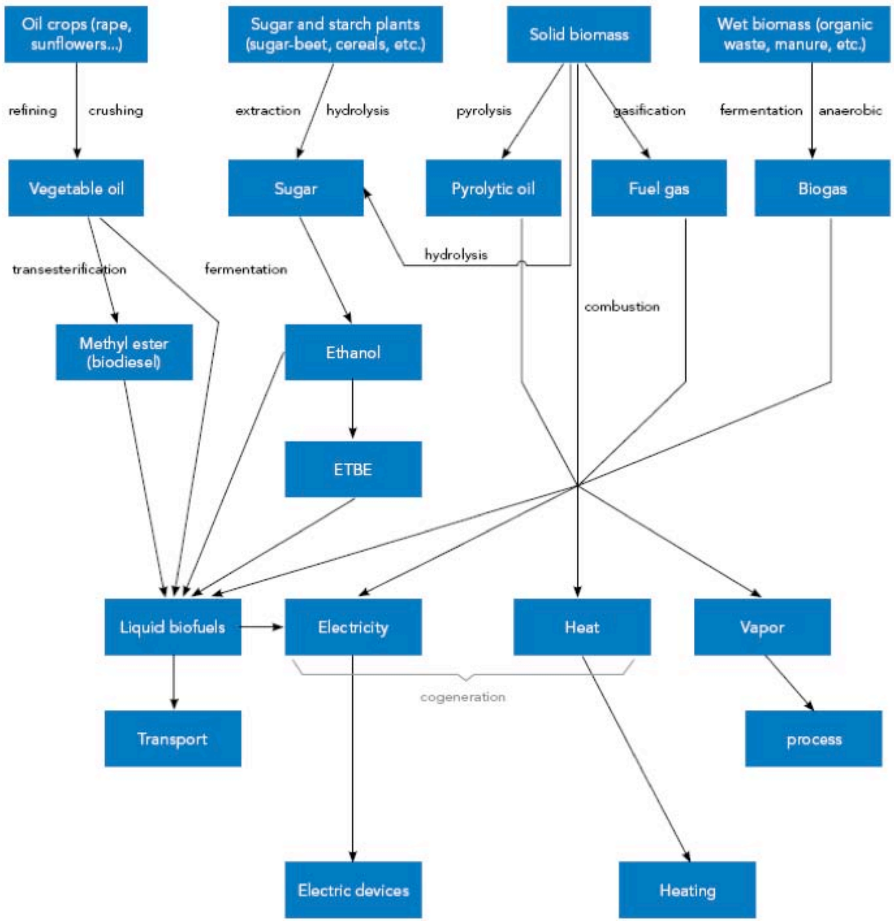


A matrix matching the most relevant bioenergy resources streams per mohafazat with the chosen conversion options is also presented.
Chapter 2 proposes an accurate and detailed assessment of the technology conversion paths suiting the most relevant biomass streams duly defined and characterized in chapter 1. Sixteen (16) mature conversion options and four (4) promising ones, expected to reach maturity by 2020, are also presented and discussed.

II.SELECTION OF BIONERGY CONVERSION OPTIONS

There are various conversion technologies that can convert biomass resources into power, heat, and fuels for potential use in Lebanon. Figure 9 summarizes many of the various available bioenergy conversion routes, without specifying the conversion technologies used.
In general, conversion options can be classified by the resulting intermediate or end product into the following four categories:

Figure 9: Various available bioenergy conversion processes



1.Production of liquid fuels
 a.Conversion paths based on biochemical processes
 b.Conversion paths based on thermochemical processes
2.Production of gaseous fuels
 a.Conversion paths based on biochemical processes
 b.Conversion paths based on thermochemical processes
3.Direct combustion for production of heat and power
4.Pre-treatment options for bioenergy carriers

A selection of 20 technology conversion options classified as mature technologies, and relatively more promising for 2020, have been chosen for Lebanon. Each conversion option has been characterized using reliable sources and the consortium's expertise. Data from Lebanon was used where available from reliable sources, otherwise international figures are adopted. The detailed selection of technologies is shown in Table 79.

The bioenergy conversion options selected are classified not only by their level of maturity, but also by four different sub-categories: liquid fuel production, biogas production, direct combustion and pre-treatment.

Table 79: List of selected technologies and a brief description

	Name technology	Description
	Mature technologies	
	Liquid fuels production	
1	Vegetable oil biodiesel	Alternative to fossil diesel fuel, made from plant oils
2	First generation bioethanol	Alternative to fossil gasoline, made from agricultural crops
3	Animal fat and recycled oil biodiesel	Alternative to fossil diesel fuel, made waste fats and oils
4	Fischer Tropsch biodiesel	Feedstock gasified into syngas then condensed into a diesel replacement
	Biogas production	
5	Anaerobic co-digestion (manure and agro residues)	Feedstocks are converted by bacteria into biogas
6	Anaerobic digestion of sewage sludge	Sewage sludge is converted into biogas by bacteria
7	Slaughterhouse waste biogas	Slaughterhouse waste is sterilized, then converted into biogas by bacteria
8	Landfill gas	Biogas is released by landfills, which can be collected and purified for fuel usage
	Direct combustion	
9	Waste to energy	Waste-to-energy (WtE) is the process of creating energy by combusting waste
10	Combustion combined heat & power	CHP = combined Heat & Power: simultaneous generation of useful bioenergy
1	Combustion boiler	Converts biomass into heat
12	Co-combustion of biomass and coal	Partial substitution of coal by biomass in coal fired power plant
	Pretreatment	
13	Pelletization	Drying and pressing biomass under high pressure into pellets with an improved energy density
14	Torrefaction	Heating at atmospheric pressure in the absence of oxygen to improve energy density
15	Gasification-CHP	Thermal conversion of solid fuel into a combustible gas under oxygen limitation
16	Pyrolysis	Direct thermal decomposition of biomass into gas, bio-oil and char
	Promising technologies	
17	Algae options (centered in biodiesel)	Simple organisms that use sunlight to grow and produce oil (or other products)
1	Salicornia biodiesel	Salicornia as a salt tolerant plant that produces oil
19	Lignocellulosic ethanol	Woody biomass, grasses, or the non-edible parts of plants are broken down into ethanol
2	Fuel from MSW	Using waste to produce a high quality biofuel

III. FACTSHEETS FOR BIOENERGY CONVERSION OPTIONS SUITABLE TO LEBANON

A thorough assessment of all selected bioenergy conversion technologies applicable to Lebanon is also presented in individual factsheets containing all associated aspects to them. The content of these factsheets is the following:

- Technology description
- Typical configuration
- Application
- Application conditions
- Scale
- Assessment of the feedstock used
- Process parameters and conditions
- Energy & mass balance
- Status of technology, including bottlenecks regarding further development
- Efficiency of the process
- Known advantages and disadvantages
- Commercial availability
- Investment and operational costs
- Suppliers
- Learning curves and recommendation
- Recommendations about its use

All detailed technology factsheets are presented in the volume "Annexes" of this study, chapter 2, annex I "Factsheets of the selected bioenergy technology conversion options for Lebanon."

IV. MOST RELEVANT CHARACTERISTICS OF SELECTED CONVERSION OPTIONS

The selected conversion options represent the full range of available technologies that can transform biomass into bioenergy products. Most of these technologies have reached a good level of commercial maturity, and their deployment in the market is common in several regions of the world. For instance, all technologies for liquid fuels production are commercially available for capacities ranging from 5 kton per year up to 600 kt per year for biodiesel production from vegetable oil. Annual operational costs for these techonologies are generally 4 to 7% of total investment costs. Investment costs are competitive with other technologies, except for Fischer-Tropsch production that still has a relatively large investment cost. Feedstock for the production of biofuels is derived from several sources. Some of the commercial options such as biodiesel from vegetable oil, and bioethanol from grains, may create competition with food due to substitution of crops in large extensions of land. This consequently raises food prices. For this reason, it is important to look at more advanced technologies such as Fischer-Tropsch biofuel and lignocellulosic ethanol that use non-food feedstock and that can actually use a wide variety of residues.

Conversion options for biogas production are all commercially available at any scale. Biological biogas production has the main advantage that it can be applied to wet biomass streams, while other technologies would require a high energy input for drying the wet biomass streams first. In terms of conversion efficiency, the share of biomass that can be converted into bioenergy is high. The biggest barrier for this technology group is financial; multiple conditions have to be met for biogas projects to become economically viable.

There are various technologies commercially available for direct combustion of solid biomass to produce power and heat. The size of production units range from 4 kW (household level) to 50 MW in the case of co-combustion or combined heat and power (CHP) installations. The overall efficiency levels for this technology group ranges from 75% to 90%. Operational and investment costs are larger for CHP generation than for boiler and co-combustion technologies. Specific technologies, such as Waste-to-Energy combustion can solve other problems such as waste disposal. Other technologies such as CHP and co-combustion technologies can use a variety of feedstock resources.

As for pre-treatment technologies, while torrefaction and pyrolysis are expected to become available in the short term, palletisation is widely available. Energy efficiency levels range from medium efforts of 65 to 75% for pelletisation and pyrolysis, to optimum for torrefaction (85 to 90% efficiency). Investment costs are lower for pelletisation than for pyrolysis and torrefaction. Annual operational costs are on average 10% of total investment cost.

Finally, we have selected a list of four promising technologies. These technologies are not yet fully commercially available; however cellulosic ethanol conversion is expected to become commercially available in the near future with several semi-industrial plants currently being tested in Europe and in the United States. Understandably, operational costs are still largely unknown, and investments costs will still be relatively high still in the near future. These promising technologies generally target waste streams and cheap biomass sources that do not compete with food. It is expected that a wide range of biomass resources can be used for these promising technologies, including algae or salt tolerant crops.

A summary of most important aspects of each conversion option is presented in Table 80 through to Table 89.

Table 80: Liquids fuel production: Vegetable oil biodiesel and first generation bioethanol

Technology	Vegetable oil biodiesel	First generation bioethanol
Application	Contrary to (green) electricity, transportation has very few alternative energy sources, because the energy source needs to be mobile. Vegetable oil biodiesel is currently the most common alternative used in diesel cars and trucks. Blending of biodiesel with fossil diesel is possible, above 10% biodiesel some small modifications to the engines but also the logistics system are necessary. For Lebanon: application is limited to commercial vehicles, private citizens are not allowed to own diesel cars	Based on locally available feedstock; mainly corn in USA, wheat in EU and sugarcane in Brazil. In the case of cereals, leftover biomass is sold as dried distiller grains as cattle feed For Lebanon: currently the application limited to private citizens, which are the only market for petrol
Feedstock	Any vegetable oil. Selection is based on availabillity, price and in the near future on the GHG emissions associated with oil production. For Lebanon: The main vegetable oil currently produced in Lebanon is olive oil. The market price of olive oil is too high for conversion into biodiesel. Using heat and/or solvent mediated oil extraction from the olive oil pressing cake can yield non-food grade oil for biodiesel, however volumes are expected to be low, and inefficient for small olive mills, transportation distances are high. More sources of vegtable oils will be needed for a large biodiesel plant. Land, currently unused or used for cultivation of other plant, can be converted to grow oil crops. Soy or oil palm may be cultivated, but from a sustainabillity point of view, jatropha or camelina are likely more intersting as they are more resilient agianst suboptimal agricultural conditions. Further research and carefull planning is needed to make sure that these oil crops can be grown sustainably. Oil crops interesting for Lebanon: jojoba, sun flower, palm oil and jatropha, in the future possibly algae and salicornia	Many: sugar cane, sugar beet, sorghum, grain sorghum, barley, kenaf, potatoes, sweet potatoes, cassava, sunflower, fruit, molasses, corn, grain, wheat For Lebanon: Wheat is the main starch crop currently cultivated, followed by barley, corn and oats. However, these cereals are currently used for food purposes, and extending the current cultivated are to produce an extra 100+ Kt/y is not expected to be possible in a sustainable way. Some reports of some sugar cane cultivation have been found, although this crop yields a better GHG balance than cereals, its water requirements inhibit wide scale cultivation in Lebanon
Investment costs	Very size, feedstock, technology and glycerine-purity dependent. Indication for 50Kt/year plant: 20-30M€	120M€ for 100kt/y plant
Operational costs	Feedstock price range: 500-900$/tonne product Labour, methanol and catalyst, totalling about 160$/tonne product Rough indication for 50Kt/y plant in M€: Investment 0.3, Maintenance, 0.1, Oil feedstock 26.1, Chemicals & catalysts 1.4, Utilities 0.6, Personnel 0.2	Feedstock costs differ per crop, ranging 100-300$/ton feedstock. Conversion and capital: 150 $/tonne product Ethanol transport: 40 $/tonne product Feedstock transport: 20 $/tonne product
Recommendation	This straightforward technology is being used all over the world, however for Lebanon the potential is limited due to the absence of existing oil crops which are needed as feedstock. Import of vegetable oils or conversion of existing agricultural land to oil crops is less desirable, but selecting crops that can successfully be cultivated on non-agricultural land can be, given certain conditions, certainly be interesting	Many feedstocks can be used to produce bioethanol, but for the first generation processes evaluated in this factsheet, all feedstocks can also be used as food or feed and require agricultural land to cultivate. For Lebanon, it is most likely the easiest liquid biofuel to produce at the short term, but due to competition with food and agricultural land, for large scale biofuel production on the medium and long term other bioethanol technologies should be given a more important role.

Table 81: Liquids fuel production: Recycled oil biodiesel and Fischer-Tropsch biodiesel

Technology	Recycled oil biodiesel	Fischer-Tropsch biodiesel
Application	Contrary to (green) electricity, transportation has very few alternative energy sources, because the energy source needs to be mobile. Used oil is a wasteproduct, therefore used oil biodiesel has very large GHG savings and can be counted double for the EU member states national targets. Blending of biodiesel with fossil diesel is possible, above 10% biodiesel some small modifications to the engines but also the logistics system are necessary. For Lebanon: application is limited to commercial vehicles, private citizens are not allowed to own diesel cars	Solid biomass is converted into a liquid biofuel. Process already commercially operating with coal or natural gas, but doesn't yield biofuel. Co-gasifying coal and biomass (technically) feasible.
Feedstock	Used oil: needs to be collected from larger consumers like food industry, restaurants, hospitals etc. several pretreatment steps required. In many EU countries, this feedstock is already almost fully used. Feedstock limited on the supply side and by difficulty of collection. Animal fats: Chicken and swine-originating feedstock most common. Sourced at slaughter houses and meat processing plants. Difficult feedstock, often mixed with other feedstocks. For Lebanon: It appears there is one small used cooking oil-based biodiesel producer in Beirut, using about 20% of the used oil collected in Beirut. Company growth is currently not foreseen, and selling the biodiesel has proven difficult. Animal fats are currently mixed in with slaughterhouse waste, yellow grease is sometimes recovered, most likely for use in animal feed or soap manufacture	Wood fuel: Forestry residues, wood chips, bark, demolition wood, agricultural residues (palm kernel shells etc), saw dust. Depending on regional availability. Moderate to short transport distances for feedstock possible. Straw: low energy density, high risk of corrosion: only suitable for regional application, when concentration of biomass is high and remuneration for electricity and heat is high. Even car tires and other waste is a potential feedstock although technically more complicated For Lebanon: forestry residues would be most appropriate, followed by fruit and olive tree residues, and crop residues which require more drying. Certain energy crops like perennial grasses could become an interesting feedstock in the future.
Investment costs	Very size, feedstock, technology and glycerine-purity dependent. Indication for 50Kt/year plant: 20-30M€	150-1500 M€, 800-1200k€ / MWth input
Operational costs	Rough indication for 50Kt/y plant in M€: Investment 0.3, Maintenance, 0.1, Oil feedstock 26.1, Chemicals & catalysts 1.4, Utilities 0.6, Personnel 0.2	4% of total capital investment
Recommendation	The potential scale of this technology is restricted by the amount of used oils and animal fats that can be sourced within the country, but within this limit, biodiesel production from recycled oils is very interesting. Not only does it transform an (often problematic) waste stream into biofuel, a network of intermediary oil collectors provides additional employment, and this technology has a very good greenhouse gas balance.	This technology has a very high potential, therefore could become a real break-through technology for liquid biofuels. For Lebanon: it is recommended to follow the development of this technology closely, and to step in a bit further along the learning curve

Table 82: Biogas production: Anaerobic digestion of organic waste and of sewage sludge

Technology	Anaerobic digestion of organic waste	Anaerobic digestion of sewage sludge
Application	Co-digestion can be applied to many combinations of organic waste streams, including from agriculture, food processing, household waste, nightsoil, manure, straw, wood, crops and sewage sludge. Anaerobic digestion is a simple concept, but process conditions should be well controlled to achieve a stable process. It's ability to make bioenergy from a wet biomass stream is a big advantage because it prevents the need for drying; which saves energy	Anaerobic digestion is a simple concept, but process conditions should be well controlled to achieve a stable process. It's ability to make bioenergy from a wet biomass stream is a big advantage because it prevents the need for drying; which saves energy
Feedstock	Almost any organic waste stream, provided it is not toxic to the methanogenic bacteria For Lebanon: many organic waste streams available, which are less appropriate for other technologies due to a high water content, but transport is the main issue: best location is where multiple feedstocks are easily accessible, preferable not only seasonal	Sewage sludge or manure, but many organic sludges can be (co-)digested, provided it is not toxic to the methanogenic bacteria For Lebanon: Elaborate plans for many more wastewater treatment facilities exist, however distances between facilities are likely too large to justify one anaerobic digester for multiple facilities. Per facility it should be investigated wether there is enough sludge + other locally available biowaste to justify a biogas project.
Investment costs	typically € 3,000 - € 4,000 per kWe, but may range from €2,500 up to €7,500 per kWe. Gas motor is 20-30% of project cost A complex 1MWe plant (with a 10,000m3 digester) will cost 2.3 to 3.3 M€	typically € 3,000 - € 4,000 per kWe, but may range from €2,500 up to €7,500 per kWe. Gas motor is 20-30% of project cost A complex 1MWe plant (with a 10,000m3 digester) will cost 2.3 to 3.3 M€
Operational costs	digester: about 2 percent of its capital value, gas motor: 0.0063-0.0083€/kWhe	digester: about 2 percent of its capital value, gas motor: 0.0063-0.0083€/kWhe
Recommendation	Two highly relevant characteristics of this technology are that it can be applied to wet waste streams, and can be built near the waste stream source. Waste treatment and biofuel production in one, it is recommended that Lebanon uses the experiences with this technology from surrounding countries, so that it becomes a commonly applied technology in Lebanon on the medium term. Active stimulation of example projects on a variety of scales is recommended	This technology should be an integral part for the new wastewater treatment facilities planned and being built in Lebanon.

Table 83: Biogas production: Slaughterhouse waste biogas and landfill gas capture and use

Technology	Slaughterhouse waste biogas	Landfill gas capture and use
Application	Slaughterhouse waste is a difficult waste stream to treat. For hygiene reasons, the waste is first sterilized by steam injection (130C for 20 min). A pre-heating step could be added, in which animal fats are recovered. After sterilization, DM content is decreased if necessary and pumped into the digester. Anaerobic digestion is a simple concept, but process conditions should be well controlled to achieve a stable process.	Although technically the feedstock is already in place, as the gas is formed naturally. Large, closed, old landfills with a lot of organic materials and few toxic compounds work best.
Feedstock	Primarily slaughterhouse waste, including bones, stomach and intestine content. Straw, wastepaper or other low nitrogen wastes can be co-digested to keep the process from producing toxic amounts on ammonium For Lebanon: Slaughterhouse waste needs to be sterilized before transport, which usually includes the addition of hot water/steam. The subsequent waste stream is very wet, therefore suitable for biogas production, but co-feedstocks will be needed. Butchers also produce small amounts of this feedstock.	There is no real feedstock: landfill gas is produced unintentionally inside landfills For Lebanon: the future of landfilling is currently unclear. MSW in Lebanon has a high organic fraction, therefore a high methane production potential. This methane should be captured and burnt where possible, to prevent GHG emission, using this methane for bioenergy can generate some income for this type of GHG emission prevention
Investment costs	Example of the Beirut Slaughterhouse: total 4.2M€: 2.2M€ for biogas plant components, 1M€ for sterilizer and 1M€ for construction and engineering	1 MW or less $2,300/kW 3 MW or greater $1,400/kW
Operational costs	Digester: about 2 percent of its capital value, gas motor: 0.0063-0.0083€/kWhe	1 MW or less $210/kW 3 MW or greater $130/kW
Recommendation	Even without taking biogas production into account, this technology is an efficient and safe way to treat slaughterhouse waste, the bioenergy production associated with it can be regarded as an extra benefit. The implementation of this technology on-site at slaughterhouses, requires a well-engineered integral waste treatment system, adapted to the local requirements and conditions, so no "off the shelve" solution.	Landfill gas is formed in any landfill, and has a strongly negative environmental impact if not captured. Given Lebanon's existing problems with landfilling, it is recommended that this technology is applied at both existing and new landfills. Per landfill, further research is required on what to do with the captured landfill gas, in the most basic option it is simply burned off to prevent emission to the environment, in a slightly more advanced scenario the heat released by this burning is used in some way, and in the most advanced scenario the gas is cleaned and compressed to serve as a substitute for natural gas.

Table 84: Direct combustion: Waste-to-Energy and combustion CHP

Technology	Waste-to-Energy (WtE)	Combustion / CHP
Application	Many applications possible. A typical example: Household waste is gasified at 1200-1500°C, and the combustion gas has an energy content of 2-5 MJ/Nm³.	CHP is a clean and reliable power source suitable for base-load service. The highest efficiency is obtained in co-generation mode, however due to high cost for a heat distribution grid, production of power only is in some cases more cost effective depending on the subsidy scheme in the country. Heat application is well developed in industrial processes like: wood processing, pulp and paper industry and district heating. Remaining steam can also be used for absorption cooling.
Feedstock	Municipal solid waste. Refuge derived fuel For Lebanon: plans for construction of three waste incineration plants have been announced, however there is no full political consensus and no expected completion date is known	Wood fuel: Forestry residues, wood chips, bark, demolition wood, agricultural residues (palm kernel shells etc), saw dust. Depending on regional availability. Moderate to short transport distances for feedstock possible Straw: low energy density, high risk of corrosion: only suitable for regional application, when concentration of biomass is high and remuneration for electricity and heat is high Pellets are expensive, therefore only suitable when electricity and heat remuneration are very high. In general biomass is applicable with moisture content 10% -60%. High quality wood waste is getting scarce in several countries. Short rotation crops are more expensive, but are gaining market share. More problematic biomass streams are straw and grass, due to high K and Cl contents, causing aggressive corrosion, which demands higher investment costs due to higher quality materials for the boiler. For Lebanon: Feedstock exists in large amounts, but a market driven collection and distribution system doesn't exist.
Investment costs	104-128M$ for 250t waste/day	Medium scale 5000 Euro/kWe (5 MWe). Up scaling will reduce costs to 2000 Euro/kWe.
Operational costs	47 MW plant $2255 per MWh	The operational costs are around 5-8% of the investment costs Ash production merely 1-2% of biomass input.
Recommendation	The volume of municipal solid waste to be treated is problematic in Lebanon, therefore incineration is an interesting option. Energy recovery from incineration is far more efficient if the heat produced can be used directly, rather than converting this heat into electricity. Co-location of heat-consuming industry should thus be explored	A commercially available technology at a scale >1 MWe. Interesting at locations with a high heat demand: 1) <5 MWth for space heating or cooling 2) >5 MWth industrial activities like steam delivery At this moment the suppliers have overloaded order books especially at large scale. In some European countries increasing interest due to subsidy schemes. In these countries it is interesting to develop projects and to operate as ESCo (Energy Service Company) or as fuel supplier. For Lebanon: both centralized large-scale combustion facilities and many small-scale decentralized facilities require a stable biomass market. Large scale offers lower relative investment costs and lower dust and NOx problems, but faces logistical challenges.

Table 85: Direct combustion: Combustion boiler and co-combustion

Technology	Combustion / Boiler	Co-combustion
Application	Small and large scale, conversion of local biomass for local heat or steam demand. Small scale: heating of apartment buildings and chicken farms. Large scale: process heating: paper mills and ethanol plants.	Co-firing in coal power plants
Feedstock	all kinds of biomass: wood residue, peat, sawdust, wood pellets, bark, chips, hog fuel, shavings, end cuts, sander dust, straw. However preferable to use pellets for small scale (< 100 kWth) and for large scale wood chips. Moisture content < ~60 % For Lebanon: potential woody feedstocks exist in large amounts, but a market driven collection and distribution system doesn't.	Woody biomass, needs to be grinded till dust or pretreated (pyrolysis, gasification, torrefaction), in order to be used in a pulverized coal power plant. Moisture < ~60 % For Lebanon: co-combustion assumes combustion of solid fossil fuels like coal, in Lebanon liqued fossil fuel like fuel oil is predominant
Investment costs	Small scale: 200-2000 Euro/kWth Large scale: 50-200 Euro/kWth	Coal power unit of 600 MWe Additional investment costs for direct co-firing of 10% biomass: 35 Euro/kWe Additional investment costs for direct co-firing of 40% biomass: 20 Euro/kWe
Operational costs	The operational costs are around 3-5% of the investment costs. Ash production merely 1-2% of biomass input.	Direct: 0.01 Euro/kWh e Indirect: 0.02 €/kWh e
Recommendation	A commercial available technology at a wide range of capacities. Due to increasing fossil fuel prices increasing interest. At small scale (<100 kWth) most interesting fuel: wood pellets. At larger scale wood chips. Relative low investment costs (compared to wood-CHP) but higher than fossil fuel system. Due to small scale it is interesting to develop portfolio's of projects and to operate as ESCo (Energy Service Company) or pellet supplier. For Lebanon: both centralized large-scale combustion facilities and many small-scale decentralized facilities require a stable biomass market. Large scale offers lower relative investment costs and lower dust and N0x problems, but faces logistical challenges	Direct co-combustion is a commercial available technology. Indirect co-combustion is more a demonstration technology. Most interesting is to deliver specific biomass streams, like wood pellets, torrefied biomass. It is a market with large volumes.

Table 86: Pre-treatments options: Pelletising and torrefaction

Technology	Pelletising	Torrefaction
Application	In a small scale boiler (<100 kWth) and for co-combustion	Short term: torrefied pellets for co-firing in coal plants. To generate the possibility to transport torrefied biomass from outside EU to the European market. Long term: large scale entrained flow gasification for the production of biofuels. Torrefied pellets are more expensive then normal wood pellets, but by transportation on long distance it's cheaper.
Feedstock	Lignocellulosic biomass: Wood pellets are usually made from industrial wood waste (sawdust, shavings, wood chips). The raw material needs to be dry and homogeneous and is therefore usually pulverised. The ash content is dependent on bark content and for DIN pellets, percentage of ash content and therefore bark is limited. (DIN is a quality standard) Small feedstock particles, maximum 6 mm, Moisture content < 15%. (Piston press can handle up to 20%) For Lebanon: Feedstock exists in large amounts, but a market driven collection and distribution system doesn't.	'dry': wood, straw, nut shells, husks, grass Reactor criteria: particle size <100 mm, moisture content 10-20 wt.% For Lebanon: Primarily forestry residues, other woody feedstocks require significant drying.
Investment costs	50 Kt/year: 8 M€ 100 Kt/year: 12 M€	15 - 20 M€ (70 Kt) ECN: 5.5-7.5 M€ (capacity 60 Kt) Eclair-E: 35 M€ (capacity 75 Kt), including CHP
Operational costs	10-15% of the investment costs if natural gas is used 5-10% of the investment costs if biomass is used for heat production	Production costs: 50-60 Euro/ton
Recommendation	A commercial available technology which becomes interesting due to the increase of fossil fuel prices (household market). Furthermore the higher energy density compared to the original feedstock, leads to transport cost reduction (co-combustion). Other advantages are a homogenous product with low moisture content and high energy content (compared to other biomass), easy to use in small households and in large co-combustion plants. Pellets can degrade when contacted with moisture, so indoor storage and covered transportation is needed. However new technologies are know which produce pellets which are less vulnerable to moisture. Interesting market for biomass suppliers. For Lebanon: The country is relatively small, therefore it is less likely that the energy spent on pellitisation is recovered by the reduction in transport	Torrefaction is a technology in the demonstration phase with high interest from the energy supply market, causing a technology pull. The torrefied biomass has a higher energy density and is more homogeneous, which leads to transport cost reduction, better handling and wider application. Furthermore torrefied biomass is a water resistant, coal-like material, which has logistics and storage advantages compared to "normal" wood pellets. For Lebanon: The country is relatively small, therefore it is less likely that the energy spent on pellitisation is recovered by the reduction in transport. This product is the form of solid bioenergy that could be exported most easily by Lebanon

Table 87: Pre-treatments options: Gasification CHP - Pyrolysis

Technology	Gasification-CHP	Pyrolysis
Application	Current: for electricity generation. On the long term: Entrained flow Gasification, where syngas is converted into biofuels Syngas may be burned directly in internal combustion engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel.	Co-firing Production of biofuels
Feedstock	Wide range: Wood, agricultural residues, rice hulls, shell, sewage sludge Size: 0,01 – 10 cm (depening on type of gasifier) Moisture content 10% to 50%	Wide range: sugar cane bagasse, woodchips, corn stover, waste paper, poplar, peat, miscanthus, eucalyptus Reactor criteria: particle size 1-6 mm, moisture content < 10 wt.% For Lebanon: many feedstocks exist on a regional level, additional drying is required
Investment costs	Demonstration plants: 2000-5000 Euro/kWe.	Investment: 16 M€, capacity 50 Kt bio-oil.
Operational costs	The operational costs are around 5-8% of the investment costs. This could increase due to technical problems, like tar formation. Ash production merely 1-2% of biomass input.	10-15% of the investment costs
Recommendation	Many suppliers offer gasifiers in CHP modus it's still early to invest in this technology. Substantial progress has been made with this application but still too high risks to invest. Product gas cleaning is a major bottleneck due to high tar concentrations. The focus of this technology is small scale at the moment, mainly small scale demonstration installations. For Lebanon: Technology is not mature and easily available yet, but might be by the time big bioenergy projects are planned realized in Lebanon, therefore the developments of this technology should be followed closely	Pyrolysis is a technology in the demonstration phase. An interesting technology comparable with torrefaction. However Pyrolysis can produce: solid, liquid and gaseous products, whereas torrefaction only produces coal-like material. Both technologies however can be used to produce biofuels. Like torrefaction Pyrolysis increases the energy density of the biomass, leading to transport cost reduction. Torrefaction and pyrolysis are both technologies that can play a significant role in bioenergy supply. For Lebanon: depending on the cost reduction that can be achieved, it is currently unclear if the scale required for this technology can be realized in Lebanon

Anaerobic Digestion of Sewage Sludge

Table 88: Most promising conversion options for 2020: Algae biodiesel

Technology	Algae for Biodiesel	Salicornia biodiesel
Application	Producing biofuels and co-products on non-agricultural land	Application on land where seawater is available for irrigation,
Feedstock	Focus on oil, but wide range of algae products can be produced For Lebanon: Climatic conditions are interesting	Feedstock is selected because of unique salt tolerance For Lebanon: Substantial area of semi-arid land available for seawater irrigation
Investment costs	100-1000k€/ha	4900ha project planned for 35M$
Operational costs	main cost factor	Still unknown irrigation: $3,000 per hectare
Recommendation	Algae cultivation will gradually take over/complement agriculture. Bioenergy will initially be produced from algae by-products. Lebanon has unused land and easy access to seawater. When algae technology proves economically viable, Lebanon has a good geographic location	This technology is still in early development. However, for a country like Lebanon, this relatively simple technology could potentially be the most interesting alternative for fossil diesel. It is recommended that potential yields, locations and costs for this technology in Lebanon are investigated further

Table 89: Most promising conversion options for 2020: Lignocellulosic ethanol and fuel from MSW

Technology	Lignocellulosic Ethanol	Fuel from MSW
Application	Production of biofuel to displace fossil petrol For Lebanon: currently the application limited to private citizens, which are the only market for petrol	Novel processes to produce liquid fuels from municipal solid waste
Feedstock	Cheap woody biomass: forestry residues, agricultural residues, straw and fast growing trees For Lebanon: any woody or grassy feedstock if it can be supplied cheaply. Extensive, perrenial energy crops like Giant Reed could be cultivated with minimal inputs and labour, while preventing soil erosion	Municipal solid waste. Glycerine For Lebanon: municipal solid waste only
Investment costs	0.07€/l : $1 billion will be invested for approximately 440 Kt/year capacity	39 M$ plant will utilize 100 tons of landfill per day to produce up to 23 kt/y of torqazine
Operational costs	now: 0.44€/l future: 0.21€/l	Proprietary knowledge
Recommendation	For Lebanon, this will most likely be the main technology for fossil gasoline displacement on the longer term, but it is recommended to hold off on a major investment in this technology until the claims made by the industry are further substantiated in practice.	Biomethanol from glycerine (by BioMCN) is the only example of a commercially operating technology, but since Lebanon does not produce large glycerine streams, this technology is not recommended. Despite the problems in Lebanon with processing MSW, the immaturity and technical barriers of this technology justify the recommendation to wait with investing in it.

A full summary and thorough comparison of the above selected technologies are listed in the next five tables. In these tables, all technical parameters and costs are evaluated on three levels:

- Optimum (green indicator with + sign);
- Medium (yellow indicator with 0 sign);
- Deficient (red indicator with - sign).

Table 90: Comparison of technologies for liquid fuels production

	Technology	Scale	Process	Status	Feedstock	Efficiency	Investment costs	Annual operational costs
Liquid fuels production	**Vegetable oil biodiesel production** Generates: Biodiesel	**100-600 kt/y**	"Low" Temp **80°C** **1-5 bar** Absence of **H_2O**	o Commercial subsidy dependent overcapacity	o Rising feedstock price Competition with food	+ Conversion >95%	+ 150-450k€ per kt/y capacity	+ 4% of investment
	Bioethanol (fermentation) Generates: Bioethanol	**150-200 kt/y** (current trend)	"Low" Temp **40°C** **25-40 bar** Absence of **O_2**	o Commercial subsidy dependent overcapacity	o Rising feedstock price Competition with food	+ Conversion >95%	+ 55-120k€ per kt/y capacity	+ 3-5% of investment
	Used oil biodiesel Generates: Biodiesel	**30-100 kt/y**	"Low" Temp **80°C** **1-5 bar** Absence of **H_2O**	+ Commercial	o Difficult to collect limited resource	+ Conversion >95%	+ 150-450k€ per kt/y capacity	+ 4-7% of investment
	Fischer Tropsch biodiesel (2nd generation) Generates: Biodiesel	**Up to 2000 MW**	"Low" Temp **230°C** **25-40 bar** Absence of **O_2**	- status of the application is disputed	+ Wide range of biomass	+ Overall: 49 - 52%	o 150-1500M€ or 800-1200 € per kWth input in the reactor	+ 4% of investment

Table 91: Comparison of technologies for biogas production

	Technology	Scale	Process	Status	Feedstock	Efficiency	Investment costs	Annual operational costs
Biogas production	**Anaerobic digestion of organic waste** Generates: Gas for power and/or heat	**Any scale** waste treatment and fertilizer can generate additional income	**around 35 °C** 55 °C (thermophilic system) is used as well	+ Commercial	o wet waste: transport costs Dry waste: feedstock cost	o Low: wet waste approx. 10% overall	o **2500 - 7500 €/KWe** 3500 € average	+ **digester: about 2 % of its capital value,** gas motor: 0.0063-0.0083€/kWhe
	Anaerobic digestion of sewage sludge Generates: Gas for power and/or heat	**Any scale** waste treatment and fertilizer can generate additional income	**around 35 °C** 55 °C (thermophilic system) is used as well	+ Commercial	o free, but high transport cost may need 2nd feedstock with low N-content	o Low: wet waste approx. 10% overall	o **2500 - 7500 €/KWe** 3500 € average	+ **digester: about 2 % of its capital value,** gas motor: 0.0063-0.0083€/kWhe
	Slaughterhouse waste biogas Generates: Gas for power and/or heat	**Any scale** waste treatment generates most income	**around 35 °C** 55 °C (thermophilic system) is used as well	+ Commercial income from waste treatment	o free, but needs sterilisation, smells	o 440Nm3 biogas/tonne waste 850 kWhe/tonne waste	o Example of the Beirut Slaughterhouse: total **4.2M€ for 1500 ton waste/year**	+ **digester: about 2 % of its capital value,** gas motor: 0.0063-0.0083€/kWhe
	Landfill gas capture and use Generates: Gas for power and/or heat	**Up to 50MW**	Ambient Temp **25 °C low vacuum**	+ Commercial	+ "Feedstock" is landfill, which produces gas anyway	+ **Thermal step: Overall: 20 - 35%** But feedstock free	o **1 MW or less 1,600 €/kW 3 MW or greater 1,000 €/kW**	+ 1 MW or less 150€/kW 3 MW or greater 90€/kW

Table 92: Comparison of technologies for direct combustion for power and heat production

	Technology	Scale	Process	Status	Feedstock	Efficiency	Investment costs	Annual operational costs
Direct combustion	Waste to Energy Generates: Power + heat	Average 150 kit MSW/y range 10-1000 kit	Temperature (high): 850 °C or more, ambient pressure	+ over 400 in EU	+ Cheap feedstock that needs treatment anyway - Polluted exhaust	o Overall: 14-28%	+ 75-90M€ for 250t waste/day	o 47 MW plant 1600€ per MW
	CHP Generates: Power + heat	1 - 50 MWe, <1 MWe R&D	High Temp 800 -1200 °C 30-150 bar	+ Commercial at scale > 1 MWe	o Cl, Na, K limitation	+ Electrical: 20 - 35% Overall: 75 - 90%	o 2000 - 5000 €/KWe	o 5-8% of investment
	Boiler Generates: Heat	4 kWth (households) - 100 MWth (industrial)	High Temp 800 - 1200°C ≈ 1 bar	+ Commercial at a wide range of capacities	+ Wide range of biomass < 100 kWth: pellets Large: wood chips	o Overall: 80-90%	+ Small: 200-2000 Large: 50-200 €/kWth	+ 3-5% of investment
	Co-combustion Generates: Power and/or Heat	10-50 MWe	High Temp 800 - 1200°C	+ Commercial, less risks	o Biomass needs to be grinded to dust	+ Electrical: 35 - 40% Overall: 85 - 90%	+ Additional investment costs co-combustion of: 10% biomass: 35 €/kWe 40% biomass: 20 €/kWe	+ Direct: 0.01 Indirect: 0.02 €/kWh e

Table 93: Comparison of technologies for pre-treatment options for bioenergy carriers

	Technology	Scale	Process	Status	Feedstock	Efficiency	Investment costs	Annual operational costs
Pretreatment	**Pelletizing** Generates: Pellets	10 -250 Kt/y	'Low' Temp 90°C 500 bar	+ Commercial	o Moisture < 15% small particles <6 mm	o Energy eff.: 70-75% Massa eff: 40-45% (65,6 Kt pellets/ 157 feedstock)	+ 50 Kt/y: 8 M€ 100 Kt/y: 12 M€	o 10 -15% of investment if natural gas is used 5 -10% of investment if biomass is used for heat
	Torrefaction Generates: Solid fuel (water resistant, coal like)	25 -100 Kt/y	'Low' Temp 240 – 300°C 1 bar Absence of O2	– – 2 yrs commercial	+ Wide range of biomass Moisture into reactor 15-20%	+ Energy eff. 85-90% Massa eff. 45-50% (75 Kt product/ 157 feedstock)	o 15 - 20 M€ (70 Kt/y)	o 10 -15% of investment
	Gasification CHP Generates: Power and heat	Focus small scale (<5 MWe). At larger scale wood-CHP more interesting	High Temp 700 – 1400 C 1 bar Limited O2, air, steam	– status of the application is disputed	o Wide range of biomass Moisture < 10%	+ Electrical: 15-30 %. Overall: 35-65% (<1MWe)	o 2000-5000 €/kWe Demonstration plant 500-1000 €/kWe within the coming decade.	o 5-8% of investment. Could increase due to technical problems
	Pyrolysis Generates: Charcoal Bio oil Gas	25 -100 Kt/y	Mediate Temp 400-800°C Absence of O2	– – 2 yrs commercial	o Wide range of biomass moisture into reactor < 10 wt.% particle size 1-6 mm	o Energy eff.: 65-70% Massa eff.: 40-45% (66 Kt product/ 157 feedstock)	o 16 M€ (50 Kt product)	o 10 -15% of investment

Table 94: Comparison of most promising technologies for 2020

	Technology	Scale	Process	Status	Feedstock	Efficiency	Investment costs	Annual operational costs
Promising Technologies for 2020	**Algae for Biodiesel** Generates: biodiesel	Order of 1000s of ha	**Mild temp** sensitive to heat and cold	- 10 years or more	+ Highly productive Many environ benefits	+ Very efficient sunlight use - difficult to dry	o **100-1000k€/ha**	o **important**
	Salicornia Generates: Biodiesel	**4900 ha proposed** seawater needed	**Mild temp** Ambient temp in warm climate	- Field testing just starting	+ salt water tolerant	o unknown	**4900ha project planned for 25M$**	o **still unknown**
	Cellulosic Ethanol Generates: Bioethanol	**10-250Kt/year** Demo and commercial	**Mild temp** except steam explosion	o > 2 years commercial scale built	+ Wide range of biomass	+ feed to fuel - **90%**	+ 0.07€/l	o **0.50€/l for enzymes**
	Fuel from MSW Generates: Biofuel	**20-200Kt/year**	"Low" Temp **240 – 300°C**	- status of the application is disputed except specific examples	+ Waste	o unknown	+ 39M$ for 20kt/year	o unknown

V.MATRIX OF MOST FEASIBLE CONVERSION OPTIONS FOR LEBANON

A matrix matching the most suitable conversion technologies with relevant bioenergy streams identified in chapter 1 for each mohafazat have been constructed herein and explained in Table 95 through to Table 99. Similarly as above, a scoring based on three levels has been used to indicate the applicability of each technology for each Mohazafat:

- Optimum (green indicator);
- Medium (yellow indicator);
- Deficient (red indicator).

Among the mature technologies, direct combustion for the production of power and heat are the most relevant for Lebanon, using forestry residues, agricultural and fruit residues as feedstock. Waste to Energy (WtE) plants are also of relevance for the country.

Among the biomass production technologies, anaerobic digestion of sewage sludge and of slaughterhouse waste are the most relevant technologies. Biofuel production technologies are relevant in the medium term and need to be further explored. Pre-treatment technologies for bioenergy carriers are not relevant for Lebanon as densification of biomass is interesting only when there is a need to carry the biomass over long distances; therefore these technologies are not to be considered for further analysis in this study. Among the most promising technologies that will reach maturity by 2020, bioethanol from lignocellulosic is the most promising, while biofuels either from algae, Salicornia or from municipal solid waste, remain interesting medium-term options for Lebanon.

V.1 LIQUID FUEL PRODUCTION

Liquid fuel production technologies are relevant in the medium term for Lebanon. The mohafazat with larger potential to develop biofuels is that of North Lebanon, followed by the Beqaa region. Potential for the production of first generation biodiesel and bioethanol is directly related to the amount of agricultural land available to cultivate the relevant crops. Biodiesel production from recycled oil is a possibility in most populated cities of Lebanon, especially when supplemented with animal fat from slaughterhouses and butcheries. Fischer-Tropsch biodiesel (and other advanced technologies) are not commercially available yet, but when they are, they can utilize many bio-waste streams, and therefore are expected to become suitable over time for North Lebanon, Mount Lebanon and the Beqaa region (See Table 95).

Table 95: Relevance of liquid fuel production technologies for each mohafazat in Lebanon

No.	Governorate	Mature technologies			
		Liquid fuel production			
		Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fischer Tropsch biodiesel
1	Beirut			Larger amounts of yellow grease from restaurants collected	
2	North Lebanon	Intensive agricultural area	Intensive agricultural area with high yields	Larger amounts of yellow grease from restaurants collected	Forestry, olive and fruit residues
3	Mount Lebanon			Larger amounts of yellow grease from restaurants collected	Forestry, and fruit residues
4	Beqaa	Intensive agricultural area	Very intensive agricultural area with higher yields	Less amount of existing yellow grease	Agri and fruit residues
5	South Lebanon		Suitable existing agricultural areas	Less amount of existing yellow grease	
6	Nabatiyeh		Suitable existing agricultural areas	Less amount of existing yellow grease	
RELEVANCE FOR COUNTRY					

V.2 BIOGAS PRODUCTION

Biogas production from anaerobic digestion of sewage sludge and from slaughterhouse wastes is interesting for Lebanon, especially for the Beirut area, Mount Lebanon and the Beqaa regions because the waste feedstock streams for these technologies are generated in relatively more densely populated areas. On the other hand, co-digestion is most suitable in rural regions (Table 96).

Table 96: Relevance of biogas production technologies for each mohafazat in Lebanon

No.	Governorate	Mature technologies			
		Biogas production			
		Anaerobic co-digestion (manure and agri residues)	Anaerobic digestion of sewage sludge	Slaughterhouse waste biogas	Landfill gas
1	Beirut		Large waste water treatment plant	Residues already composted	Naameh landfill
2	North Lebanon	Poultry manure agri residues			Tripoli landfill
3	Mount Lebanon	Poultry manure agri residues	Large waste water treatment plant together with Beirut	Along with Beirut	
4	Beqaa	Poultry manure agri residues	Large waste water treatment plant	Less residues available	
5	South Lebanon			Saida/Sour region	
6	Nabatiyeh				
RELEVANCE FOR COUNTRY					

V.3 DIRECT COMBUSTION FOR POWER AND HEAT PRODUCTION

The most relevant technologies for Lebanon are the ones that involve direct combustion of biomass. Combustion of waste and especially combustion of woody and agricultural residues for power and heat production are relevant for the whole country. Moreover, waste to energy would positively impact the problems concerning land filling (Table 97). Energy crops are an optional feedstock resource in the medium to long term, depending on feedstock costs.

Table 97: Relevance of direct combustion technologies for each mohafazat in Lebanon

No.	Governorate	Mature technologies Direct combustion			
		Waste to energy	Combustion combined heat & power	Combustion boiler	Co-combustion of biomass and coal
1	Beirut	MSW management plan	Wood waste Feedstock from North and Mount Lebanon		For future large power plant
2	North Lebanon	MSW management plan	Woody biomass Residues from fellings Residues from olive trees Residues from fruit trees Residues from cereals		
3	Mount Lebanon	MSW feeding Beirut WtE	Woody biomass Residues from fellings Residues from fruit trees Wood waste		
4	Beqaa		Residues from olive trees Residues from fruit trees Residues from cereals		
5	South Lebanon	MSW management plan	Residues from fruit trees		
6	Nabatiyeh		Residues from olive trees		
RELEVANCE FOR COUNTRY					

V.4 PRE-TREATMENTS FOR BIOENERGY CARRIERS

Pre-treatment technologies are commonly used to make a solid (often woody) biomass source cheaper and easier to transport and store. Feedstock resources for pre-treatment technologies are especially wood-based and agricultural residues, which are available, in principle, on a national level.

More advanced technologies like gasification of biomass for the production of power and/or heat could be an interesting option for bio-waste that is not very moist (it operates at elevated temperatures given that water is energy-intensive to heat up). The regions of Beirut-Mount Lebanon, North Lebanon and the Beqaa region are candidates for gasification of biomass (Table 98).

Note that these pre-treatment technologies are generally only applied and profitable in locations where transport over long distances of a large amount of biomass resource materials is required. Given this perspective, pre-treatment technologies for bioenergy carriers are not relevant for Lebanon.

Table 98: Relevance of pre-treatment technologies for each mohafazat in Lebanon

No.	Governorate	Mature technologies Pretreatment bioenergy carriers			
		Pelletization	Torrefaction	Pyrolisis	Gasification-CHP
1	Beirut				Sewage sludge wood and agri residues from North and Mount Lebanon
2	North Lebanon	Woody biomass Residues from fellings Residues from olive trees Residues from fruit trees Residues from cereals			Forestry, olive and fruit residues
3	Mount Lebanon	Woody biomass Residues from fellings Residues from fruit trees			Along with Beirut
4	Beqaa				Sewage sludge agri residues
5	South Lebanon				
6	Nabatiyeh				
RELEVANCE FOR COUNTRY					

V.5 PROMISING TECHNOLOGIES

Production of bioethanol from lignocellulosic crops is the most relevant future technology for Lebanon. Controlled cultivation of species such as perennial grasses are promising applications for the production of bioethanol through enzymatic fermentation.

Flat land that is not suitable for agriculture would also be interesting for algae cultivation and, in particular, land with easy access to seawater would be interesting for Salicornia. There are not many extensive areas available in Lebanon. A detailed study for analysing the feasibility for deploying algae crops at large scale in Lebanon is required to fully understand the real potential of these resources.

MSW is problematic in Lebanon, especially in the densely populated areas; turning it MSW into liquid fuels is a possibility that would grow with the matureness of the technology. Table 99 shows the relevance of promising technologies for each mofahazat in Lebanon.

Table 99: Relevance of promising technologies for 2020 for each mohafazat in Lebanon

No.	Governorate	Promising technologies Maturity reached by 2020			
		Algae options (centered in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW
1	Beirut				
2	North Lebanon			Woody and agri residues straw	
3	Mount Lebanon			Woody and agri residues straw ligno crops	
4	Beqaa			ligno crops agri residues straw	
5	South Lebanon				
6	Nabatiyeh			Some grass can be adopted	
RELEVANCE FOR COUNTRY					

VI RELEVANT STRATEGIC CONVERSION PATHWAYS PER MOHAFAZAT

Technologies can be combined in different ways, resulting in different bioenergy chains. These combinations of technologies (or bioenergy chains) are not applicable in all mohafazats, as they depend on the availability of biomass resources. The most suitable conversion technologies' combinations for each mohafazat in Lebanon, and for each relevant bioenergy stream, are presented in the matrix (Figure 10) below. This matrix is for the understanding of the real opportunities in each mohafazat; the information given is useful as a guide for investors and policy makers for future planning of projects.

Forest residues and short rotation coppices residues are very suitable for co-firing in power plants, for heat production in boilers, or for combustion if CHP plants are considered. Considering the resources available, they are a latent opportunity for projects in Beirut and North and Mont Lebanon. These combinations of biomass-technologies for co-combustion in power plants, or for cogeneration of heat and power are not a relevant option for neither the Beqaa region, nor South Lebanon or Nabatiyeh.

Additional to forest and agricultural residues, industrial wood residues could also be combined with the same direct combustion technologies. However this resource-technology combination could only be interesting for the Beirut area as it is there where the industrial wood residue potential is located.

Agricultural residues could be combined with direct combustion technologies as it is the case for forestry residues, but they could also be used in the future for the production of second generation biofuels. For their combination with direct combustion technologies, the best projects could be planned in North Lebanon and the Beqaa region and to a lesser extent in the other mohafazats. For the production of second generation biofuels, North Lebanon and the Beqaa region could offer interesting options.

Animal manure could be used basically for biogas production with anaerobic digestion processes. North Lebanon, Mount Lebanon and the Beqaa regions are potentially the most suitable for these types of projects.

Food energy crops such as oil seeds or sugar/starch crops could be converted into first generation biofuels in basically all the regions of Lebanon, with exception of Beirut and Mount Lebanon.

Lignocellulosic energy crops offer interesting possibilities as they can be combined with direct combustion technologies in North Lebanon, the Beqaa region and Nabatiyeh. But this biomass stream could offer far better options for the country if they are used for the production of second generation biofuels (biodiesel and bioethanol).

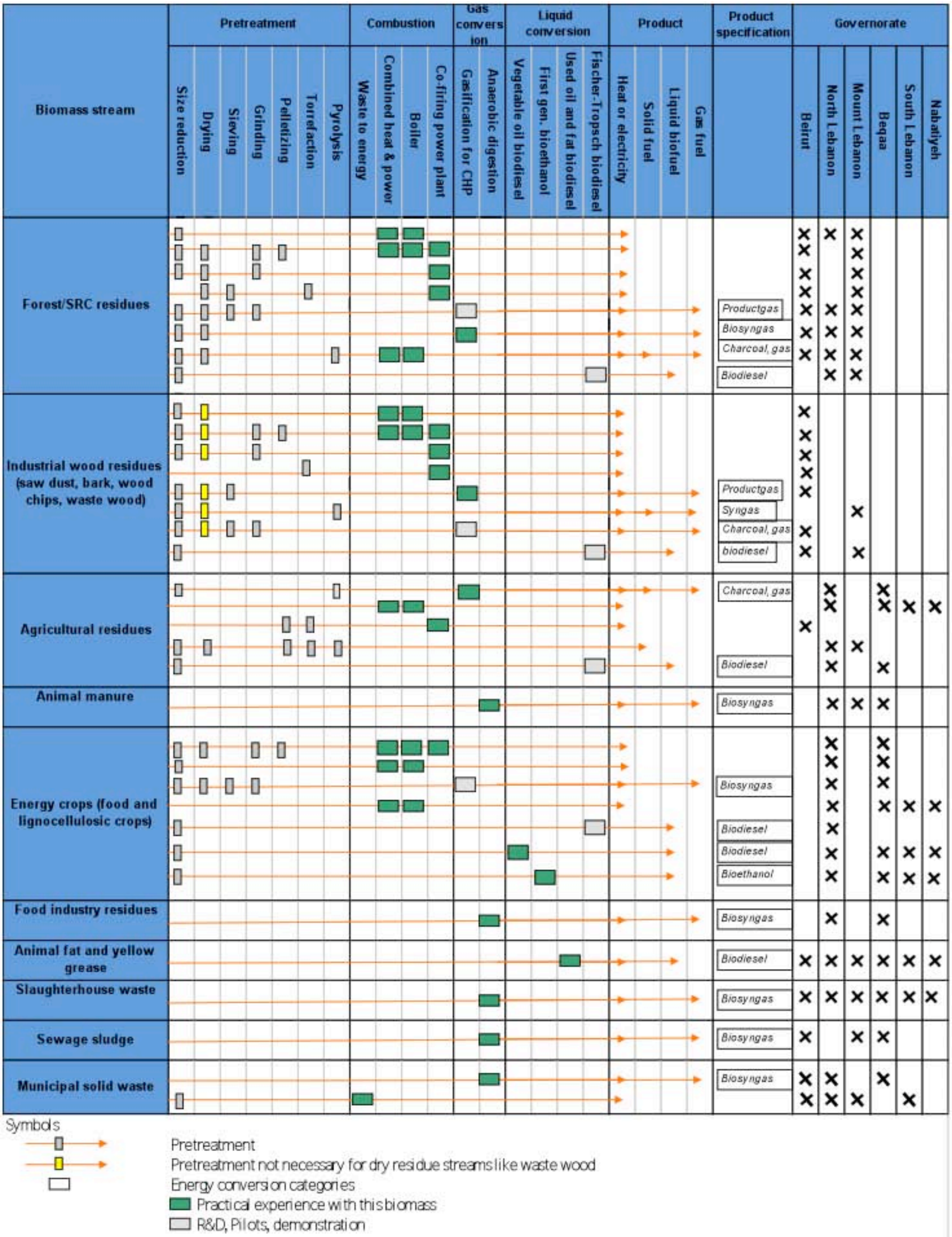
Animal fat and yellow grease can clearly be used for the production of biodiesel. All regions in Lebanon offer the possibility of this type of combination biomass resource/technology. Local production of biodiesel could contribute to lower the dependence on foreign fossil fuel diesel and at the same time environmental impacts of the disposal of used oil could be avoided.

Slaughterhouse waste and sewage sludge could be turned into biogas through anaerobic digestion processes basically in all regions of the country.

Municipal solid waste is an important energy resource in Lebanon. It can be used either in Waste-to-Energy plants (WTE), or when landfilled, the methane produced can be recovered and combusted in stationary generators for the production of electricity and heat. Both combinations are feasible in proximity to dense population areas. Therefore Beirut offers the largest potential for these types of projects, followed by North Lebanon.

Biodiesel plant

Figure 10: Most interesting technology conversion pathways per mohafazat



VII KNOW-HOW AND OPTIMAL PATHWAYS FOR FEEDSTOCK PROVISION

An overall description of the agricultural practices, collection, sorting, transport, storage, and other relevant issues required by each of the conversion processes studied is provided in this section. Furthermore, generic estimation of their related costs (non-location related) is also provided.

FEEDSTOCK PRODUCTION, COLLECTION AND TRANSPORT

Costs associated with feedstock production are a key factor in the total cost of bioenergy production. These costs include agricultural and harvesting costs (labour, input, machinery, etc.), collection costs, storage costs, and short distance transportation costs. Besides the price of a bioenergy feedstock, the potential availability of a sufficient amount of feedstock is critical. Key factors influencing the biomass potential are land availability (for energy crops) and choice of feedstock type; level of improvement in agricultural technology, water supply, efficiencies in use and competing uses of this feedstock type.

Some general considerations for the development of the biomass resource and short distance logistics are:

- Equipment: Collection methods may vary by region. Mechanization of the harvesting process and integration of residue collection may significantly influence efficiency, but may also require investments.
- Current harvesting methods and agricultural practices: Agricultural residues may be burnt or ploughed back into the soil. Agricultural modernisation in Lebanon will result in improvement of efficiency and sustainability.
- Agricultural best practices are recommended for all biomass feedstock resources. There exists a wide range of approaches to "sustainable agriculture" that out-perform conventional agriculture on certain key aspects such as "integrated pest management" (IPM) which lowers pesticide use, or "no tillage" cultivation (improving soil structure and conservation). Most widely developed and implemented are the principles of organic agriculture (OA) and forestry management. OA focuses on nutrient cycles, soil protection, crop diversity and bio-control of pests and weeds.
- Physical constraints: Steep slopes, wet soils, small sizes of fields and low-quality infrastructure can make the cultivated area inaccessible for mechanized harvesters or may cause harvesting to be relatively inefficient. Specialized equipment may partially help to overcome these problems.
- Storage: collected biomass needs to be kept protected from rain and fire risk. Collection is often seasonal depending on the biomass type, while biomass use is commonly year-round; therefore correct design of storage capacity and storage management are important.
- Generally, cost structures are dependent on available infrastructure, harvesting practices and transportation modes.

TRANSPORT TO CONVERSION PLANT

In general and when considering the logistics for large-scale bioenergy conversion plants, the following factors must be taken into account:

- Biomass has a low energy density and often high moisture content. Increasing the energy density by baling, bundling or drying is crucial to reduce the transportation costs and to improve physical properties and storability.
- Economics of biomass conversion plants generally become more favourable with increasing scale. Feedstock costs, on the other hand, generally rise as required feedstock volumes increase. This is due to greater transport distances. A trade-off between the two factors determines the economic optimal plant size.
- Seasonal variability and storability may impact feedstock supply for conversion plants.
- In terms of both costs and energy requirements, transportation by boat (for long distances by instance in the case of biomass exports from Lebanon) is by far superior to trucks or even to trains (if made available in the future in Lebanon).
- The optimal biomass supply chain also strongly depends on the requirements of quality and requirements of frequency and amount of feedstock by the end-user. Quality requirements may impact strongly the type of storage and transport needed.

BIOENERGY DISTRIBUTION

The last step in this chain depends on local conditions. The distribution considerations are determined by the bioenergy output type:

- Liquid biofuel: The finished biofuel product needs to be transported to the consumer. It is common practice to blend biofuel with fossil fuels. This blending step takes place at the fossil fuel bulk storage locations, where fuel trucks receive the fuel and transport it to gas stations;
- Bioelectricity: mostly grid connected;
- Bioheat: local use because it is difficult and expensive to transport;

- Biogas: Mostly converted into bioelectricity and heat;
- Solid biofuels: Mostly stored at the location of (stationary) use.

In the next sections, an analysis of the feedstock production, collection, transport and conversion is done for each technology selected.

VII.1 LIQUID FUELS PRODUCTION

1. VEGETABLE OIL BIODIESEL PRODUCTION

Feedstock provision

This biofuel production process uses vegetable oils as feedstock. In almost all cases, these oils can also be marketed for food purposes, which commonly have a much larger market than biodiesel. In practice, this means that vegetable oil production is a well-established agricultural system, and subsequent oil seed processing and oil trading. In other words, in many countries, a biodiesel producer can buy his/her feedstock in the market; there is no need to be involved in the processes upstream.

The case for Lebanon is distinctly different in the way that there is currently little vegetable oil production that may be considered for biodiesel. Therefore, a new agricultural system has to be set up, based on oil crops that are suitable for the Lebanese climate, like jojoba, palm oil and Jatropha. These crops can then be considered energy crops. After harvesting the oil seeds, the oil needs to be extracted from the plant material, which is done in an oil mill or oil seed crusher. Since this would be a new industry in Lebanon, it is recommendable to locate the oil mill in the same complex as the biodiesel plant. This reduces the cost of:

- Building oil storage capacity at the oil mill
- Transport costs from oil mill to biodiesel plant
- Dedicated oil transport vehicles (these trucks have to have an expensive cleaning process when switching from vegetable oil to other products and back)
- Building oil storage capacity at the biodiesel plant

Feedstock storage capacity will need to be built at the oil mill, to allow year-round operation even though the crop is only harvested once per year.

The finished biodiesel product needs to be transported to the consumer. It is common practice to blend biodiesel with fossil diesel. This blending step takes place at the transport fuel bulk storage locations, where fuel trucks receive the fuel and transport it to gas stations. Additionally, it is important to locate the oil mill and biodiesel plant centrally near main highways, to further minimize transport costs.

Costs

Feedstock costs differ by oil source. Where existing production in absent, as in the case of Lebanon, only a rough estimate of $500-900/ton can be given. Processing the oil has important costs like labour, methanol and catalyst, totalling about $160/ton product.

2. BIOETHANOL FERMENTATION

Feedstock provision

The different feedstock streams for this biofuel are well-known agricultural crops; therefore established agricultural practices apply (refer to vegetable oil biodiesel production for the general implications and for the Lebanese case).

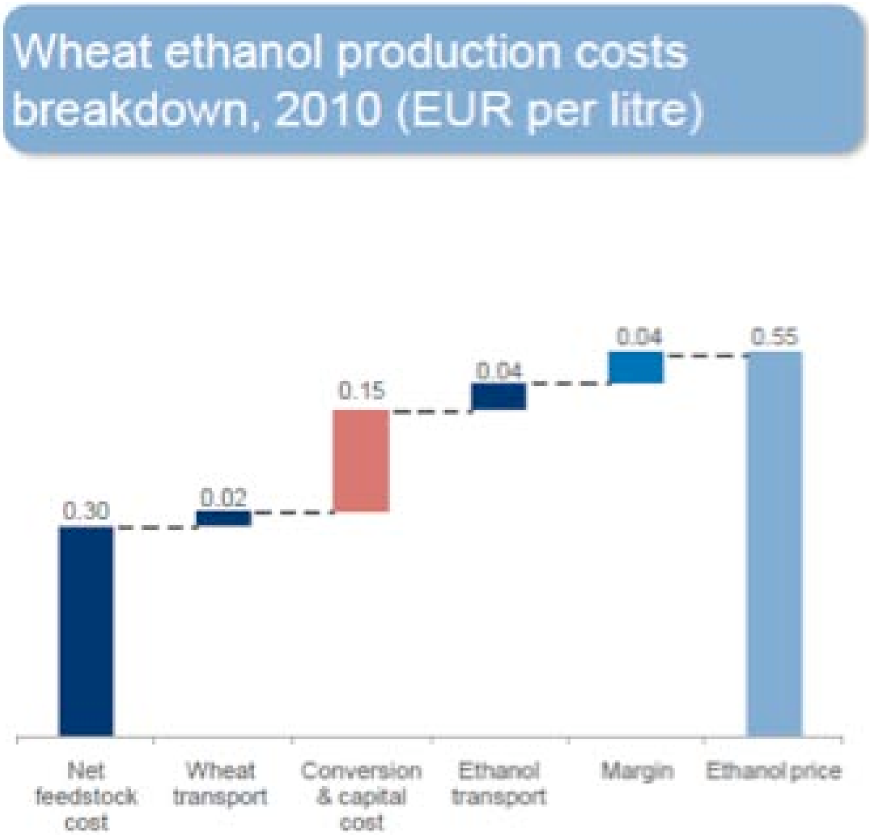
Bioethanol plants generally receive the raw feedstock, and output the finished biofuel and by-products, without the need for storage or transport of intermediates. Feedstock and bioethanol storage can be located on-site and/or off-site.

Costs

Feedstock costs differ per crop, ranging $100-300/ton of feedstock

Processing costs have been estimated at $550/ton ethanol. A detailed description of costs for the production of bioethanol is presented in Figure 11:

Figure 11: Breakdown of ethanol production costs. Source Bloomberg Energy Finance



3. USED OIL BIODIESEL

Feedstock provision

This biofuel feedstock is known to be relatively cheap; it is made from a waste product. However for the case of Lebanon, a substantial amount of money and time will be required to build up a proper and reliable network of collecting used oils at the dispersed sources. The oil is collected and then moved to an intermediary collection and storage location 1 to 3 times before it arrives at the biodiesel plant for processing. See also Figure 25.

This waste resource requires significant pre-treatment, which commonly consists of a simple filtering step at the intermediate storage facilities while the rest of the pre-treatment is done at the biodiesel plant, neutralization of free fatty acids being an important step.

Animal fat is another feedstock for this type of biodiesel. Animal fat is typically produced at meat processing locations; therefore the sources are more centralized than used or vegetable oil. This feedstock is also cleaner than used oils which is polluted with e.g. burned food rests, therefore can be used in other applications besides biodiesel production, and subsequently has a higher market price.

Additional logistical considerations for this feedstock are that many fats may solidify at ambient temperatures, making transport more difficult than liquid oils; bad odours and environmental problems can be caused if the feedstock is not well packed.

Costs

Feedstock costs for used oils depend heavily on how much effort is needed to collect them and the national policy on the treatment requirements of this waste; $100-250/tonne oil is indicated. Typical prices for poultry fat are around $250/tonne, yellow grease costs $400-450/tonne.

For the case of Lebanon, an oil collection network has to be set up. This involves multiple middle men and intermediate transport and storage. This can be expected to be most cost-effective in zones with a higher population density, so primarily the greater Beirut area.

Further processing costs depend mostly on how much pre-treatment is needed. For biodiesel quality reasons, mostly mixes of different oil sources are used, as the cheapest sources tend to deliver the poorest quality biodiesel.

4.FISCHER-TROPSCH (FT) BIODIESEL (2ND GENERATION)

Feedstock provision

This biofuel can utilize any biomass that can be used for syngas production; in practice different kinds of woody biomass are regarded as the feedstock for this technology. Suitable feedstock resources for Lebanon are sewage sludge, wood and agricultural residues, forestry and olive and fruit residues. These resources can be found in Beirut (combined with Mount Lebanon), North Lebanon and the Beqaa region.

Feedstock supply chain:

- Production of feedstock: Issues to take into consideration are the economic performance of the feedstock with other competitive markets, quality requirements, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee all year supply;
- Storage: Development of storage capacity near feedstock resource;
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs.

Costs

Fischer-Tropsch based technology is relatively complex and therefore more expensive. To compensate for this, mainly feedstock with a very low cost will be used, such as feedstock with no competing uses, like used car tires. Wood and straw are technically easier to handle. For the specific case of FT biodiesel, the UK DfT (Department for Transport) expects these feedstock to cost €10.50/GJ in Western Europe and €8.60 /GJ in Eastern Europe.

Operating costs

Since the technology is not mature yet, processing costs are still unclear, and as with most advanced bioenergy technologies, estimates range from pessimistic to highly optimistic values. The EU RENEW project[1] calculated the price of this fuel to become equivalent with $100/barrel oil prices.

VII.2 BIOGAS PRODUCTION

5. ANAEROBIC DIGESTION OF ORGANIC WASTE

Feedstock provision

Anaerobic digestion, as a bioenergy production technology, has comparatively low overall energy conversion efficiency, but can use a variety of feedstock, most notably wet feedstock. Given the low energy yield, this technology focuses on the cheapest of feedstock, which in practice means waste streams.

The main supply chain consideration is that wet feedstock has relatively high transportation cost given that it involves a lot of water content transport. Also gas transport is expensive. Biogas will need to be cleaned, purified and compressed for transport. Therefore, these technologies are typically implemented on a small, local scale, dimensioned to the locally available volume of feedstock. Biogas is converted into electricity and/or heat on site. Part of the generated heat is commonly applied to heat the digestion reactor, but ideally the produced heat can be used for other processes as well.

Costs

Although almost all biomass sources could be subjected to anaerobic digestion, this technology typically focuses on feedstock that has no market value (or even disposal costs), and no real alternative treatment method. Very often, these are very wet streams, like manure. Though cost for the feedstock itself is free, or even negative, for the process to run well, a second feedstock is sometimes needed (usually one with a low nitrogen content).

6. ANAEROBIC DIGESTION OF SEWAGE SLUDGE

Feedstock provision

This is typically a conversion technology that is located in-situ and dimensioned on the total expected amount of sludge production. Figure 12 below gives an overview of the (idealized) complete cycle.

Sewage sludge is surplus bacterial biomass from the wastewater treatment process. This sludge is very wet (80-90% water), difficult to dry and needs to be disposed of. Anaerobic digestion offers disposal which produces biogas and fertilizer. Instead of transporting the feedstock to the bioenergy production plant, this system is built on the site where the feedstock is produced. Transport of the produced gas in Lebanon (contrary to Figure 12) is restricted to compression into gas cylinders, due to the lack of a national gas grid.

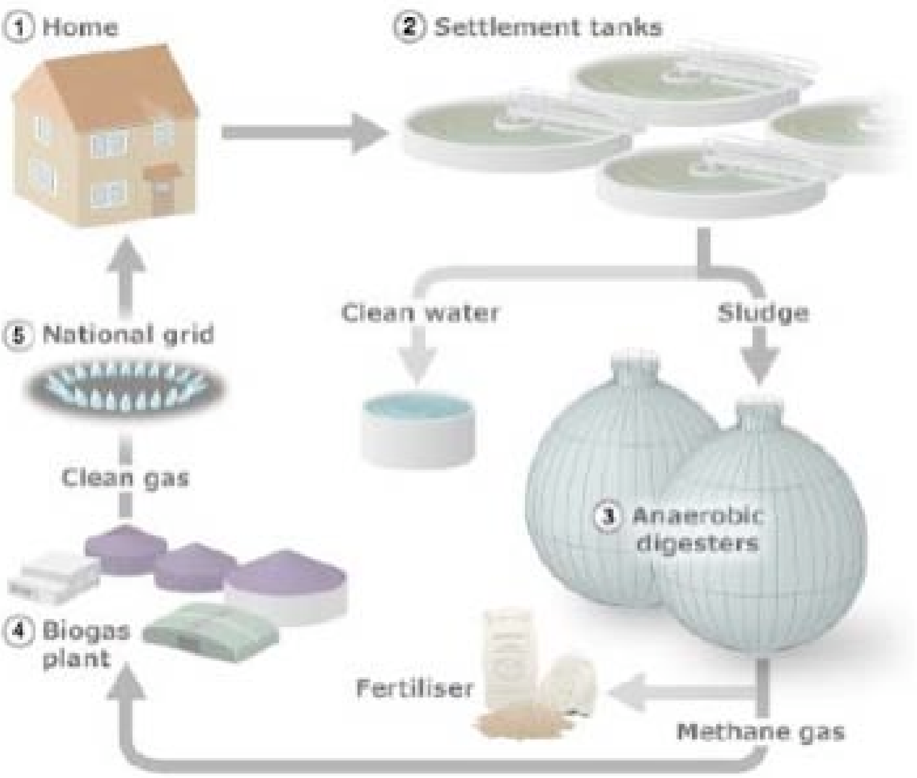
Costs

Sewage sludge as a feedstock is a waste stream requiring treatment, and therefore its cost is zero.

Transport costs can be substantial; therefore this technology is normally installed close to the biomass source. The

[1] http://www.renew-fuel.com

Figure 12: Overview of biogas production from sewage sludge



biomass feedstock may be signifincatly wet that it can be pumped, or else it can be transported with screws or conveyer belts.

This is primarily a waste treatment technology; therefore this technology is commonly seen as an option for reduction of waste treatment costs. To evaluate the actual cost of this technology, a comparison with the cost of alternative waste treatment technologies must be done.

7. SLAUGHTERHOUSE WASTE BIOGAS

Feedstock provision

In this specific case, a flexible bioenergy production technology is applied to a problematic waste stream. The generation of bioenergy and fertilizer are only secondary goals. In terms of feedstock provision, in most countries, including Lebanon, slaughterhouse waste cannot be transported without treatment; therefore the anaerobic digestion plant needs to be located on-site. Because of the high nitrogen content of the waste, co-digestion of low-nitrogen bio waste may be needed for a stable process (e.g. landscaping residues, waste paper, or organic waste).

Legal requirements state that the slaughterhouse waste needs to be sterilized before any other treatment can be applied. This process often uses hot water, making the feedstock wetter. Large recalcitrant particles like bones can be crushed or filtered out.

Costs

This is primarily a waste treatment technology; therefore this technology is commonly seen as an option for reduction of waste treatment costs. To evaluate the actual cost of this technology, a comparison with the cost of alternative waste treatment technologies must be made.

8. LANDFILL GAS CAPTURE AND USE

Feedstock provision

This biofuel is basically produced "naturally" in landfills from the biodegradable fraction of the landfilled waste, and only needs to be "harvested" and cleaned. Figure 13 shows a general diagram for the landfill collection and conversion to energy.

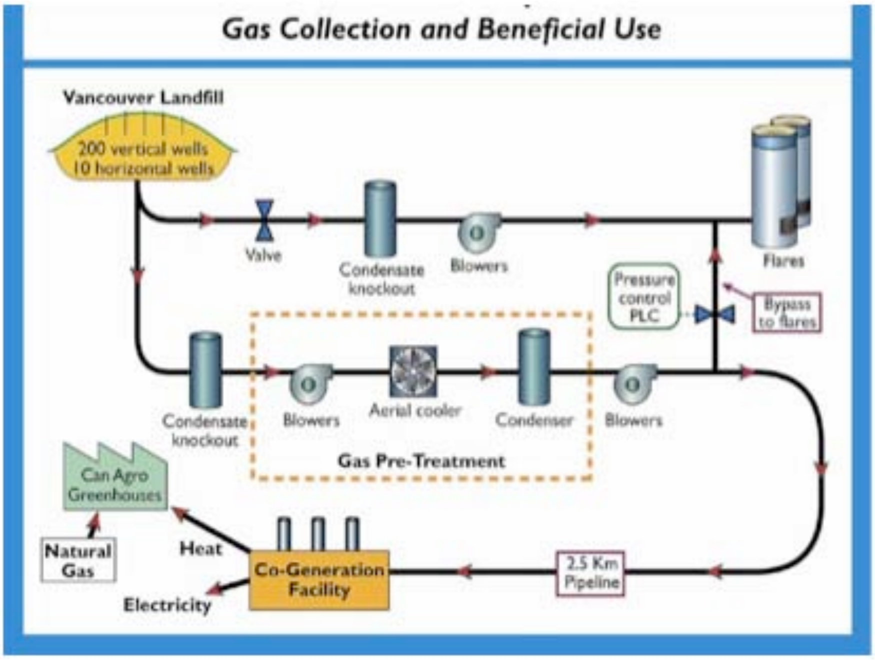
Costs

There are no actual feedstock costs, but:

- Capital cost for building the biogas capturing and conversion system;
- Energy cost for gas transport;
- O&M cost for landfill gas cleaning and conversion to energy.

A typical landfill gas project with conversion to energy has

Figure 13: General diagram of landfill gas collection and usage



a capital investment cost of $900-1300 per kW installed, and operating and maintenance cost of $c1.5-1.8 per kWh.

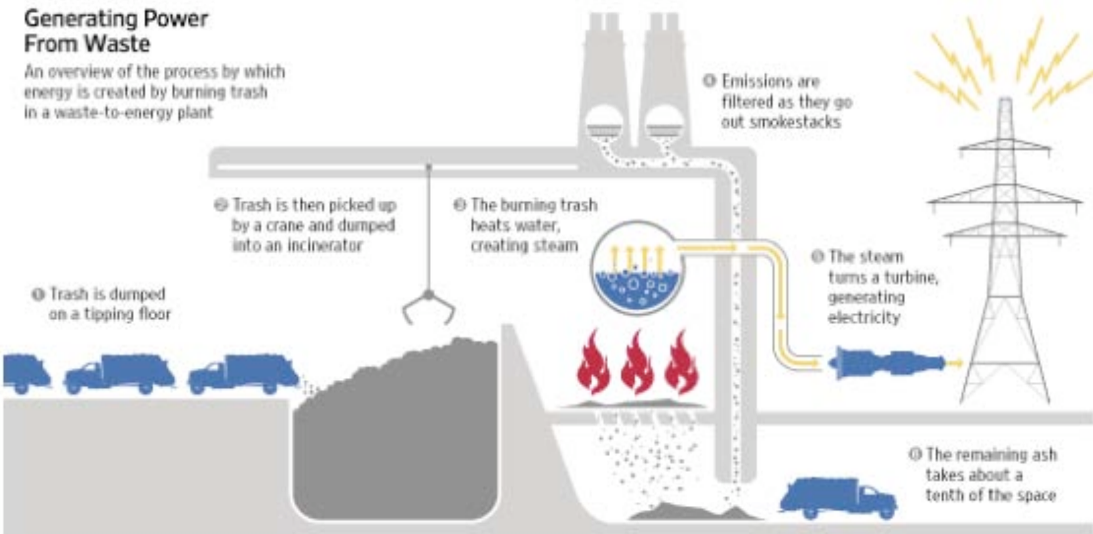
VII.3 DIRECT COMBUSTION FOR POWER AND HEAT PRODUCTION

9. WASTE TO ENERGY (WTE)

Feedstock provision

Waste collection and centralized treatment is present in all densely populated areas. Waste collection is an organised service supplied to most households and companies. Waste can also be valorised for energy purposes, and at the same time reduces dependency on landfilling. Suitable feedstock resources for Lebanon are municipal solid waste and similar industrial waste. These resources can be found in all densely populated locations: mainly Beirut (and surroundings), along the coast, Mount Lebanon, North Lebanon and the Beqaa region. A diagram of a WtE plant is shown in Figure 14.

Figure 14: Diagram of a Waste-To-Energy plant



Costs

As a rule of thumb, around 80% of the income of a WtE plant is supplied by the gate fees received for treating the delivered waste. The other 20% is derived from selling the produced electricity and heat.

A typical medium scale plant can treat 25 tonne/h. Investment costs are $700-800 per tonne/year capacity, while operational costs vary strongly; (heat-only production is cheapest), yet the average is between $110 and 160/tonne. Using an average energy yield of 0.55 MWh/t of MSW yields $60-90/MWh, of which 10-25% is used by the WtE plant, the rest is exported. Heat-only systems obtain a higher efficiency at lower cost (IEA 2009).

10. CHP

Feedstock provision

The main way to increase the overall efficiency of a power plant (and hence its effectiveness) is to use its heat through cogeneration.

Feedstock resources

Biomass for CHP generation is generally applicable when having the moisture content from 10 to 60%.). Feed-stock used in direct combustion for the production of power and heat are often residues such as woodchips, sawdust, bark, hog fuel, black liquor, bagasse, straw, municipal solid waste and waste from the food industry.

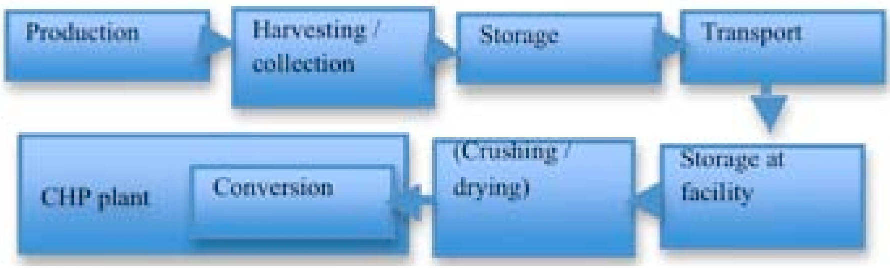
Until recently, dedicated biomass power plants have only proved competitive when using large quantities of zero cost residues (e.g. MSW, pulp from the paper industry or bagasse). However, a growing number of viable smaller scale plants are found throughout Europe and North America, using other types of residues.

Suitable feedstock resources for Lebanon are wood waste, woody biomass, and residues from fellings, olive trees, fruit trees or cereals. Energy crops are to be developed. These resources can be found in Beirut, North Lebanon, Mount Lebanon and the Beqaa region.

Feedstock supply chain:

A general outline of the feedstock supply chain is presented in Figure 15. Note that some of the processes (e.g. drying or crushing) can also take part in another part of the chain, e.g. after harvesting.CHP is often deployed on a large to medium scale, meaning that sufficient biomass resources should be available in the region to supply the CHP plant all year round.

Figure 15: Outline of feedstock chain



Some considerations when developing the feedstock supply chain:

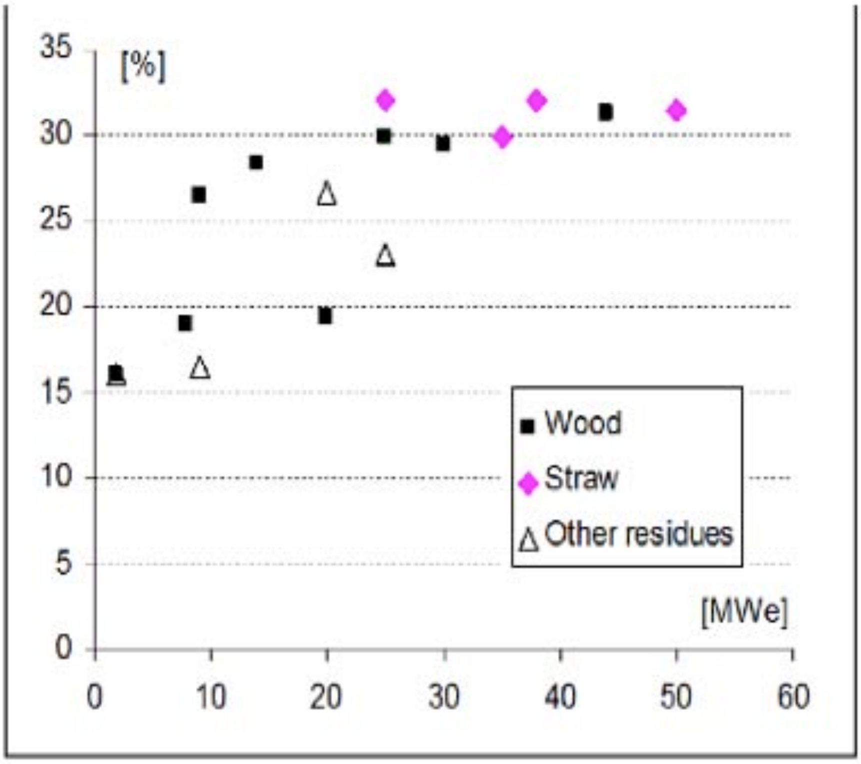
- Production of feedstock: Wood is generally used as feedstock although other resources are also possible. Issues to take into consideration are the economic performance of the feedstock with other competitive markets, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee year-round supply);
- Storage: Development of storage capacity near feedstock resource;
- Solid biomass feedstock generally has a low bulk density and comes in a variety of structures and types, which must be considered in handling and storage.
- Transport: Availability and quality of infrastructure, distance to CHP plant, transportation costs;
- The large-scale operation and input from CHP plants may suffer from poor economics at small-scale due to resource availability and/or insufficient logistics. This is a particular problem because of the difficulty in supplying mainly lignocellulosic feedstock to large plants.

Costs

The investment costs of biomass-based CHP and power generation depend upon several parameters such as the feedstock used (e.g. wood, straw, waste, etc.), the boiler technology (Water-cooled vibrating grate, Bubbling fluidised bed combustion, Circulating fluidised bed combustion) or the capacity of the plant (MWe). Figure 16 below shows the investments costs of biomass CHP plants with capacities of up to 50 MWe. The investment costs of biomass-based CHP plants are between $3,000 and $6,000/kWe (typically, some $4000/kWe in 2008). Operation and maintenance (O&M) costs are in the order of $100/kWe per year.

As a general estimation: Feedstock costs generally represent 50% to 90% of the production costs of bioenergy.

Figure 16: Investments costs share of biomass CHP plants



The viability of CHP, especially in smaller CHP installations, depends upon a good base load of operation, both in terms of an on-site (or near site) electrical demand and heat demand. In practice, an exact match between the heat and electricity needs rarely exists. A CHP plant can either meet the need for heat (heat driven operation) or be run as a power plant with some use of its waste heat. CHP is more energy and cost efficient when the heat can be used on site or very close to it. While about 30% of total energy can be converted into electricity, additional 50% to 60% can be used as heat.

11. BOILER COMBUSTION

Feedstock provision

The devices used for direct combustion of solid biomass fuels range from small domestic stoves (1 to 10 kW) to the largest boilers used in power and CHP plants (>5 MW). Intermediate devices cover small boilers (10 to 50 kW) used in single family houses heating, medium-sized boilers (50 to 150 kW) used for multi-family house or building heating and large boilers (150 to over 1 MW) used for district heating.

Feedstock resources

The figure (EUBIA, 2010) below shows the most frequently used furnaces for biomass combustion and its typical feedstock input and size range. Basically, all kind of biomass can be used as feedstock when having moisture content lower than 60%: wood residues, peat, sawdust, wood pellets, bark, chips, hog fuel, shavings and cuts, sander dust, straw. It is preferred though to use pellets for small-scale applications (<100 kWth) and for large-scale applications wood chips are use see Table 100.

Table 100: Types of combustion boilers

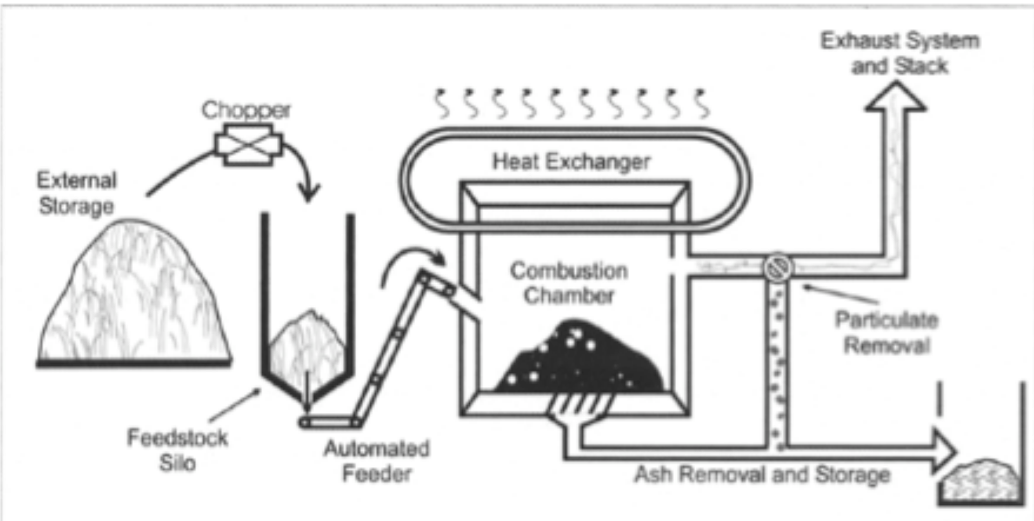
Application	Type	Typical size range	Fuels	Ash	Water content
Manual	Wood stoves	2 kW – 10 kW	dry wood logs	<2%	5%-20%
	Log wood boilers	5 kW – 50 kW	log wood, sticky wood residues	<2%	5%-30%
Pellets	Pellet stoves and boilers	2 kW – 25 kW	wood pellets	<2%	8%-10%
Automatic	Understoker furnaces	20 kW – 2.5 MW	wood chips, wood residues	<2%	5%-50%
	Moving grate furnaces	150 kW – 15 MW	all wood fuels, most biomass	<50%	5%-60%
	Pre oven with grate	20 kW – 1.5 MW	dry wood (residues)	<5%	5%-35%
	Understoker with rotating grate	2 MW – 5 MW	wood chips, high water content	<50%	40%-65%
	Cigar burner	3 MW – 5 MW	straw bales	<5%	20%
	Whole bale furnaces	3 MW – 5 MW	whole bales	<5%	20%
	Straw furnaces	100 kW – 5 MW	straw bales with bale cutter	<5%	20%
	Stationary fluidised bed	5 MW – 15 MW	various biomass, d < 10 mm	<50%	5%-60%
	Circulating fluidised bed	15 MW – 100 MW	various biomass, d < 10 mm	<50%	5%-60%
	Dust combustor, entrained flow	5 MW – 10 MW	various biomass, d < 5 mm	<5%	<20%

Suitable feedstock resources for Lebanon are wood waste, woody biomass and residues from fellings, olive trees, fruit trees or cereals. These feedstock resources can be found in Beirut, North Lebanon, Mount Lebanon and the Beqaa region.

Feedstock supply chain:

A general outline of a biomass combustion system is given in Figure 17.

Figure 17: General outline of a biomass combustion system



The majority of raw biomass materials may require some form of processing before they become biomass fuels. Processes can range from simple cutting and drying to more involved processes like pelletizing. Biomass heating systems require physical handling mechanisms for transferring fuel from where it is stored to where it is combusted (in the plant). All biomass fuels can come in a wide variety of shapes and sizes.

Aside from moisture content, the particle size is the other key issue to consider when matching system design with the fuel available. Certain fuel feed systems can handle fuels with a broader range of particle sizes (e.g. walking floors and 'ram stokers'). Others (e.g. those designed to use pellet fuels) can only tolerate a more narrow range of particle sizes.

Some considerations when developing the feedstock supply chain:

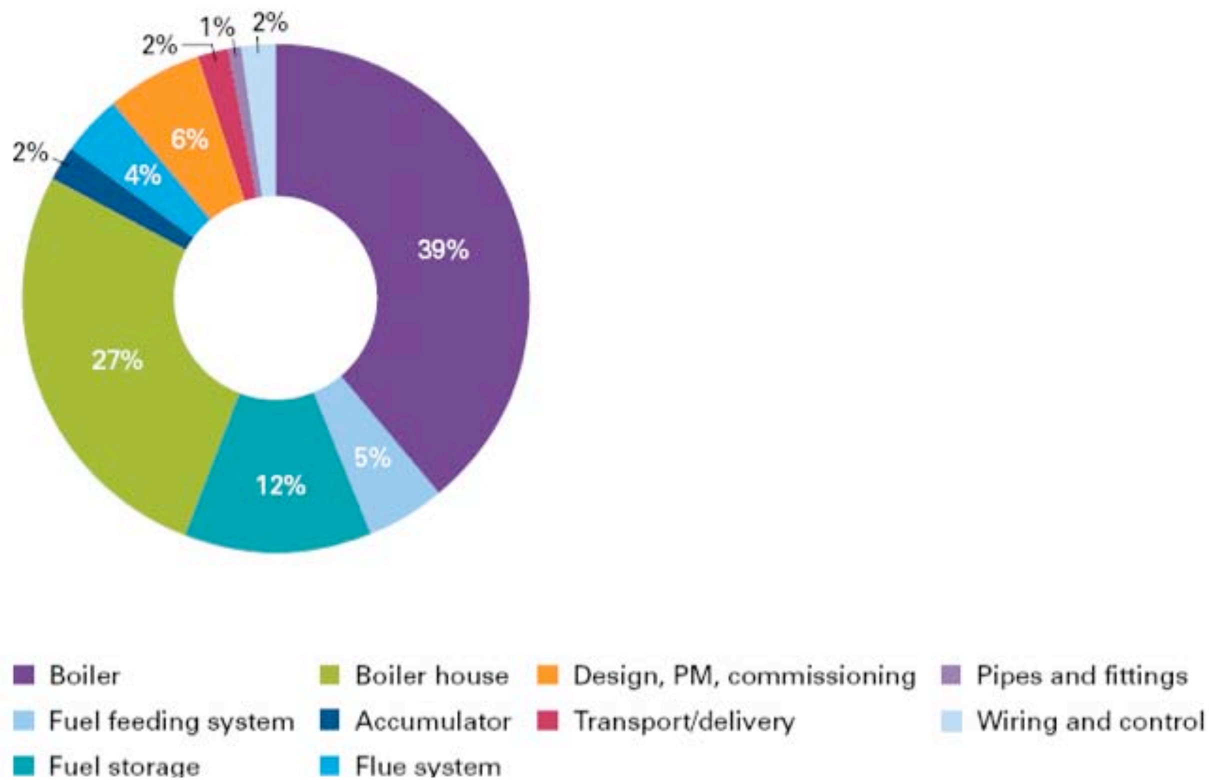
- Production of feedstock: Wood is generally used as feedstock although other resources are also possible. Issues to take into consideration are the economic performance of the feedstock with other competitive markets, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock;
- A well-designed system for delivering, storing and transferring solid biomass fuel is essential to ensure a smooth-running biomass heating system.
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs.

Costs

Production costs of biomass based heating systems vary widely with size and fuel cost. Heat production costs in pellet boilers from 5 to 100 kW range from 8 to 99 Euro per GJ with an average of 26 Euro per GJ.

Figure 18 gives the capital cost breakdown for an indicative biomass-heating project, based on a designed project of 500 kWth rated capacity. In addition, there are two main aspects to the operational costs of a biomass system: fuel costs, and system operation and maintenance (O&M) costs. The feedstock costs can vary considerably and depends, among others variable, on competition, availability, quality of the fuel, transportation costs, etc.

Figure 18: Capital cost breakdown for an indicative biomass heating project



12. CO-FIRING

Feedstock provision

Direct co-firing means that biomass fuel and coal are burned together in the same furnace, using the same or separate mills and burners depending on the biomass fuel characteristics. Biomass properties may pose several challenges to coal plants that may affect their operation and lifetime, in particular when a feedstock other than wood is used. This generally limits the amount of biomass that can be co-fired.

Feedstock resources

Many different types of biomass can be utilized in co-firing systems. Co-firing experience includes wood, residues from forestry and related industries, agricultural residues, as well as various biomass streams in refined form such as pellets. Energy crops could be perceived as potential candidates for co-firing. However, currently woody biomass is generally used as feedstock, although (developing) pre-processing technologies broaden the option to other feedstock resources.

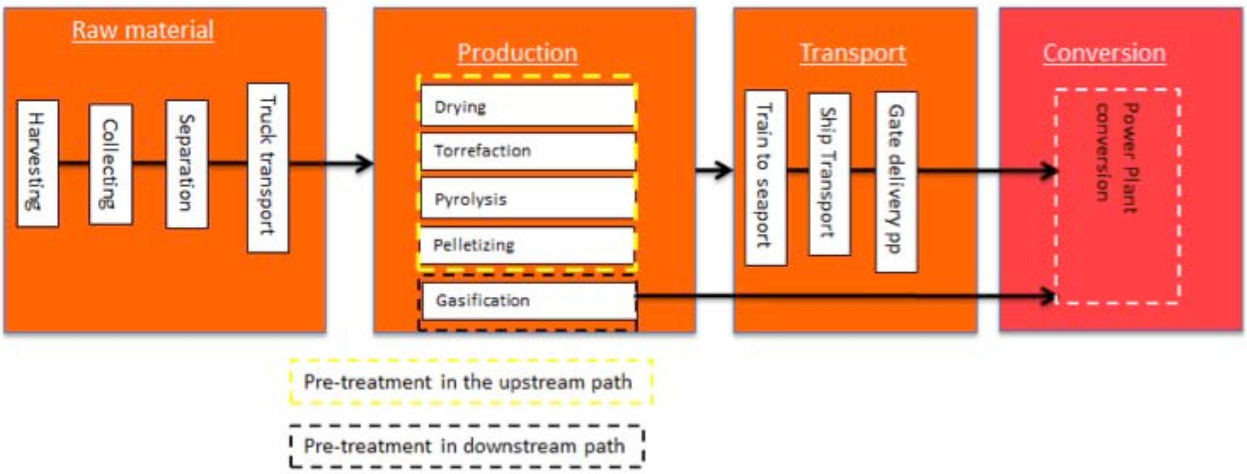
Suitable feedstock resources for Lebanon (provided sufficient potential can be collected over time) are wood waste, woody biomass and residues from fellings, olive trees, fruit trees or cereals. These feedstock resources are located in or around Beirut, North Lebanon, Mount Lebanon and the Beqaa region.

Feedstock supply chain:

The feedstock supply chain for co-firing generally is shown in Figure 19.

The biomass needs to be grinded to dust or pre-treated

Figure 19: Feedstock supply chain for co-firing installations



(pyrolysis, gasification, torrefaction) in order to be used in a pulverized coal power plant. The biomass pre-treatment options broaden feedstock options and chain optimization. Feeding of biomass in co-firing systems can be done by using the existing coal infrastructure or by a separate line. Some considerations when developing the feedstock supply chain:

- Production of feedstock: Wood is generally used as feedstock although other resources (in combination with pre-treatment options) are also possible. Issues to take into consideration are the economic performance of the feedstock with other competitive markets, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee all year supply;
- Storage: Development of storage capacity near feedstock resource;
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs;
- Sufficient biomass needs to be supplied to guarantee a whole year input of resource. Possible limitations are insufficient resource availability, distribution, density and logistics.

Costs

Generally, the energy systems co-firing biomass with coal are more expensive than dedicated coal systems. On the other hand, the capital costs of co-firing projects are usually lower than those of establishing new, dedicated biomass-to-energy plants. One of the most sensitive factors in economics of co-firing is the cost of biomass fuel. The cost of biomass fuel, as well as costs of co-firing, could be a subject to political decisions regarding e.g. environmental or preferential taxes, subsidies, or trade with emission quotas.

The costs of biomass as a fuel for energy consist of two main parts: the purchase price and the costs of logistics (transport, storage, handling and pre-treatment). In general, the operation costs of biomass are higher when compared to the fossil fuels due to a number of reasons, for example, a lower energy density of biomass in comparison with fossil fuels that translates into higher transportation and storage costs per energy unit.

Coal and CO_2 prices are of great influence for the cost effectiveness of biomass co- firing.

VII.4 PRETREATMENTS FOR BIOENERGY CARRIERS

13. PELLETISING

Feedstock provision

Pelletisation is an efficient energy densification technique. This, combined with their high net caloric value, can make it economically viable for material to be pelletised to reduce transportation and storage costs.

Feedstock resources

Pellets can be made from virtually any type of woody feedstock, as well as from herbaceous biomass, fruit biomass, and peat. However, the use of such alternative feedstock might result in pellets with ash or contamination contents that do not comply with internationally agreed quality standards as the European Committee for Standardization (CEN[2]) or the Deutsches Institute für Normung (DIN[3]). Today, pellets are mostly produced from sawdust, a co-product of sawmills.

Suitable feedstock resources for Lebanon are woody biomass and residues from fellings, olive trees, fruit trees or cereals. These feedstock resources can be found in the regions of North and Mount Lebanon.

The raw materials for pellets need to be dry and homogeneous and therefore are usually pulverized. The moisture content should be below 15%, and particles sizes below 6 mm length.

Feedstock supply chain

The general feedstock supply chain for pelletisation is shown in Figure 20.

Figure 20: Schematic overview of the pelletisation supply chain

Some considerations when developing the feedstock supply chain:

- Production of feedstock: Issues to take into consideration are the economic performance of the feedstock with other competitive markets, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee all year supply;
- Storage: Development of storage capacity near feedstock resource;
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs;
- Pellets are hygroscopic, i.e., they tend to absorb moisture during transport and storage, which can reduce their net caloric value. This therefore calls for various mitigation measures along the chain, including quality control.

Costs

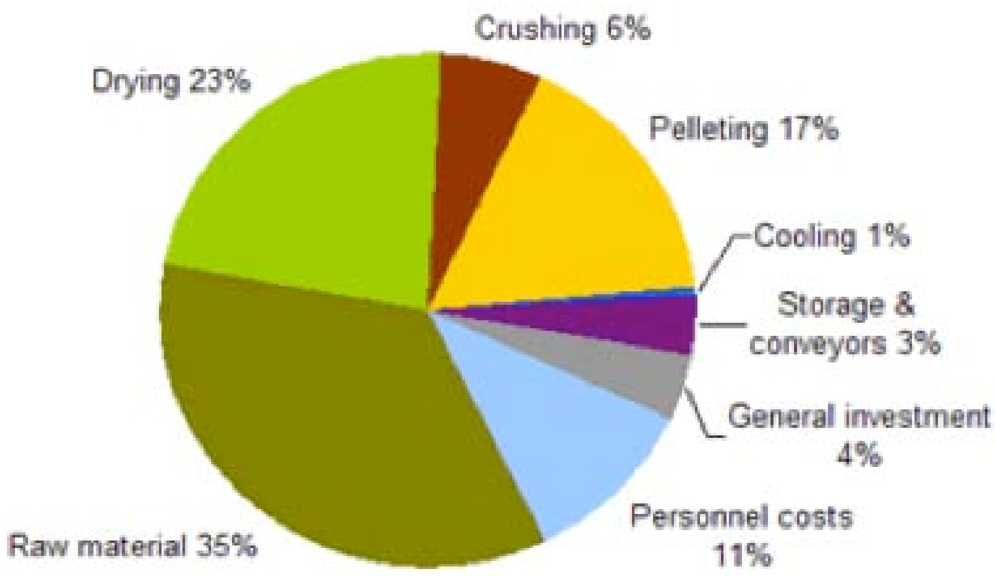
In Europe, average production costs of wood pellets

[2]http://www.cen.eu/cen/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/default.aspx?param=19930&title=CEN/TC%20335

[3]http://www.din.de

(Figure 21) is estimated to be in the range of 50 to 80 Euro / tonne, compared to 60 to 84 $/ tonne in Canada. Costs of switchgrass (Panicum virgatum) pellets are generally 40% higher. The market price of pellets ranged from 120 to 270 Euros per tonne in 2007.

Figure 21: Cost structure for pellets production



Thek and Obernberger (2002) analysed the pellet production costs in Austria and Sweden. Depending on the operative conditions, those two parameters can cause up to one third of the total pellet production costs. Pellet production costs were found to vary between 79 and 101 Euros/t if raw material was wet and between 52 and 81 Euros/t if raw material was dry.

14. TORREFACTION

Feedstock provision

Torrefied biomass can also be pelletized in order to further reduce its transport and handling costs. Torrefaction is currently in the demonstration stage but could become commercially available in the near future. This would facilitate access to remote resources such as forest residues from remote areas. Note that torrefaction is still in its development phase, and still experimenting with types of feedstock to be used.

Feedstock resources

Torrefied biomass produced from a wide variety of raw biomass feedstock has similar product properties as basically all biomass is composed by the same polymers (lignocelluloses).

Depending on the availability of possible biomass feedstock (type and amount), a certain degree of flexibility in the production plant is necessary. The applied technology will strongly limit the allowable variation in feedstock properties of which size and shape characteristics are the most important ones. A significant factor in determining yields at a given set of reaction conditions (residence time, temperature) is the hemicellulose content: The higher the hemicellulose content, the lower the yields. Experiences with agro-residues are variable.

In Lebanon, the following feedstock resources could be used: Woody biomass and residues from fellings, olive trees, fruit trees and cereals. Suitable regions are North and Mount Lebanon.

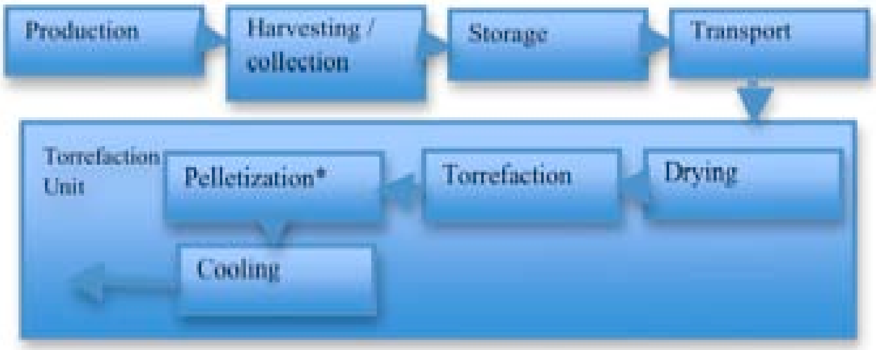
Feedstock supply chain:

A torrefaction process typically consists of pre-drying, torrefaction, product cooling and combustion of the torrefaction gas to generate heat for drying and torrefaction. The typical full-scale production capacity is estimated to range 50-60 kton/a (or 100-130 kton/a feedstock input with 50% moisture content).

The feedstock supply chain for torrefaction generally is shown in Figure 22 (*optional): Some considerations when developing the feedstock supply chain:

- Production of feedstock: Issues to take into consideration are the economic performance of the feedstock with

Figure 22: Schematic overview of the feedstock supply chain for torrefaction



other competitive markets, sustainable forest management issues, policy and regulation constraints;

- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee all year supply);
- Storage: Development of storage capacity near feedstock resource
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs;
- Torrefaction technologies generally operate on a medium to large-scale, which means that sufficient biomass needs to be supplied to guarantee a whole year input of resource.

Possible limitations are insufficient resource availability, distribution, density and logistics.

Costs

Various studies are available about the economics of torrefaction. According to our estimations the total capital investment of a 60 kton/a production plant ranges from €5 to €7.5 and the total production costs in the range from 40 to 56 €/ton product (excluding feedstock costs). The largest costs items are natural gas, depreciation, and financing. Other important items are costs of labour and electricity.

Total production costs of three torrefaction concepts are shown in Table 101.

Torrefaction

Table 101: Capital investment for a 60 kton/a pellets plant

Cost item	Screw reactor €/ton	Rotating drum €/ton	Moving bed €/ton
Direct product costs			
Operating labour	5,42	6,5	5,42
Electricity	5,75	6,77	5,88
Natural gas	13,44	13,44	13,44
Maintenance and repairs	6,1	6,1	2,04
Other	3,8	4,07	3,19
Total direct product cost	34,5	36.9	30.0
Fixed charges			
Depreciation	20.88	15.24	10.2
Other	3.06	2.29	1.53
Total fixed charges	23.4	17.5	11.7
Plant overhead	3.25	3.9	3.25
General expenses			
Financing	10.46	7.89	5.37
Other	5.15	5.31	5.15
Total general expenses	15.6	13.2	10.5
TOTAL	77	71	55
€/GJ	3.8	3.5	2.7

Note that this cost estimation excludes feedstock supply costs (including transportation).

15. GASIFICATION CHP

Feedstock provision

Gasification involves subjecting solid biomass to hot steam and air to produce a gaseous biofuel. This gas (also called synthesis gas) can be burned for heating, electricity production, or may be further converted to act as a substitute for almost any fossil fuel. Biomass gasification is also considered one of the most promising routes for syngas or combined heat and power production because of the potential for higher efficiency cycles.

Feedstock resources

In principle, gasification can proceed from just about any organic material, including biomass and plastic waste. Thus a wide range of feedstock can be used as wood, agricultural residues, rice hulls, shells or sewage sludge. For input into the gasification unit, the moisture content should be below 10%.

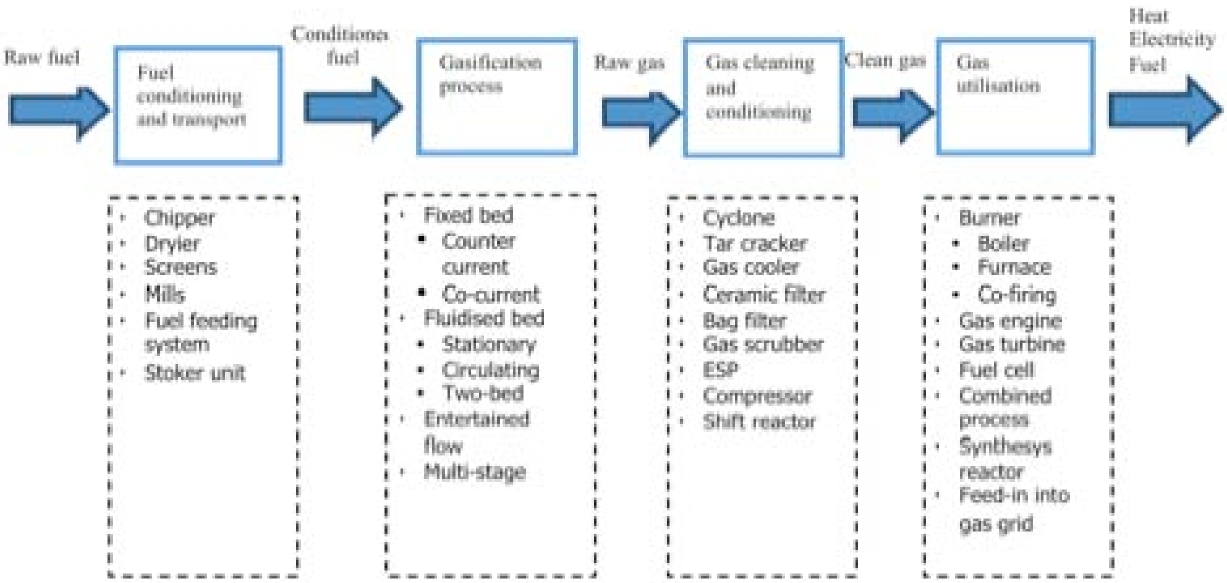
Suitable feedstock resources for Lebanon are sewage sludge, wood and agricultural residues, forestry and olive and fruit residues. These resources can be found in Beirut (combined with Mount Lebanon), North Lebanon and the Beqaa region.

Feedstock supply chain

Figure 23 shows the basic process steps of a biomass gasification plant.

Note that this cost estimation excludes feedstock supply costs (including transportation).

Figure 23: Basic process steps of a biomass gasification plant



The solid biomass fuel delivered needs to be adjusted (fuel conditioning and handling) to the fuel characteristics (particle size, water content) required for the gasification process. The conditioned fuel enters the gasification process, which produces raw product gas. The raw product gas needs to be cleaned in order to achieve the product gas quality needed for further utilization. The cleaned product gas is used for the production of electric power, heat and fuel based on different technologies.

Some considerations when developing the feedstock supply chain:

- Production of feedstock: Issues to take into consideration are the economic performance of the feedstock with other competitive markets, quality requirements, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee all year supply;
- Storage: Development of storage capacity near feedstock resource;
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs.
- Biomass gasification technologies are still in the development phase and improvements need to be made for adaptability to feedstock quality, moisture content and gas clean-up (tar formation, process monitoring);
- The large-scale operation and input from CHP plants may suffer from poor economics at smaller-scales. This is a particular problem because of the difficulty in supplying mainly lignocellulosic feedstock to large plants, due to insufficient resource availability, distribution, density and logistics.

Costs

Several economic studies have been performed on biomass gasification regarding the feasibility and long-term prospects. The first demonstration projects are far too expensive to become profitable. Investment figures can be more than 5,000 €/kW electric, which is far more than competitive technologies. New biomass gasification technologies for gas engines (i.e. BIG/CC plants) are still in the demonstration phase and struggle for entrance into the market due to limited plant capacities, collection and transportation costs (especially when compared to centrally located energy plants). The production costs of (first of a kind) demonstration plants are usually 3 to 4 times higher than their conventional alternatives.

However, it is expected that due to the learning curve, the investment costs can be reduced to approximately 2,000 €/kW electric within the coming decade. Operational experience, success stories and value engineering is needed to achieve this goal.

Another aspect is the operational costs, in particularly the price of the feedstock. These can be expensive like short rotation coppice (SRC) or cheap (negative) waste residues. Transportation, fuel handling and processing adds to the cost of the feedstock. Furthermore, labour costs must be minimized through process control and automation. Practical experience is needed to determine the maintenance costs. Remuneration of electricity and heat can also be decisive in the overall economics.

For the short to medium term, biomass gasification cannot compete with fossil fuel produced power. Therefore, comparison must be made to alternative renewable energy sources. Studies showed that biomass gasification could compete with other RES when capital costs can be reduced and favourable conditions are created. Both conditions are likely to happen.

16. PYROLYSIS

Feedstock provision

While the intention of slow pyrolysis is to produce mainly charcoal, fast pyrolysis is meant to convert biomass to a maximum quantity of liquids (bio-oil). Both processes share the fact that the biomass feedstock is densified in order to reduce storage space and transport costs. A more stable and cleaner intermediate energy carrier is obtained, which is much more uniform and well defined. Fast pyrolysis of biomass is in the demonstration stage (in power production) and yet is expected to commercialise in the near term.

Feedstock resources

A large number of different feedstock can be processed in the pyrolysis process. The type of biomass/residue influences the pyrolysis oil yield and quality. Typically, woody biomass gives the highest yields. Before entering the reactor, the particles must be reduced to a size below 6 mm to allow rapid conversion, and its moisture content to below 10% in weight content to avoid too much water concentrating in the pyrolysis oil.

In Lebanon, the following feedstock resources could be used: Woody biomass and residues from fellings, olive trees, fruit trees and cereals. Suitable regions are North and Mount Lebanon.

Feedstock supply chain

A pyrolysis process typically consists of the steps shown in Figure 24.

Figure 24: Pyrolysis process steps

Some considerations when developing the feedstock supply chain:

- Production of feedstock: Woody biomass is preferred although other resources can be used as input as well. Issues to take into consideration are the economic performance of the feedstock with other competitive markets, sustainable forest management issues, policy and regulation constraints;
- Harvesting and collection: Improvement of methods of collection and harvesting, accessibility of the forest areas, harvesting window of the feedstock (to guarantee year-round supply);
- Storage: Development of storage capacity near feedstock resource
- Transport: Availability and quality of infrastructure, distance to pellet plant, transportation costs;
- Technology is still in development phase

Costs

When international bio-energy transport is considered, pyrolysis pre-treatment option seems attractive. The liquid product can either be stored or readily transported depending on the requirement. Due to its relatively high energy content and bulk density, it can be economically advantageous compared to pellet transport.

Studies over the years indicated that pyrolysis oils can be produced at costs in a range of €4 to €14/GJ (corresponding €65 to €225/t), with feedstock costing between €0 and €100/t (€0 to €6/GJ).

VIII DEMONSTRATION PROJECTS SUITABLE FOR LEBANON

Considering the current biomass resource potentials in Lebanon, the following demonstration projects would be suitable for a more in-depth analysis (i.e., a feasibility study).

1. Co-digestion of several waste/residues streams
2. CHP plant using olive oil cake
3. Combustion of different residues from fruit and/or olive trees
4. Biodiesel production from recycled oils and/or animal fat
5. Biofuel production from energy crops grown in unused land

Additionally and thinking of future technologies and developments, the following is an interesting option to keep in mind :

6. Biodiesel production from Salicornia. Salicornia grows on salty soils and environments. There are some initiatives going on in Egypt and the USA, however all are still at pilot plant level.

Detailed factsheets for the first three demonstration projects presented are shown in the volume "Annexes" of this study, chapter 2, annex II "Factsheets of the selected bioenergy technology conversion options for Lebanon".

Also a checklist for the evaluation of demonstration projects in Lebanon is presented in the volume "Annexes" chapter 2, annex III "Checklist for the evaluation of demonstration projects in Lebanon".

A list of risks and mitigation actions for the implementation of demonstration projects that can be developed in Lebanon is presented in the volume "Annexes" chapter 2, annex IV "Checklist for the evaluation of demonstration projects in Lebanon".

Incinerator plant

IX. CONCLUSIONS

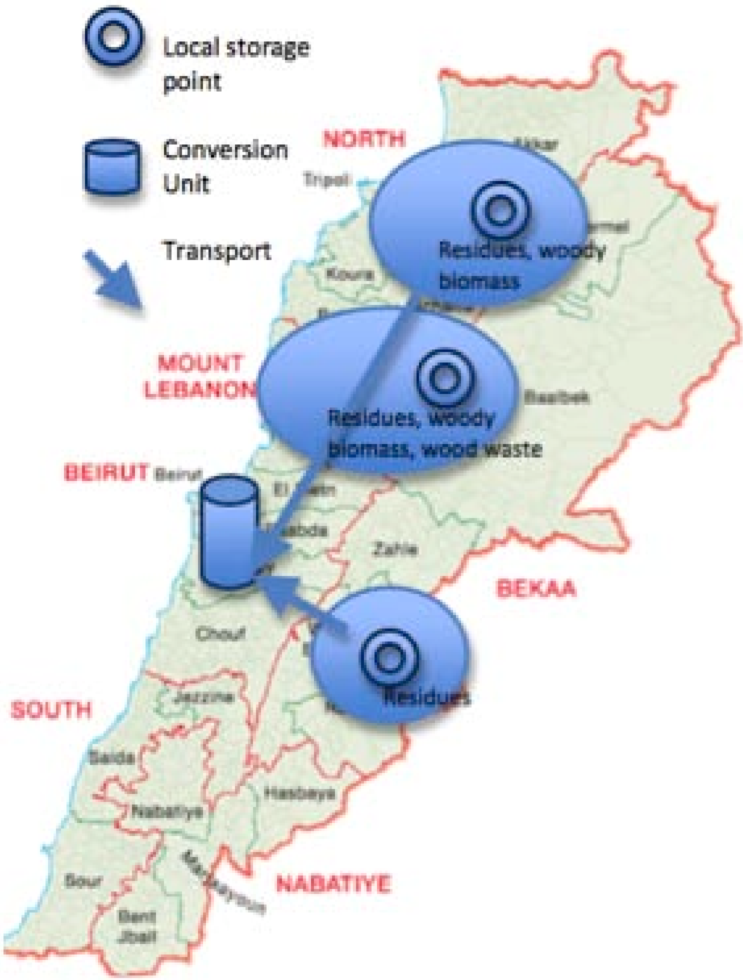
A variety of technology options exist for biomass that relies on several feedstock alternatives. These options can serve many different energy needs (power, heat and fuels), from large-scale industrial applications to small-scale rural end-uses. Best agricultural practices are recommended to improve efficiency and sustainability of the feedstock resource. Good agricultural practices may include "no tillage" practices, integrated pest management or organic agriculture and sustainable forest management. For all resources, the seasonal availability and the low energy density needs to be taken into consideration when further considering the logistics of the biomass supply chain. Various pre-processing steps can be used to reduce transportation costs and improve physical properties, e.g. the storability and the amount of energy contained per volume of biomass.

The most important conclusions from Chapter 2 are presented below:

- Many of the biomass streams with the highest potential for Lebanon can be converted into bioenergy through direct combustion of biomass. This technology is readily available, and may be succeeded by other technologies in the medium to long term if their costs can be reduced sufficiently. Combustion of waste and especially combustion of woody and agricultural residues from cereals, fruit or olive trees for power and heat production are relevant for the whole country. These feedstock resources are found in all regions, although they predominate in Beirut, North Lebanon, Mount Lebanon and the Beqaa.
- Biogas production from anaerobic digestion of sewage sludge and from slaughterhouse waste is interesting for Lebanon, especially for more densely populated cities of Beirut and Mount Lebanon and the Beqaa region, and due to the lack of alternative treatment technologies for these waste streams. More advanced technologies like gasification of biomass for the production of power and/or heat could be an interesting option for Beirut-Mount Lebanon, North Lebanon and the Beqaa region.
- Liquid fuel production technologies are mainly relevant for Lebanon in the case of waste oils, followed by energy crops. Exploiting food agricultural crops at a large scale for the production of biofuels embeds potentially several risks (such as food competition). In general, energy crops (especially lignocellulosic crops) may offer relatively less risks, still, careful analysis is required to avoid potential negative impacts. The mohafazats with larger potential to develop biofuels are North Lebanon, followed by the Beqaa region. Biodiesel production from yellow grease is a possibility in most populated cities of Lebanon, while more advanced technologies like Fischer-Tropsch biodiesel seem suitable in time for North Lebanon, Mount Lebanon and the Beqaa region.
- Production of bioethanol from energy lignocellulosic crops is the most relevant future technology for Lebanon.
- Pre-treatment technologies for bioenergy carriers are not relevant for Lebanon given the relative short transportation distances involved and the absence of the need to convert biomass into intermediary carriers.
- The supply chain for bioenergy production includes various steps: production, harvesting and collection, short distance transportation, storage, transportation to the conversion plant and conversion of the resource in the bioenergy carrier. Distribution of the bioenergy carrier is then required to supply the final consumer. One or more pre-processing steps (e.g. drying, grinding) may be needed.
- Waste and residues are to be collected. Waste is generally free or may even have a negative cost. The collection and short-term transportation of the residues to a storage point may increase the cost, which is dependent on various local factors such as the availability of infrastructure, collection methods or possible regulation constraints.
- Energy crops and woody biomass are harvested in the field and production costs depend on yield levels, input levels and the agricultural management system. Harvesting practices and physical constraints may also have an influence on the costs.
- Best agricultural practices are recommended to improve efficiency and sustainability of the feedstock resources. Good agricultural practices may include no tillage, integrated pest management or organic agriculture and sustainable forest management.
- For all resources, the seasonal availability and the low energy density needs to be taken into consideration when further considering the logistics of the biomass supply chain. Various pre-processing steps can be used to reduce transportation costs and to improve physical properties.

• The availability of biomass resource (considering competition of resources) over the year partially determines the scale of bioenergy conversion (and vice versa).
• Note that various feedstock resources can be merged or brought over larger transportation distances to increase the feedstock input capacity of a conversion plant. Generally, feedstock costs rise when transportation distances increase: a trade-off between volume, efficiency and distance determines the optimal plant size and location (see also Figure 25).

Figure 25: An example of combining various feedstock resources as input for large-scale conversion plant.



Furthermore, a combination of feedstock resources can be integrated over time to secure long-term feedstock supply and feedstock prices. A bioenergy plant can be built now, relying on currently available feedstocks, while establishing new energy plantations and feedstock collection systems, to make sure there is enough feedstock to keep up with the growth of the bioenergy industry in Lebanon.
• As new technologies and processes continue to develop, including second-generation options, they should be tracked and assessed by Lebanon, especially in conjunction with the potential that energy crops can provide for the country.
• The profitability and success of a bioenergy project (including the processing steps in the supply chain) is very much dependent on the local, regional and national circumstances. Detailed information and knowledge on the local situation, and possible risks, are needed when further developing a project.

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CHAPTER **3**

FUTURE SCENARIOS FOR BIOENERGY IN LEBANON

INTRODUCTION

The government of Lebanon has ambitious plans for the year 2020, aiming to have 12% of its total energy needs from renewable energy sources (RES) at that time. Table 102 below shows an increasing trend with respect to energy needs in Lebanon to 2030, which may be partly supplied by renewable sources.

Table 102: Projections of the energy demand for 2030 (NMPLT, 2005)

Year	Population	Need per capita (W/capita)	Safety margin (%)	Total need (MW)	Existing power plants capacity in 2002 (MW)	Necessary additional capacity (MW)
2002	4,080,000	430	31	2,300	2,300	0
2005	4,200,000	470	18	2,300	2,300	0
2010	4,400,000	545	10	2,600	1,700	900
2015	4,600,000	630	10	3,200	1,700	600
2020	4,800,000	700	10	3,700	1,700	500
2025	5,000,000	770	10	4,200	1,700	500
2030	5,200,000	800	10	4,600	1,700	500

The scenarios, as developed here, are to explore various bioenergy perspectives over time contributing to this target, including options of technology and feedstock resource combinations.

The present characteristics of the existing economic and energy systems in Lebanon are static in the next five to ten years and leave limited room for change in that time period. However for longer periods, the future certainly can or will be different; this future will develop - to a certain extent - according to determined actions taken over time. For this reason, we will look to the future beyond the simple assumption that present trends will just continue tomorrow, especially in the development and deployment of renewable energies in Lebanon, as they are still in the early stages. It has to be taken into consideration that some future actions may have a large potential impact on the success or failure of Lebanon's national bioenergy strategy and may take different or unexpected paths.

Usually the future is explored through scenarios. A scenario approach will provide logic in describing the future potential for bioenergy in Lebanon and the level of fulfilment to the desired 12% renewable energy target in 2020. It provides insights with respect to the accelerating or slowing effects that development may likely have on the level of deployment of bioenergy in Lebanon.

A look into possible futures can also expose unintended risks and opportunities in the future and technological and legal and financial barriers to bioenergy market deployment.

These findings are extremely useful to allow time to respond to changing policies, behaviours and aspirations and to give recommendations on what plan of action will maximize the chance of success of Lebanon's national bioenergy strategy in possible different futures.

II.METHODOLOGY

Scenarios are useful tools to explore an imaginable possible future situation placed in a defined time set. They are, in simple terms, guesses about what may happen in the future. This is partly based on past experiences and on the current situation, but also and most importantly, on an understanding of the main elements of uncertainty that determines the future. The methodology used in this study for the development of scenarios is the one used for the realisation of the "Millennium goals Energy Scenarios" (2006) produced for the "Millennium Project"[1] and also used by the International Energy Agency (IEA) in their study "ENERGY TO 2050: Scenarios for a Sustainable Future" (2003). An example of the use of this methodology for bioenergy scenarios is the project "Study on the implementation of renewable energy in the Basque Country: Scenarios for the development of RE"[2] which explores different options of bioenergy deployment.

II.1 KEY ELEMENTS IN THE DEVELOPMENT OF SCENARIOS

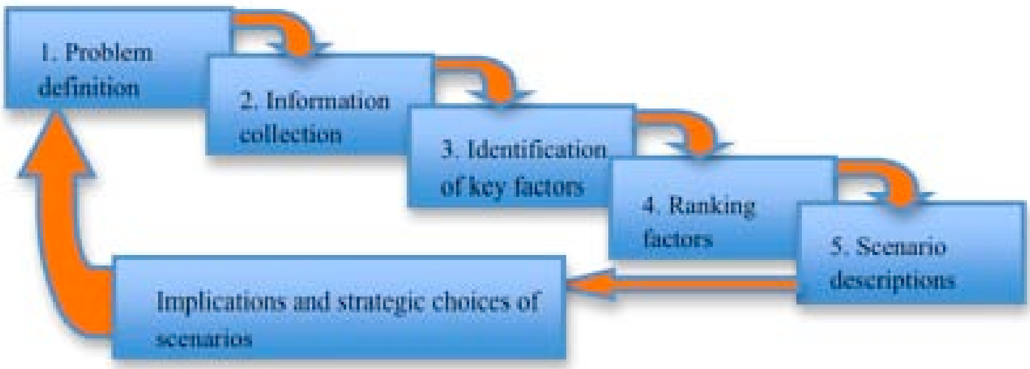
A key requirement for scenario building is that they must be internally consistent, logical and plausible to reflect best how different futures can be developed over time. Furthermore, scenario building needs to take into account the various political, economic, technical and environmental dimensions that have an impact on the same problem. The scenarios need to integrate long-term trends (including demographic or technological trends or long-term changes in ecosystems) with short-term trends (such as price inflation or changes in oil prices). Additionally, the scenarios must take into account possible deviations from this trend. The scenarios should also possess the ability to challenge the mind-sets of those responsible for designing the strategy of bioenergy development in Lebanon in the future.

Figure 26: Five processing steps for scenario building

The scenario building process is therefore a complex analytical exercise and contains at least five steps, which are described below (see Figure 26).

1.Define the problem and define its boundaries, or isolate the decision that needs to be taken;

Figure 26: Five processing steps for scenario building



2.Collecting information, expert opinions and historical data on the system under investigation and build a coherent system that includes all stakeholders and relevant actors, including the factors and links between them;

3.Identify the key factors that affect decisions and changes and separate the predetermined factors from the factors that have a high uncertainty;

4.Rank these factors according to their impact on the problem (defined in step 1) or by their uncertainty and identify the 2 or 3 factors that are the most important and most uncertain. These represent the main axes along which the scenarios will vary and will be characterized;

5.Describe in detail the scenarios in the form of storylines. The two or three factors that are most uncertain will be linked to the main axes along which the scenarios will vary, as shown in Figure 27. The next logical step is to examine the implications of various scenarios on bioenergy development and deployment in Lebanon and translate them into clear strategic choices.

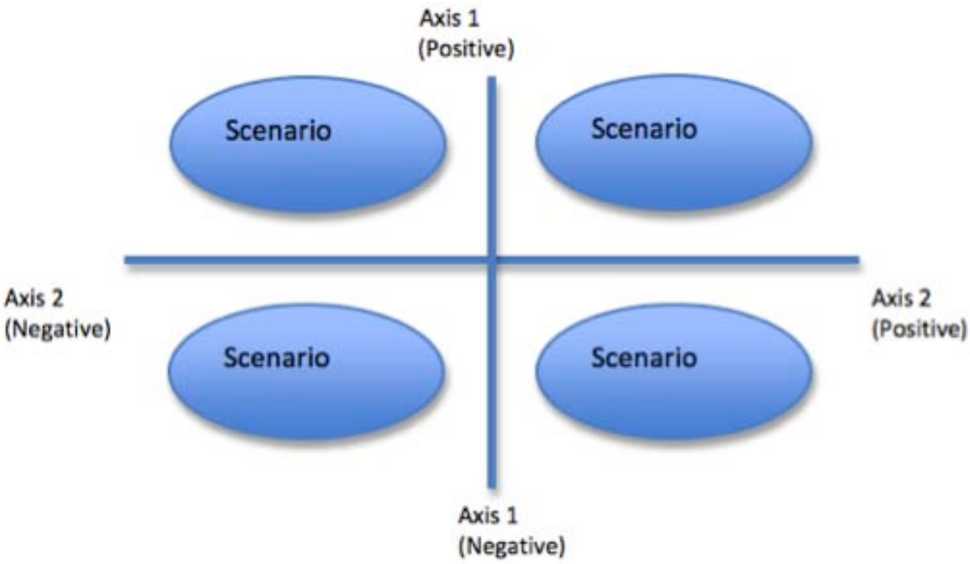
II.2 SCENARIOS AND PREDICTIONS FOR BIOENERGY DEVELOPMENT

The kind of scenario we are most familiar with is the ba-

[1] This project was commissioned by the General Secretariat of the United Nations and Supported by UNEP

[2] SQ Consult, "Desarrollo de las energias renovables en la Comunidad Autonoma del Pais Vasco", CES VASCO, 2011

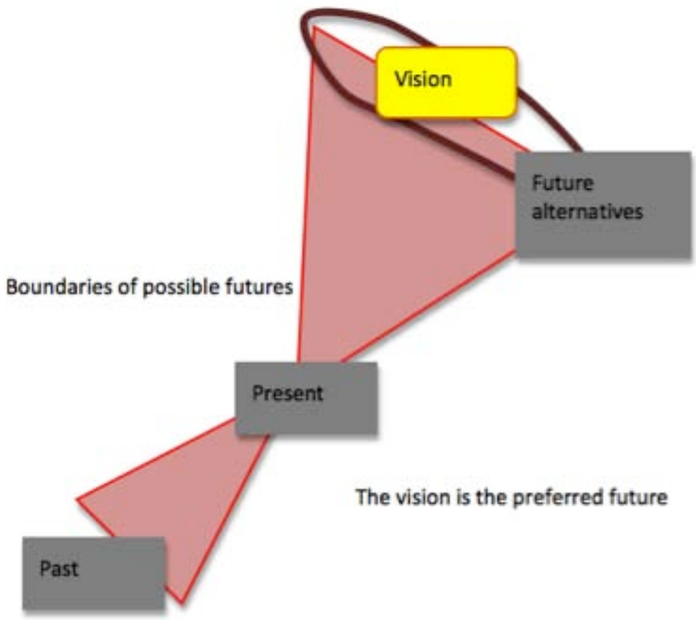
Figure 27: Example of building of scenarios along two axes with most uncertainty



seline or reference scenario or the forecast prediction. This scenario type assumes a continuation of an historical trend towards the future; the structure of the system remains unchanged or responds in predetermined ways. This type of scenario is usually referred to as the "business as usual (BAU)" scenario or predictions. This type of scenario is often considered to be of high probability and focuses exclusively on those assumptions involving a low level of uncertainty. BAU scenarios or predictions are useful when looking on short-term horizons as no drastic, unexpected changes can be expected in this short time frame.

Over a longer time frame, the factors that determine an energy system and its environment (including technological development, openness to markets, social and environmental values) become, however, considerably less predictable. It is precisely these critical issues that may become more relevant in the long term. The scenarios on bioenergy development in Lebanon will be analysed for a longer time period to 2030 (2015, 2020 and 2030). When projecting scenarios over longer time horizons (to 2030), BAU scenarios may become extremely unlikely. In this situation, the use of “development scenarios” are more useful to explore, and therefore integrate radical departures from

Figure 28: The cone of possibilities for the future



the trends, system breakdowns, technological breakthroughs, and major changes in consumer patterns or unexpected regulatory and institutional changes.

The future is uncertain and can go to various directions. The development scenario approach will therefore be useful to handle these uncertainties and to think about their chances in such way that allows conceptualizing the structure and description of the future.

There are clearly possible futures, probable ones and preferable ones. The range of alternative futures is bounded by their limits of possibility (Figure 28). While you cannot control the future, it can be influenced by acting proactively and by designing a strategy for bioenergy development in Lebanon on the longer term.

The most important differences between development scenarios and predictions are presented in Table 103.

Table 103: Most important differences between development scenarios and predictions

Scenarios	Predictions
Conceptual description of plausible futures	Statistical summary and prognosis of expert opinion
Focus on uncertainties	Focus on certainties
Goes from a qualitative analysis (story line) to a quantitative analysis	Makes a qualitative analysis, based on a qualitative prediction
Transforms complexity to simplicity by describing the future	Tries to explain the complexity of the future by a single analysis
Assumes that the future cannot be predicted or considers it as irresponsible to do so	Assumes that the future can be predicted in detail
Approach to clarify and analyse risks	A more static approach that hides risks
Rich in information but poor experience in summaries	Efficient but poor experience in expertise
Promotes flexibility in actions and gives answers to complex questions	Promotes inertia and comfort
The various scenarios together emphasize the uncertainties by creating a range of futures	Describes the most likely result

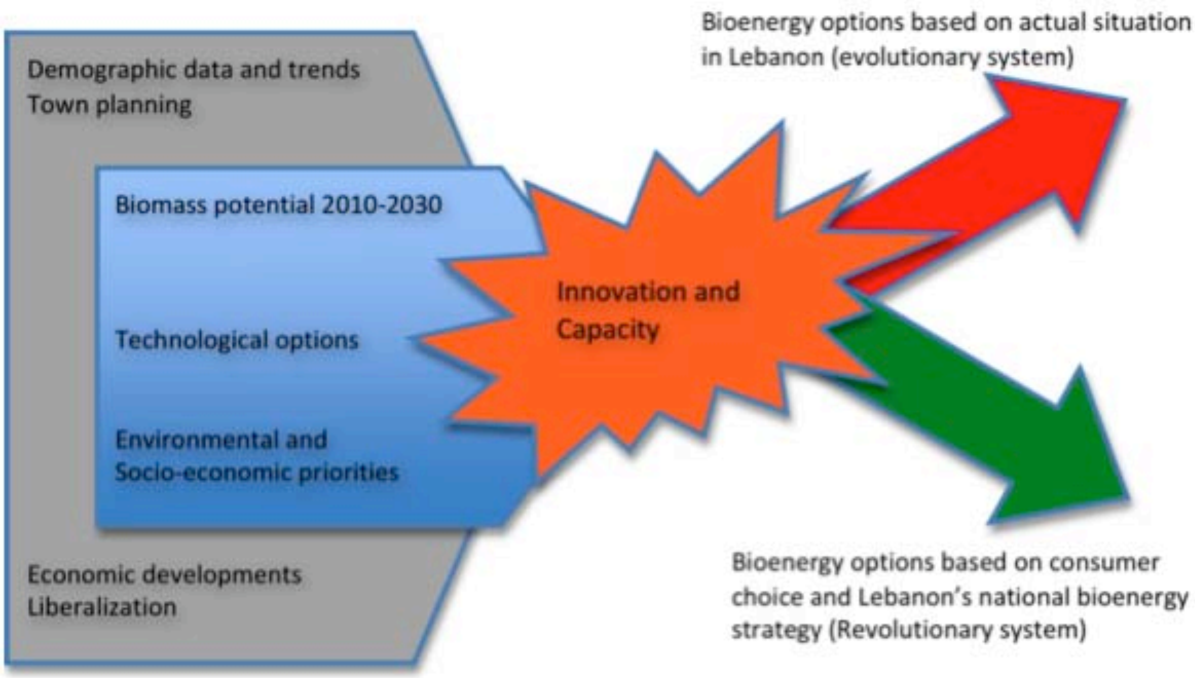
II.3 VISION ON BIOENERGY DEVELOPMENT IN LEBANON

Analysing the intersection of bioenergy development and the problem of growing energy needs, fuel dependency and climate change mitigation requires the adoption of long-term prospects. Energy infrastructure takes time to build; new technologies take time to develop and to penetrate the market. It is for these reasons that an analysis aimed at energy and environmental problems will look at a horizon of around 20 years (from 2015, to 2020 and to 2030), 10 years after the 12% renewable energy target or pledge maturity date.

The proposed scenarios will methodologically integrate the various variables identified in the three phases of the project (chapter 1 on resource potential, chapter 2 on technology development and chapter 4 on sustainability impacts). The relevant variables (e.g. environmental policies) will be integrated in the scenario story lines so as to bring out their interaction and, eventually, their overall influence on the objectives to which the scenarios can aspire to contribute to bioenergy development and deployment by 2015, 2020 and 2030 (Figure 29); thereby giving coherence to the recommendations that may arise for the development of each bioenergy chain.

Under the current early development stage of bioenergy in Lebanon, coupled with the still relatively unexplored field of legislation and support mechanisms, we can consider two different visions;

Figure 29: Two different visions on bioenergy development in Lebanon



1.The current trends continue: This vision is based on a linear evolutionary system from the present, where the approach to the definition of energy options is to provide power to Lebanon's citizens, without differentiating in preferences between the existing fossil fuel energy options and renewable energy resource options, and without taking into account the capabilities of industry or of different groups of developing various businesses around renewable energy.

2.The spirit of a new industry in Lebanon: This vision is based on revolutionary development of bioenergy. The approach to the definition of energy options is oriented to the consumer preferences. In this vision, the development of various businesses are enhanced and promoted around bioenergy through Lebanon's national strategy. There will be increased competitiveness on the longer term, which will decrease the level of support through incentive mechanisms significantly. In this view, the client selects his/her own energy option. For example, consumer groups set their own energy supply companies via the creation of local biomass supply.

II.4 DEVELOPMENT OF SCENARIO AXES WITH HIGH UNCERTAINTY

Factors that have a greater uncertainty in Lebanon for the development of bioenergy over time are those related to the attained level of development and economic welfare (including environmental and social well-being) in Lebanon in the coming decades and to the political developments; the attained level of security in Lebanon (including drug issues and unrest between groups) and in the surrounding region and level of investment support. This includes the regulatory developments. We therefore propose that the scenarios are built along the following two axes:

- The political axis: The political and regulatory framework as developed in Lebanon, which will define the future balance between economic profits versus the socio-economic and environmental dimension;
- The economic axis: Differentiates between a globally-oriented economy versus a regional orientation. The characteristics of a world towards regional orientation are limiting trade between countries and regions, while trade operates more optimally in a globally-orientated world, which is also reflected in technological development.

Along the above two axes, the below classification for the scenarios are followed;

- Low development: It is anticipated that the set of determinants follows a slow, ad-hoc change to bioenergy development and deployment, without facing decisive action to accelerate changes;
- Medium development: The combination of favourable

technical and economic circumstances would create a suitable legal, economic and political environment for bioenergy development and deployment in Lebanon without radical changes.

- High development: A positive combination of factors clearly creates favourable conditions to enable optimal development of bioenergy in Lebanon.

Factors that are considered predetermined over time (or having a low uncertainty) and which therefore remain constant across all proposed scenarios are displayed in the list below. The building of scenarios takes these parameters as premises and they define, together with the political and economic trends under the scenarios, the development of bioenergy in Lebanon.

List of predefined parameters

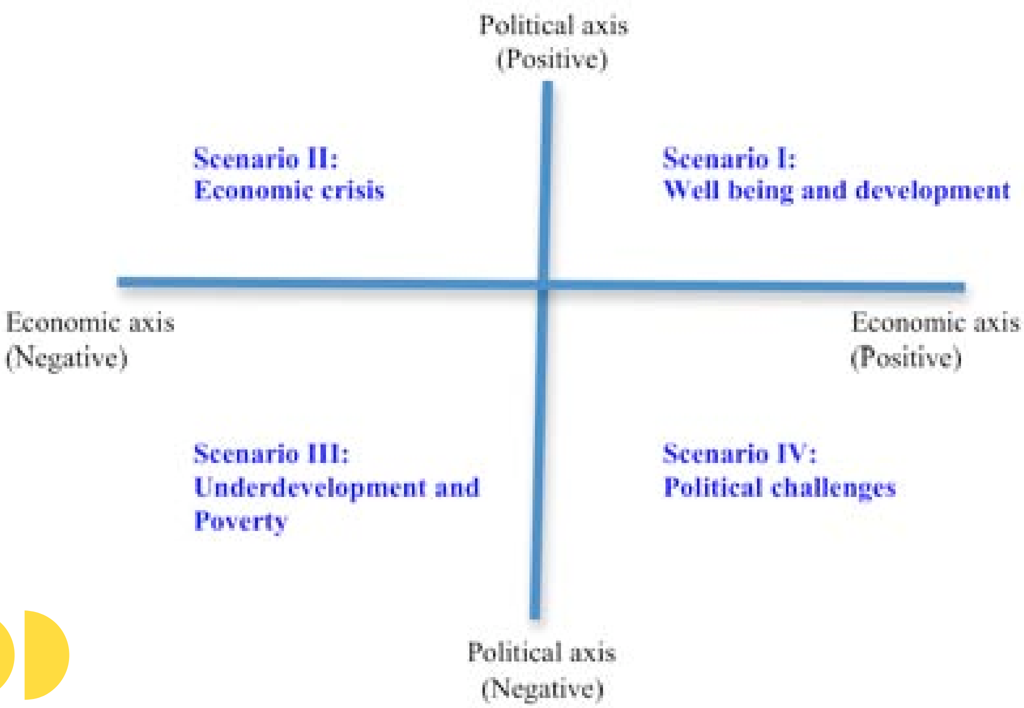
1. Population growth in Lebanon
2. Land use in Lebanon
3. Technological developments in the world; even though realised deployment of bioenergy technologies may differ from country to country, it is assumed that the level of state-of-the-art technologies, especially for non-commercialized bioenergy technologies, is predefined for all scenarios.
4. Economic developments in the world and in the MENA region
5. Energy demand over time in Lebanon
6. Global expected technological and non-technological barriers; some technological and non-technological barriers are predefined for all scenarios (see also chapter 2), such as the limited level of commercialization of algae technologies.

II.5 PROPOSED BIOENERGY SCENARIOS FOR LEBANON

By 2030, the world may have changed in ways that are difficult to imagine at present. The combination of political and economic axes, varied from a low to a high level of development, produces four different scenarios, each with its own characteristics and resulting futures. The four divergent scenarios describe a range of characteristics of the future, such as demographic change, economic developments and technological changes combined with factors of larger uncertainty (political and economic), which together form the driving forces for future bioenergy development and deployment in Lebanon. The feasibility of each scenario should be considered as likely futures of bioenergy in Lebanon to 2030, with political and economic realities that may be feasible in the medium and long terms.

These four scenarios are depicted in Figure 30.

Figure 30: Outline of bioenergy scenarios in Lebanon with axes of high uncertainty



III.DEVELOPMENT OF PROPOSED SCENARIOS

III.1 PREDEFINED FACTORS

As was mentioned in the previous chapter, the following list of factors is considered as either predefined or with a low uncertainty evolution in the proposed scenarios:

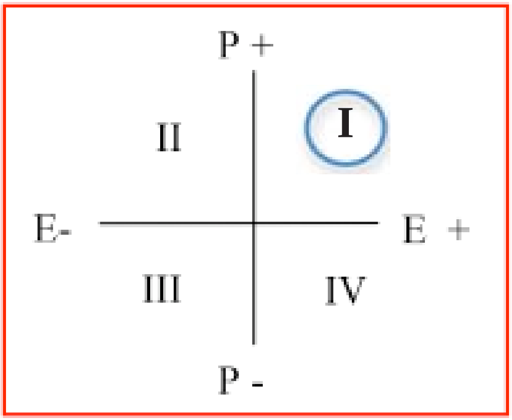
- Population growth in Lebanon
- Potential available land area for bioenergy production in Lebanon
- Technological developments in the world
- Global economic developments and in the MENA region
- Energy demand over time in Lebanon
- Global expected technological and non-technological barriers[3].

A full description of these predefined factors is presented in the volume "Annexes" of this Study, chapter 3, annex I "Predefined factors for the scenarios development".

IV.DETAILED ELABORATION OF PROPOSED SCENARIOS

IV.1 SCENARIO I – WELL BEING AND DEVELOPMENT

General description
Political axis (+)
Economic axis (+)
Story line



Scenario I describes a convergent world with a global population that peaks mid-century and declines thereafter, but with rapid changes in economic structures toward a service and information sharing economy. There are significant reductions in material intensity by the introduction of clean and efficient use of resources. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equities. This is the scenario of major economic and social changes. Decentralized solutions are standardized in the world and achieve high efficiencies. Technological cooperation, industrial and economic cooperation between regions is more than optimal.

In this scenario, Lebanon succeeds in increasing its competitiveness in products of international concurrence (imported or exported goods) in a short period of time. The establishment of long term peace in the country and in the region greatly strengthens investors' confidence, encouraging establishment of enterprises. The private sector is promoting and developing bioenergy in Lebanon. It occupies a majority stake in the renewable energy mix in Lebanon in 2030. Awareness about sustainability and Lebanon's environmental resources increases strongly and is reflected in policies. The "balanced development" concept is applied in Lebanon so that interventions would not have negative impacts on the goal of unity of the country. This concept favours the establishment of national public facilities to enhance integration between different regions, and increase intermingling between all Lebanese.

From this vision, the government tackles the growing of illicit crops in the country by providing alternatives.
This scenario postulates that results from development aid projects are achieved as expected and planned for, with particular focus in this case on environment and energy projects, agricultural projects, and on the social and deve-

[3] Global expected technological and non-technological barriers; some technological and non-technological barriers are predefined for all scenarios (see also Chapter 2), such as the limited level of commercialization of algae technologies.

lopment programs and projects. This, combined with increased economic growth and welfare, increases the possibilities of the Lebanese population to deal with international food crises (including food price hikes) more than the case under the current situation.

KEY TRENDS: Peace in the country and in the region in a strong growing economy
Bioenergy development is promoted
Strict sustainability levels and policies are considered for bioenergy development

Specific characteristics of this scenario:

Economy	The Lebanese and world economic situations are good; there is private investment capital to promote bioenergy deployment in Lebanon.
	GDP per capita increases strongly in Lebanon from now to 2030 marked with an annual growth of 3.5 % from 2008 to 2030 (see NMPLT, 2005). This allows future generations to benefit from a considerably better standard of living.
	The business environment is improved through the strengthening/optimization of the regulatory framework, particularly on the level of protection of the investor. Lebanon, currently ranked at 11, goes higher among members of the League of Arab States on the Ease of Doing Business scale and encourages Foreign Direct Investments (FDI).
	Competitive sectors are able to achieve a balance in foreign trade, where the relative shares of "other market services", like industry and agriculture, increase significantly in comparison to the present situation.
Trade	Lebanon succeeds in increasing its international competitiveness.
	Lebanon heads towards a concentration of agricultural production: notable increase in fruits and vegetables production, dairy production and poultry production and a decrease in cereals and meat production.
	There is increased cooperation in trade in the MENA region, which results in efficient, regional solutions to promote the renewable energy sector in the region.
Technological developments	Technological developments in Lebanon reach international levels; state of the art bioenergy technologies are deployed in Lebanon.
	Agricultural developments in Lebanon result into yield improvements (1.5% per year) for agricultural crops through improved agricultural practices and management techniques.
	Collection of residue streams is fully structured and replacement solutions are found for residue streams when used for bioenergy.
	Efficiency in livestock production is attained through establishment of closed facilities and centralization of (waste) processing facilities.
	Local development plans are implemented and aim at maximizing use of resources and residues through efforts to improve Lebanon's industry and agriculture value chains.
	Connection rates to wastewater grids are improved.
Environment and land use	Strict sustainability levels are considered for bioenergy deployment (see Chapter 4).
	There is increased level of urbanization; part of the currently abandoned agricultural land is used for infrastructure and buildings.
	The remaining abandoned agricultural land (75% of 53,137 ha) is used for energy crop production
	Afforestation and reforestation activities occurring mostly in communal and private lands, and residues management efforts undertaken by local communities in forests are improved and exploited legally for bioenergy production; 50% is deployed based on a high energy content for wood (5.0 MWh/t).
	Residues are deployed for 50%, when developed in Lebanon, based on a high energy content.
	25% of the grassland areas (317,601 ha in total), excluding biodiversity areas and avoiding competition, are used for energy crop production.
	50% of the former Cannabis plantations (20,000 ha) are used for energy crop production.
	The selection of energy crops follows the potential assessment: Jatropha (Beqaa), Sunflower (North Lebanon, Mount Lebanon after 2020), Giant Reed (Nabatiyeh, South Lebanon after 2020). The selected cereal energy crop is wheat.

Policies and regulations	There is political stability in the country and in the region.
	The Lebanese government gradually restructures and increases existing tariffs to eliminate the financial deficit in the electricity sector, improve collection rates and establishes a balanced budget.
	Part of the budget will be used to decrease, as first priority, Lebanon's deficits in power and, secondly, Lebanon's deficits in diesel.
	Privatization of various public sectors helps to rationalize expenses in the given sectors (electricity, water, etc.) by investments complementary to those of the public sector.
	A Law is adopted for the new power plants with all possible technologies and encourages all forms of Public Private Partnership.
	Innovative financial mechanisms are put in place encouraging private sector participation.
	The National Energy Efficiency and Renewable Energy Account (NEEREA) is set up as planned in the policy paper for the Electricity sector (June 2010).
	The private sector explores the possibility of algae production for bioenergy in Lebanon and, to some extent, of 2^{nd} generation ethanol production.
	A forest management plan and additional legislative changes are developed that consider harvesting in sustainable conditions; this makes woody biomass resources for energy to become available.
	Burning of (cereal) residues on the field is no longer allowed.
	Standards for industrial wastewater discharges are enforced.
	The development of solid wastewater treatment plans makes organic waste more available for bioenergy production and national master plans favor the valorization of sludge.
	Energy recovery is promoted, waste to energy technologies are endorsed and implemented at a National scale for large urban centers.
	Energy recovery is promoted for larger sewage plants.
	Levels of deployment of waste streams for bioenergy production, when developed, are targeted at 75% in 2020 to 100% in 2030.
	Less developed regions gain support to improve security and economic welfare.
	Government aims to tackle the growing of illicit crops by providing alternatives as energy crop production.

Table 104 describes the relevance of all possible combinations biomass resource – technology conversion that could occur in scenario I. It also establishes the relevance of each biomass stream for the different mofahazats in Lebanon.

Table 105 shows the possible contribution of all bioenergy streams to the production of bioenergy in each mohafazat for the short term future and until year 2030.

Table 106 presents the annual contribution of bioenergy to end uses. In scenario I, the envisaged contribution to transport from biofuels in this scenario is 271 ktoe, which is about 18% of the total fossil fuels imported for transport use (when compared to IEA information on final uses for Lebanon[4]). Also in this scenario the production of electricity could reach 8.3% of the total current electricity consumed by the country, with a total capacity of 119 M. We installed in small size plants using different technologies. Waste-to-Energy plants have the largest contribution in this scenario producing 301 GWh of electricity annually from the biodegradable fraction of MSW (2.8% of current electricity consumption). The total installed capacity assigned exclusively to the biomass fraction of MSW would 38 MW. However waste-to-energy plants may also take, as feedstock, the non-biomass fraction of MSW; in this case, the electricity generated could reach 550 GWh or 70 MWe of installed capacity. This scenario considers a progressive use of more sustainable sources of heat by the industry. Heat produced by most bioenergy technologies can be used by the food industry, chemicals, pharmaceuticals and other industrial processes.

Banana Plantation in South of Lebanon.

[4]http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=LB

Table 104: Relevance of combination resource-technology for bioenergy production in scenario I

Legend: ■ Combination resource-techonology not possible / plausible ■ Full potential ■ Established after 2020 ■ Not developed

Geographical regions						SCENARIO I		Liquid Fuel production				Biogas production					Direct combustion				Promising technologies			
South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	Strong economy, open markets, high environmental consciousness, political stability		Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centred in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible	Forestry	Woody biomass and Fellings	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible		Residues from fellings	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential	Wood and paper industries	Wood residues from wood	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Not developed	Not developed	Not developed	Not developed	Not developed	Not developed		By-products from paper industry	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	Not developed	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible	Agriculture	Residues of olive trees	Not possible	Not possible	Not possible	Not developed	Not developed	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible		Residues of fruit trees	Not possible	Not possible	Not possible	Not developed	Not developed	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible		Residues of Cereals	Not possible	Not possible	Not possible	Not developed	Not developed	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible		Manure	Not possible	Not possible	Not possible	Not possible	Full potential	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Not developed	Not developed	Not developed	Not developed	Not developed	Not possible	Available land for energy crop production	Cereal crops	Not possible	Not developed	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Not possible		Oil seed crops	Full potential	Not possible	Not possible	After 2020	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
After 2020	After 2020	After 2020	After 2020	After 2020	Not possible		Lignocellulosic energy crops	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	After 2020	Not developed	Not developed	Not possible	Not possible	After 2020	Not possible
Not developed	Not developed	Not developed	Not developed	Not developed	Not developed		Salicornia	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible
After 2020	After 2020	After 2020	After 2020	After 2020	After 2020		Algae	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	After 2020	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential	Food processing industry	Animal fat	Not possible	Not possible	Full potential	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Slaughterhouse residues	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Full potential	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Not developed	Not developed	Not possible	Not developed	Not developed	Not possible		Olive cake by-products	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Org. residues & Waste food	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Wastewater& sludge food	Not possible	Not possible	Not possible	Not possible	Not possible	Full potential	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential	MSW and non-hazardous industrial waste	Biodegradable fraction of MSW	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Full potential	Not developed	Not developed	Not developed	Not possible	Not possible	Not possible	After 2020
Not possible	Not possible	Not possible	Full potential	Full potential	Not possible		Landfill potential	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Full potential	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Industrial and commercial waste	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not developed	Full potential	Not developed	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Waste wood	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	After 2020	Full potential	Not developed	Not possible	Not possible	Not possible	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Municipal sewage sludge	Not possible	Not possible	Not possible	Not possible	Not possible	Full potential	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible
Not possible	Not possible	Not possible	Not possible	Not developed	Not developed		Landscape management residues	Not possible	Not possible	Not possible	Not developed	Not possible	Not possible	Not possible	Not possible	Not developed	Not possible	Not developed	Not developed	Not developed	Not possible	Not possible	Not developed	Not possible
Full potential	Full potential	Full potential	Full potential	Full potential	Full potential		Yellow grease	Not possible	Not possible	Full potential	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible	Not possible

** Pretreatment bioenergy options are not included as Task 2 concluded that this was not a promising technology for Lebanon*

** Used land areas: Abandoned agricultural land and former Cannabis plantations

*** Yield increases over time for agriculture and livestock production in country

Table 105: Biomass resource that could be developed for bioenergy production per mohafazat in Scenario I in GWh/year of primary energy

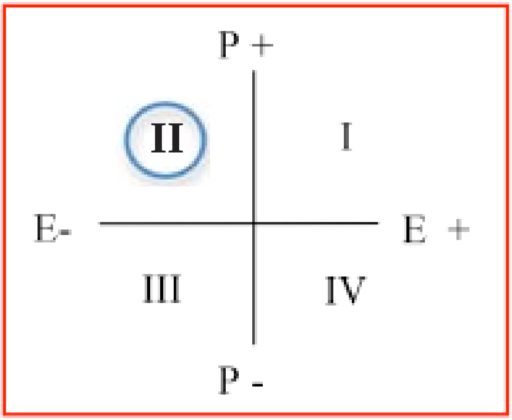
Resources		Short term						2020						2030					
		South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut
Forestry	Woody biomass and Fellings	35	27	37	153	97	0	35	27	37	153	97	0	35	27	37	153	97	0
	Residues from fellings	32	25	43	108	91	0	32	25	43	108	91	0	32	25	43	108	91	0
Wood and paper industries	Wood residues from wood industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	By-products from paper industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriculture	Residues of olive trees	27	35	8	19	46	0	27	35	8	19	46	0	27	35	8	19	46	0
	Residues of fruit trees	68	10	120	68	108	0	68	10	120	68	108	0	68	10	120	68	108	0
	Residues of Cereals	29	45	208	2	88	0	33	52	239	3	101	0	37	59	270	3	114	0
	Manure	0	0	0	0	0	0	1	1	2	6	3	3	1	1	2	6	3	3
Available land for energy crop production	Cereal crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oil seed crops	0	0	550	0	171	0	0	0	550	192	171	0	0	0	550	192	171	0
	Lignocellulosic energy crops	0	0	0	0	0	0	638	1477	0	0	0	0	638	1477	0	0	0	0
	Salicornia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Food processing industry	Animal fat	14	3	0	0	0	0	14	3	0	0	0	0	19	5	0	0	0	0
	Slaughterhouse residues	16	4	0	0	0	0	16	4	0	0	0	0	21	5	0	0	0	0
	Olive cake by-products	20	46	5	49	68	0	20	46	5	49	68	0	27	62	7	65	91	0
	Org. residues & Waste food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wastewater& sludge food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSW and non-hazardous industrial waste	Biodegradable fraction of MSW	15	17	22	78	34	44	18	22	28	99	43	55	30	35	45	159	70	90
	Landfill potential	0	0	0	143	19	0	0	0	0	143	19	0	0	0	0	143	19	0
	Industrial and commercial waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Waste wood	14	16	20	36	16	20	14	16	20	36	16	20	18	21	27	48	21	27
	Municipal sewage sludge	10	0	17	10	18	39	13	0	21	13	23	50	23	0	37	23	40	87
	Landscape management residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Yellow grease	7	9	11	39	17	22	7	9	11	39	17	22	10	11	15	52	23	29
	Totals	286	237	1042	704	773	125	936	1727	1065	927	803	151	985	1773	1161	103 9	893	236

Table 106: Annual contribution to final energy in 2030 (Scenario I)

	Liquid Fuel production				Biogas production					Direct combustion				Promising technologies				
Energy use	Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centered in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW	Total
Primary energy (GWh)	456	0	160	456	22	210	26	162	0	428	1027	1027	0	0	0	2114	214	**6305**
Final energy																		
Capacity factor					85%	90%	80%	85%	90%	90%	90%	90%	90%					
Electricity (GWh)					8	73	9	57	0	150	359		126					**782**
Electricity (MWe)					1	9	1	8	0	19	46		16					**100**
Heat (ktoe)					1	6	1	5	0	13	31	62	0					**118**
Heat (MWt)					1	11	1	9	0	22	52	104	0					**200**
Transport (ktoe)	34	0	12	34										0	0	159	16	**255**

IV.2 SCENARIO II - ECONOMIC CRISIS

General description
Political axis (+)
Economic axis (-)



Story line

This scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. There is no transfer of experience between world regions and, due to the prolonged economic crisis, countries in the MENA region have become protectionist and renewable energy solutions have limited priority. In this scenario, the world presents a constant increase in global population, but at a slower rate than in scenario III. Technological development and changes are less rapid, however a larger number of small and medium size local projects are implemented based on several already commercial technologies compared to scenario IV, and economic development is intermediate. Although this scenario is aimed at environmental protection and social development, countries are focused on local and regional levels, which represent an additional economic cost and barriers for the technological and non-technological development of bioenergy.

Lebanon's income decreases because there is not enough exports due to the prolonged international recession. Lebanon becomes economically more vulnerable to international food crises (including international fluctuations of food prices).

In this scenario, the Lebanese government is the main initiator for development and deployment of bioenergy in Lebanon with limited support from the private sector. However, deficits are increasing and the government's ability for funding is limited. Still, consciousness about social developments, sustainability and Lebanon's environment increases over time. This is reflected in policies, focusing on resources within the region that require limited investment capacity. From this vision, the government also tackles the cultivation of illicit crops in the country by providing viable alternatives. Apart from incidental unrest, there is peace in and around the country.

KEY TRENDS: Peace in the country and in the region, apart from incidental unrest.

Economic growth in Lebanon is low, limiting the possibilities for bioenergy development

Minimum sustainability levels are considered for bioenergy development.

Specific characteristics of this scenario:

Economy	There is a worldwide economic slow-down, limiting the capacity of the private sector to invest in the deployment of bioenergy in Lebanon.
	GDP per capita remains medium to low; an annual average growth of maximum 2% is assumed (NMPLT, 2005) in Lebanon and the standards of living remains the same or even deteriorates; Lebanon becomes economically more vulnerable for international food crises and international fluctuations of food prices.
	Financial deficits of the government (and specifically in the energy sector) remain significant, partly due to increased prices of imported energy sources from other countries and partly due to a dysfunctional electricity sector (operating status of power plants, technical and commercial losses in transmission and distribution, tariff structure, deteriorating financial, administrative, diminishing technical and human resources of EDL).
Trade	Trade remains limited within countries and intra-regional trade cooperation becomes restricted; there is a focus on local solutions, also when developing renewable energy sources in the region, which limits efficiency.
Technological developments	Developments for a selection of commercialized bioenergy conversion technologies that have a priority at governmental level, reach international state-of-the-art levels. Bioenergy conversion technologies that are not commercialized are not deployed (yet).
	Government promotes the centralization of (waste) processing facilities.
	Collection of residue streams for bioenergy becomes fully structured.
	Agricultural developments in Lebanon result in yield improvements (1% per year) for agricultural crops.
Environment and land use	A minimum level of sustainability for bioenergy deployment is secured.
	There is a limited increase of urbanization (10%); part of the abandoned agricultural land is used for infrastructure and buildings.
	50% of the abandoned agricultural land (53,137 ha) is made accessible and used for energy crop production.
	50% of the forest areas are exploited legally for bioenergy production through the implementation of Forest Management plans and woodland conservation and restoration initiatives; based on a low energy content for wood (3.9 MWh/t).
	Residues are deployed for 50%, when developed in Lebanon, based on a low energy content.
	No investments are made to convert suitable grassland areas to bioenergy production.
	25% of the former Cannabis plantations (20,000 ha) are used for energy crop production.
	The selection of energy crops follows the potential assessment: Jatropha (Beqaa), Sunflower (North Lebanon, Mount Lebanon after 2020), Giant Reed (Nabatiyeh, South Lebanon after 2020). The selected cereal energy crop is wheat.
Policies and regulations	There is political stability in the region apart from incidental unrest in Lebanon.
	The policy gradually restructures and increases the existing tariffs, according to citizen's economic possibilities to eliminate the financial deficit in the electricity sector and establish a balanced budget.
	A limited budget is used to decrease Lebanon's import dependency on energy resources and deficits on power and diesel; renewable energy is one of the instruments to achieve this.
	A forest management program and additional legislative changes are developed that consider harvesting in sustainable conditions; this makes woody biomass resources for energy to become available.
	Burning of (cereal) residues on the field is no longer allowed.
	Standards for industrial wastewater discharges are developed after 2020 as included in the Municipal Wastewater master plans.
	The development of solid wastewater treatment plants makes organic waste more available for bioenergy production after 2020.
	Energy recovery is promoted and waste to energy technologies are endorsed and implemented at a National scale for large urban centres.
	Energy recovery is promoted for larger sewage plants.
	Levels of deployment of waste streams for bioenergy production, when developed, are targeted at 75%.
	Government aims to tackle the growing of illicit crops by providing alternatives as energy crop production.

Table 107 describes the relevance of all possible combinations biomass resource – technology conversion that could occur in scenario II. It also establishes the relevance of each biomass stream for the different mofahazats in Lebanon.
Table 108: shows the possible contribution of all bioenergy streams to the production of bioenergy in each mohafazat for the short term future and until year 2030.
Table 109 presents the annual contribution of bioenergy to end uses. In scenario II, the envisaged contribution to transport from biofuels in this scenario is 28 ktoe, which is less than 2% of the total fossil fuels imported for transport use (when compared to IEA information on final uses for Lebanon[5]). Also in this scenario the production of electricity could reach 4.3% of the current total electricity consumed by the country, with a total capacity of 62 MWe installed in small size plants using different technologies. In this scenario, Waste-to-Energy plants also have the largest contribution producing 226 GWh of electricity produced annually from the biomass fraction of MSW. The corresponding capacity of waste-to-energy plants pertaining to the biomass fraction is 29 MW. In case all MSW fractions are used in waste-to-energy plants, the total capacity of these plants can reach 53 MW.

[5]http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=LB

Table 107: Relevance of combination resource-technology for bioenergy production in Scenario II

- [black] Combination resource-techonology not possible / plausible
- [green] Full potential
- [yellow] Established after 2020
- [red] Not developed

SCENARIO II: Low economic growth limiting possibilities for bioenergy development, peace in the country apart from incidental unrest

Geographical regions

		South Lebanon	Nabatyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut
Forestry	Woody biomass and Fellings	green	green	green	green	green	black
	Residues from fellings	green	green	green	green	green	black
Wood and paper industries	Wood residues from wood	green	green	green	green	green	green
	By-products from paper industry	black	black	black	black	black	black
Agriculture	Residues of olive trees	green	green	green	green	green	black
	Residues of fruit trees	green	green	green	green	green	black
	Residues of Cereals	red	red	red	red	red	black
	Manure	red	red	red	red	red	black
Available land for energy crop production	Cereal crops	red	red	red	red	red	black
	Oil seed crops	green	green	green	green	green	black
	Lignocellulosic energy crops	red	red	red	red	red	black
	Salicornia	red	red	red	red	red	red
	Algae	red	red	red	red	red	red
Food processing industry	Animal fat	green	green	green	green	green	green
	Slaughterhouse residues	green	green	green	green	green	green
	Olive cake by-products	red	red	black	red	red	black
	Org. residues & Waste food	green	green	green	green	green	green
	Wastewater& sludge food	yellow	yellow	yellow	yellow	yellow	yellow
MSW and non-hazardous industrial waste	Biodegradable fraction of MSW	green	green	green	green	green	green
	Landfill potential	black	black	black	green	green	black
	Industrial and commercial waste	green	green	green	green	green	green
	Waste wood	green	green	green	green	green	green
	Municipal sewage sludge	yellow	yellow	yellow	yellow	yellow	yellow
	Landscape management residues	black	black	black	black	red	red
	Yellow grease	green	green	green	green	green	green

Liquid Fuel production / Biogas production

	Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP
Woody biomass and Fellings	black	black	black	red	black	black	black	black	red
Residues from fellings	black	black	black	red	black	green	black	black	red
Wood residues from wood	black	black	black	red	black	black	black	black	red
By-products from paper industry	black	black	black	red	black	black	black	black	red
Residues of olive trees	black	black	black	red	green	black	black	black	red
Residues of fruit trees	black	black	black	red	green	black	black	black	red
Residues of Cereals	black	black	black	red	red	black	black	black	red
Manure	black	black	black	black	red	black	black	black	red
Cereal crops	black	red	black	red	black	black	black	black	black
Oil seed crops	green	black	black	red	black	black	black	black	black
Lignocellulosic energy crops	black	black	black	red	black	black	black	black	black
Salicornia	black	black	black	red	black	black	black	black	black
Algae	black	black	black	black	black	black	black	black	black
Animal fat	black	black	green	black	black	black	black	black	black
Slaughterhouse residues	black	black	black	black	black	black	green	black	black
Olive cake by-products	black	black	black	black	black	black	black	black	red
Org. residues & Waste food	black	black	black	red	black	black	black	black	red
Wastewater& sludge food	black	black	black	black	black	yellow	black	black	red
Biodegradable fraction of MSW	black	black	black	red	black	black	black	black	red
Landfill potential	black	black	black	black	black	black	black	green	red
Industrial and commercial waste	black	black	black	black	black	black	black	black	red
Waste wood	black	black	black	red	black	black	black	black	red
Municipal sewage sludge	black	black	black	black	black	yellow	black	black	red
Landscape management residues	black	black	black	red	black	black	black	black	red
Yellow grease	black	black	green	black	black	black	black	black	black

Direct combustion / Promising technologies

	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centred in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW
Woody biomass and Fellings	black	red	green	red	black	black	red	black
Residues from fellings	black	red	green	red	black	black	red	black
Wood residues from wood	black	red	green	red	black	black	red	black
By-products from paper industry	black	red	red	black	black	black	black	black
Residues of olive trees	black	red	red	red	black	black	red	black
Residues of fruit trees	black	red	red	red	black	black	red	black
Residues of Cereals	black	red	red	red	black	black	red	black
Manure	black	black	black	black	black	black	black	black
Cereal crops	black	black	black	black	black	black	black	black
Oil seed crops	black	black	black	black	black	black	black	black
Lignocellulosic energy crops	black	red	red	red	black	black	red	black
Salicornia	black	black	black	black	black	red	black	black
Algae	black	black	black	black	red	black	black	black
Animal fat	black	black	black	black	black	black	black	black
Slaughterhouse residues	black	black	black	black	black	black	black	black
Olive cake by-products	black	black	black	black	black	black	black	black
Org. residues & Waste food	black	red	green	red	black	black	black	black
Wastewater& sludge food	black	black	black	black	black	black	black	black
Biodegradable fraction of MSW	green	red	red	red	black	black	black	red
Landfill potential	black	black	black	black	black	black	black	black
Industrial and commercial waste	green	red	red	black	black	black	black	black
Waste wood	black	red	green	red	black	black	black	black
Municipal sewage sludge	black	black	black	black	black	black	black	black
Landscape management residues	black	red	red	red	black	black	red	black
Yellow grease	black	black	black	black	black	black	black	black

*Pretreatment bioenergy options are not included as Task 2 concluded that this was not a promising technology for Lebanon

**Used land areas: Abandoned agricultural land, part of grassland areas and former Cannabis plantations

***Manure and cereal residues are used for fertilizer and for livestock by rural population

Table 108: Participation of biomass resources in bioenergy production per mohafazat in Scenario II in GWh/year of primary energy

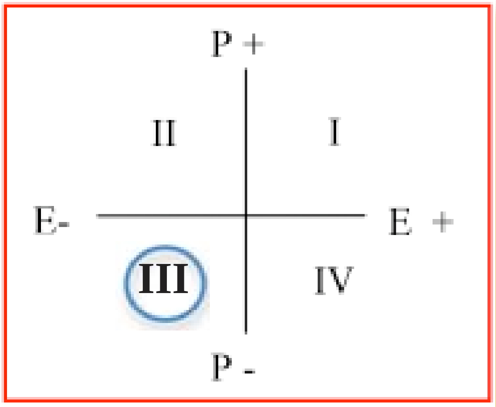
		Short term						2020						2030					
Resources		South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut
Forestry	Woody biomass and Fellings	27	21	29	119	76	0	27	21	29	119	76	0	27	21	29	119	76	0
	Residues from fellings	25	20	34	84	71	0	25	20	34	84	71	0	25	20	34	84	71	0
Wood and paper industries	Wood residues from wood industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	By-products from paper industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriculture	Residues of olive trees	23	30	7	17	40	0	23	30	7	17	40	0	23	30	7	17	40	0
	Residues of fruit trees	47	7	83	46	74	0	47	7	83	46	74	0	47	7	83	46	74	0
	Residues of Cereals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Manure	0	0	0	0	0	0	1	1	2	6	3	3	1	1	2	6	3	3
Available land for energy crop production	Cereal crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oil seed crops	0	0	112	0	44	0	0	0	112	57	44	0	0	0	112	57	44	0
	Lignocellulosic energy crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Salicornia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Food processing industry	Animal fat	14	3	0	0	0	0	14	3	0	0	0	0	14	3	0	0	0	0
	Slaughterhouse residues	16	4	0	0	0	0	16	4	0	0	0	0	16	4	0	0	0	0
	Olive cake by products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Org. residues & Waste food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wastewater& sludge food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSW and non-hazardous industrial waste	Biodegradable fraction of MSW	15	17	22	78	34	44	18	22	28	99	43	55	22	26	34	119	52	67
	Landfill potential	0	0	0	143	19	0	0	0	0	143	19	0	0	0	0	143	19	0
	Industrial and commercial waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Waste wood	14	16	20	36	16	20	14	16	20	36	16	20	14	16	20	36	16	20
	Municipal sewage sludge	0	0	0	0	0	0	13	0	21	13	23	50	17	0	28	17	30	65
	Landscape management residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Yellow grease	7	9	11	39	17	22	7	9	11	39	17	22	7	9	11	39	17	22
	Totals	187	127	318	562	391	86	206	132	347	660	426	151	214	137	359	684	441	178

Table 109: Annual contribution to final energy in 2030 (Scenario II)

Energy use	Liquid Fuel production				Biogas production					Direct combustion				Promising technologies				
	Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centered in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW	Total
Primary energy (GWh)	213	0	155	0	374	157	20	162	0	321	0	627	0	0	0	0	0	**2029**
Final energy																		
Capacity factor					85%	90%	80%	85%	90%	90%	90%	90%	90%					
Electricity (GWh)					131	55	7	57	0	112	0		0					**362**
Electricity (MWe)					18	7	1	8	0	14	0		0					**47**
Heat (ktoe)					11	5	1	5	0	10	0	38	0					**69**
Heat (MWt)					20	8	1	9	0	16	0	64	0					**118**
Transport (ktoe)	16	0	12	0										0	0	0	0	**28**

IV.3 SCENARIO III – UNDERDEVELOPMENT AND POVERTY

General description
Political axis (-)
Economic axis (-)



Story line

Scenario III describes a heterogeneous world with reduced economic, cultural and social exchange between regions. The main aspect of this scenario is a strong need for self-reliance and the maintenance of local identities. Patterns of cooperation between regions converge very slowly, even between the various mohafazats in Lebanon. Economic development is primarily local and per capita economic growth and technological changes are fragmented and slower than in any other scenario. In this scenario, renewable energy development – including the development of bioenergy - in the world and in Lebanon is slow and uncertain. Other technologies are favoured at a national scale, namely the introduction of new power plants (CCGT) and wind power.

In this scenario, Lebanon is in political turmoil, which affects the economy of the country and the South, North and the Beqaa regions in specific. Lebanon's income decreases because there is not enough production and export and there is drain of financial capital and human talents towards wealthier and more pacific nations. The industry of Lebanon is fragmented and primarily serves its own demand. The economic and political situation makes Lebanon more vulnerable to international fluctuations in food prices.

Consciousness about social developments, sustainability and Lebanon's environment is very limited, hardly reflected in policies, and does not have high priority. The cultivation of illicit crops in parts of the country is an increasing problem and limited effort is taken to restrict it. Within the energy sector, maintenance of power generation has a priority. Lack of sufficient capacity by EDL to meet demand further undermines consumer confidence in the public provision of electricity supply which, in turn, makes reforms of the sector even more difficult to implement.

KEY TRENDS: Lebanon is in a political turmoil, which affects the economy with increasing socio-economic disparities across Lebanese regions.

Bioenergy development has limited to no priority in national strategies.

No sustainability levels are considered for bioenergy development

Specific characteristics for this scenario:

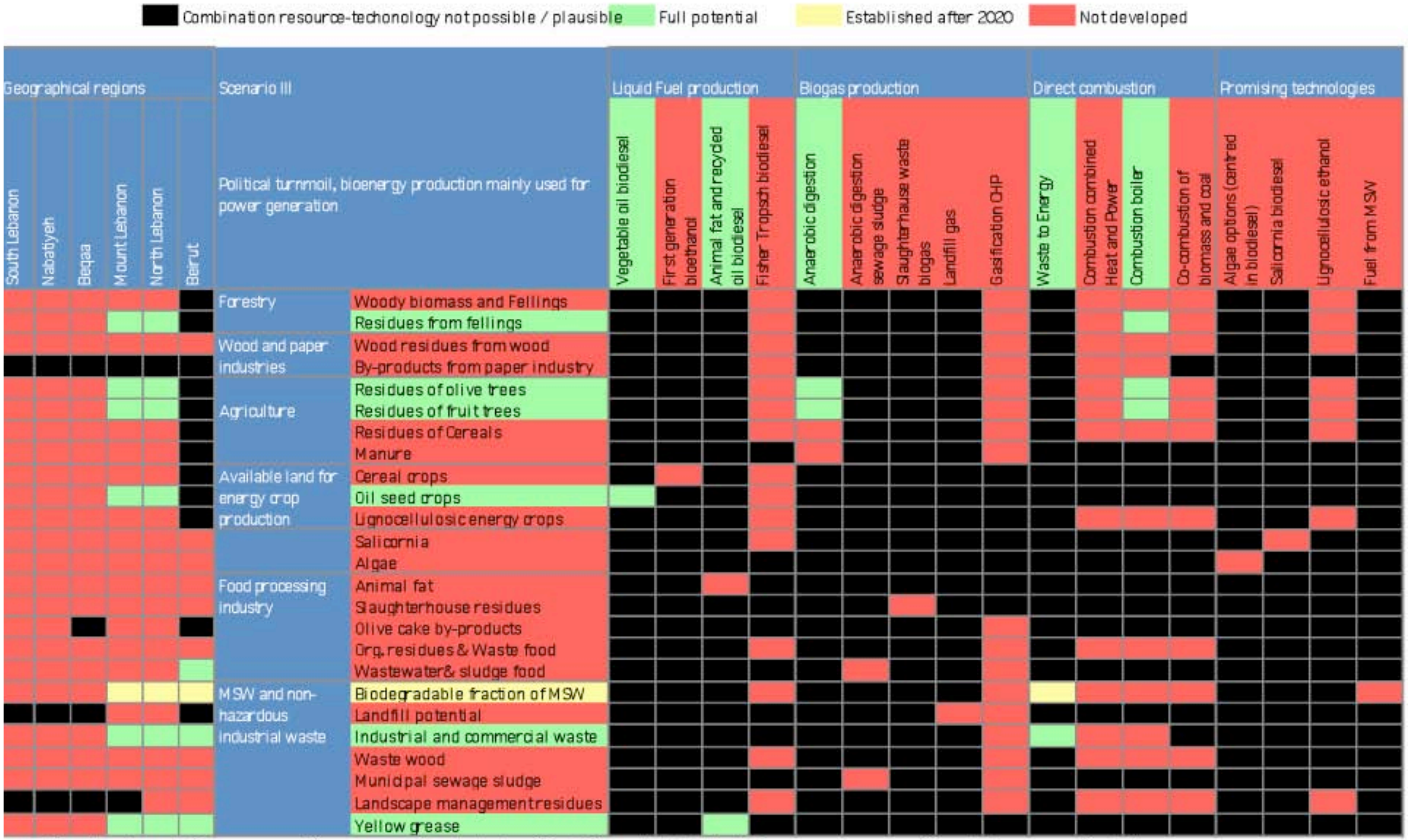
Economy	Economic growth rates in Lebanon are limited.
	GDP per capita remains medium to low with an annual average growth of maximum 2% assumed (NMPLT, 2005) and the standards of living in Lebanon remains the same or even deteriorates. The worsening economic and political situation makes Lebanon more vulnerable to international food crises (including fluctuations in international food prices).
	Foreign capital is available to support the diversification of the energy matrix in Lebanon, but on condition that money is spent on foreign technical and human resources instead of on local resources; creation of employment is therefore not incentivised in the energy business, and the local industry does not develop leadership in any area relevant to energy or any other productive activity.
Trade	Patterns of trade cooperation in the world converge very slowly; trade in the MENA region is limited due to a lack of common vision and possible political tensions; cooperation in the deployment of renewable energy sources is low, which limits efficiency levels.
Technological developments	Innovation in technology is an external process and only taking place in Lebanon through possible international business opportunities; foreign investment is limited.
	Developments for a selection of bioenergy conversion technologies, which have a priority in a selected number of private businesses, reach international, state-of-the-art levels.
	No yield improvements for agricultural crops are achieved.
	There are limited and localized initiatives to improve and enable the collection of residues in some parts of the country.
Environment and land use	There is a limited increase of urbanization; part of the abandoned agricultural land (10%) is used for infrastructure and buildings.
	The private sector explores the possibility of energy crop production in Lebanon on remaining abandoned cropland (53,137 ha); 25% is deployed.
	Forest areas are illegally exploited for various purposes but do not contribute to the development and deployment of bioenergy in the country.
	25% of residues are deployed for bioenergy in Lebanon for energy production
	Existing grassland areas are mainly used for extensive livestock production and suffer heavily from degradation due to overgrazing.
	In Lebanon, sustainability issues are not a priority for bioenergy deployment.
	Illicit crop cultivation remains of the same importance and even increases in some areas.
	The selection of energy crops follows the potential assessment: Jatropha (Beqaa), Sunflower (North Lebanon, Mount Lebanon after 2020), Giant Reed (Nabatiyeh, South Lebanon after 2020). The selected cereal energy crop is wheat.
Policies and regulations	Politically, the country is in turmoil.
	Resources to improve the energy sector come mainly from international development agencies. Investments via the private sector are limited.
	Limited legislative changes are developed to make bioenergy production from waste, residues or forest resources possible.
	Levels of deployment of waste streams for bioenergy production, when developed, are targeted at 25%.
	Limited action is undertaken to tackle the growing illicit crops issue in the country.

Table 110 describes the relevance of all possible combinations biomass resource – technology conversion that could occur in scenario III. It also establishes the relevance of each biomass stream for the different mofahazats in Lebanon.
Table 111 shows the possible contribution of all bioenergy streams to the production of bioenergy in each mohafazat for the short term future and until year 2030.
Table 112 presents the annual contribution of bioenergy to end uses. In scenario III, the envisaged contribution to transport from biofuels in this scenario is barely 14 ktoe, which is less than 1% of the total fossil fuels imported for the transport use (when compared to IEA information on final uses for Lebanon[6]). Also in this scenario the production of electricity reaches only 0.5% of the total electricity consumed by the country with a total installed capacity of only 9 MWe, mainly Waste-to-Energy plants (4-7 MWe).

Elecricity Generation from Landfill Gas

[6] http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=LB

Table 110: Relevance of combination resource-technology for bioenergy production in Scenario III



*Pretreatment bioenergy options are not included as Task 2 concluded that this was not a promising technology for Lebanon

** Used land areas: Abandoned agricultural land

*** Manure and cereal residues are used for fertilizer and for livestock by rural population

Table 111: Participation of biomass resources in bioenergy production per mohafazat in Scenario III in GWh/year of primary energy

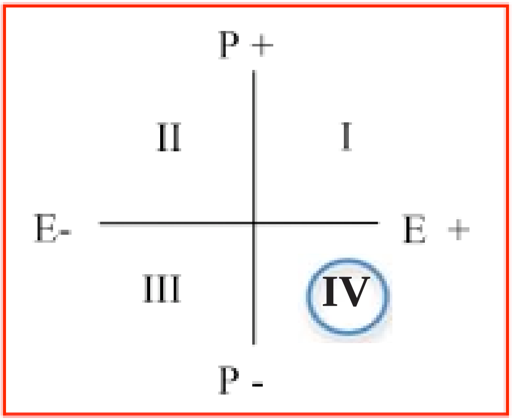
		Short term						2020						2030					
Resources		South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut
Forestry	Woody biomass and Fellings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Residues from fellings	13	10	17	42	36	0	13	10	17	42	36	0	13	10	17	42	36	0
Wood and paper industries	Wood residues from wood industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	By-products from paper industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriculture	Residues of olive trees	12	15	4	8	20	0	12	15	4	8	20	0	12	15	4	8	20	0
	Residues of fruit trees	23	3	41	23	37	0	23	3	41	23	37	0	23	3	41	23	37	0
	Residues of Cereals	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	2	1	1
	Manure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Available land for energy crop production	Cereal crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oil seed crops	0	0	37	0	22	0	0	0	37	29	22	0	0	0	37	29	22	0
	Lignocellulosic energy crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Salicornia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Food processing industry	Animal fat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Slaughterhouse residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Olive cake by-products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Org. residues & Waste food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wastewater& sludge food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSW and non-hazardous industrial waste	Biodegradable fraction of MSW	0	0	0	0	0	0	6	7	9	33	14	18	7	9	11	40	17	22
	Landfill potential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Industrial and commercial waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Waste wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Municipal sewage sludge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Landscape management residues	2	3	4	13	6	7	2	3	4	13	6	7	2	3	4	13	6	7
	Yellow grease																		
	Totals	0	0	0	86	120	7	0	0	0	150	135	27	0	0	0	157	138	31

Table 112 : Annual contribution to final energy in 2030 (Scenario III)

Energy use	Liquid Fuel production				Biogas production					Direct combustion				Promising technologies				
	Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centered in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW	Total
Primary energy (GWh)	51	0	137	0	44	0	0	0	0	80	0	122	0	0	0	0	0	**433**
Final energy																		
Capacity factor					85%	90%	80%	85%	90%	90%	90%	90%	90%					
Electricity (GWh)					15	0	0	0	0	28	0		0					**43**
Electricity (MWe)					2	0	0	0	0	4	0		0					**6**
Heat (ktoe)					1	0	0	0	0	2	0	7	0					**11**
Heat (MWt)					2	0	0	0	0	4	0	12	0					**19**
Transport (ktoe)	4	0	10	0										0	0	0	0	**14**

IV.4 SCENARIO IV – POLITICAL CHALLENGES

General description
Political axis (-)
Economic axis (+)



Story line

Scenario IV represents a future world of very rapid economic growth, with global growth of the population that peaks towards the middle of the century and with the rapid introduction of new and more efficient technologies. The most important issues are convergence among regions, increased institutional capacity, greater social interaction and a sustained reduction in regional income differences per capita. It is the world of economic globalization and efficiency of production. It is a world where fossil fuels (despite its high costs), especially natural gas, play an important role in the world energy supplies.

Lebanon succeeds in increasing its competitiveness in products of international concurrence (imported or exported goods) in a short period of time. In this scenario the Lebanese industry is fully integrated into global industrial initiatives in several areas, but not in bioenergy. There is political unrest in various parts of the country, which affects the economic development of some regions and delays policymaking and weakens enforcement measures. Increased economic growth and welfare increases the possibilities for many segments of the Lebanese population to deal with international food crises (including the increase in food prices) than the current situation, although regional differences are significant.

Consciousness about social developments, sustainability and Lebanon's environment increases among the population, although not enough for a call for political action. The growing of illicit crops in parts of the country remains a problem and limited effort is undertaken to restrict it.

KEY TRENDS: There is a strong economy; some regions remain underdeveloped due to large political and social unrest. Bioenergy is used for reducing energy deficits and export.

A minimum level of sustainability is considered for bioenergy development.

Specific characteristics of this scenario:

Economy	The Lebanese and world economic situations are good and growing rapidly.
	GDP per capita in Lebanon is increasing with an annual growth of 3.5 % from 2008 to 2030 (see NMPLT, 2005), except in some regions, which allows future generations to benefit from a considerably better standards of living and enables them to better cope with increasing international food prices.
	Competitive sectors are able to achieve a balance in foreign trade.
	The multinational capital helps to diversify the energy matrix in Lebanon but is not specifically focused on renewable energy resources or on solving Lebanon's energy deficits.
Trade	Lebanon succeeds in increasing its competitiveness in products of international concurrence.
	There is increased trade cooperation in the world; the Lebanese and MENA economies are in direct consolidation and various initiatives are deployed to ensure supply and efficiencies in the energy sector.
Technological developments	Technological developments in Lebanon, including bioenergy technologies, reach international, state-of-the-art levels.
	Agricultural developments in Lebanon result in yield improvements (1% per year) for agricultural crops.
	Collection of residue streams is fully structured and replacement solutions are found for residue streams when used for bioenergy.
	Efficiency in livestock production is attained through establishment of closed facilities and centralization of (waste) processing facilities.
Environment and land use	A minimum level of sustainability for bioenergy production is secured.
	Forest areas cannot be legally exploited for bioenergy production because of the lack of legislative changes.
	25% of residues are deployed for bioenergy in Lebanon for energy production
	There is increase of urbanization; part of the abandoned agricultural land (25%) is used for infrastructure and buildings.
	Accessible abandoned agricultural cropland is brought back into production, mainly for food production – possibly for export. 5% of abandoned farmland is used for energy crop production.
	10% of the grasslands (317,601 ha) are used for energy crop production, after 2020.
	Illicit crop cultivation remains of the same size as in the current situation.
	The selection of energy crops follows the potential assessment: Jatropha (Beqaa), Sunflower (North Lebanon, Mount Lebanon after 2020), Giant Reed (Nabatiyeh, South Lebanon after 2020). The selected cereal energy crop is wheat.
Policies and regulations	Feelings of exclusion from population groups in the country remain and provide unrest in the political field and especially in the South and border areas of Lebanon.
	At a national level, internal conflicts restrain opportunities for development in some regions.
	Policies gradually restructure and increase the existing tariffs to eliminate the financial deficit in the electricity sector and to establish a balanced budget; part of the budget will be used to decrease Lebanon's deficits on power and diesel.
	Considered privatization of various public sectors helps to rationalize expenses in the given sector (electricity, water, etc.) by investments complementary to those of the public sector. Resources to improve the energy sector come from the private sector.
	Burning of (cereal) residues on the field is no longer allowed.
	Energy recovery is promoted on the longer term (after 2020) by the private sector for larger landfills and larger sewage plants.
	Levels of deployment of waste streams for bioenergy production, when developed, are targeted at 50% in 2020 to 75% in 2030.
	No action is undertaken to tackle the cultivation of illicit crops in the country.

Table 113 describes the relevance of all possible combinations biomass resource – technology conversion that could occur in scenario IV. It also establishes the relevance of each biomass stream for the different mofahazats in Lebanon.
Table 114 shows the possible contribution of all bioenergy streams to the production of bioenergy in each mohafazat for the short term future and until year 2030.
Table 115 presents the annual contribution of bioenergy to end uses. In scenario IV, the envisaged contribution to transport from biofuels in this scenario is barely 39 ktoe, which is about than 2.6% of the total fossil fuels imported for transport use (when compared to IEA information on final uses for Lebanon[7]). Also in this scenario the production of electricity could reach up to the 2.4% of the current total electricity consumed by the country, with a total capacity of 33 MWe installed mainly in gasification of biomass for combined heat and power projects (20 MWe), and in recovery of energy from landfills and sewage sludge (14 MW total). In this scenario, gasification CHP, though not fully developed until 2015 approximately, is the preferred technology as it can use multiple feedstocks and the produced syngas can be used directly in gas engines without any adaptation. Energy recovery from landfills is preferred over Waste-to-Energy (WtE) plants due to its lower cost, though environmentally they produce higher impacts than WtE plants.

Fischer-Tropsch Biodiesel

[7]http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=LB

Table 113: Relevance of combination resource-technology for bioenergy production in Scenario IV

*Pretreatment bioenergy options are not included as Task 2 concluded that this was not a promising technology for Lebanon

** Used land areas: Grassland areas

*** Yield increases over time for agriculture and livestock production in country, at least in some regions

Table 114: Participation of biomass resources in bioenergy production per mohafazat in Scenario IV in GWh/year of primary energy

Resources		Short term						2020						2030					
		South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut	South Lebanon	Nabatiyeh	Beqaa	Mount Lebanon	North Lebanon	Beirut
	Residues from fellings	16	13	22	54	46	0	16	13	22	54	46	0	16	13	22	54	46	0
Wood and paper industries	Wood residues from wood industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	By-products from paper industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriculture	Residues of olive trees	13	17	4	9	23	0	13	17	4	9	23	0	13	17	4	9	23	0
	Residues of fruit trees	34	5	60	34	54	0	34	5	60	34	54	0	34	5	60	34	54	0
	Residues of Cereals	14	23	104	1	44	0	0	0	0	0	0	0	17	27	125	1	53	0
	Manure	0	0	0	0	0	0	1	1	1	4	2	2	1	1	1	4	2	2
	Cereal crops	3	6	11	7	5	0	3	6	11	7	5	0	3	6	11	7	5	0
	Oil seed crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lignocellulosic energy crops	0	0	0	0	0	0	155	354	0	0	0	0	155	354	0	0	0	0
	Salicornia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Algae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Animal fat	14	3	0	0	0	0	14	3	0	0	0	0	19	5	0	0	0	0
	Slaughterhouse residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Olive cake by-products	0	0	0	0	0	0	13	31	3	32	46	0	20	46	5	49	68	0
	Org. residues & Waste food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wastewater& sludge food proc. industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Biodegradable fraction of MSW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Landfill potential	0	0	0	143	19	0	0	0	0	143	19	0	0	0	0	143	19	0
	Industrial and commercial waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Waste wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Municipal sewage sludge	0	0	0	0	0	0	9	0	14	9	15	33	17	0	28	17	30	65
	Landscape management residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Yellow grease	5	6	7	26	11	15	5	6	7	26	11	15	7	9	11	39	17	22
	Totals	0	73	209	274	202	15	0	436	124	318	221	50	0	483	267	357	317	89

Table 115 : Annual contribution of final energy in 2030 (Scenario IV)

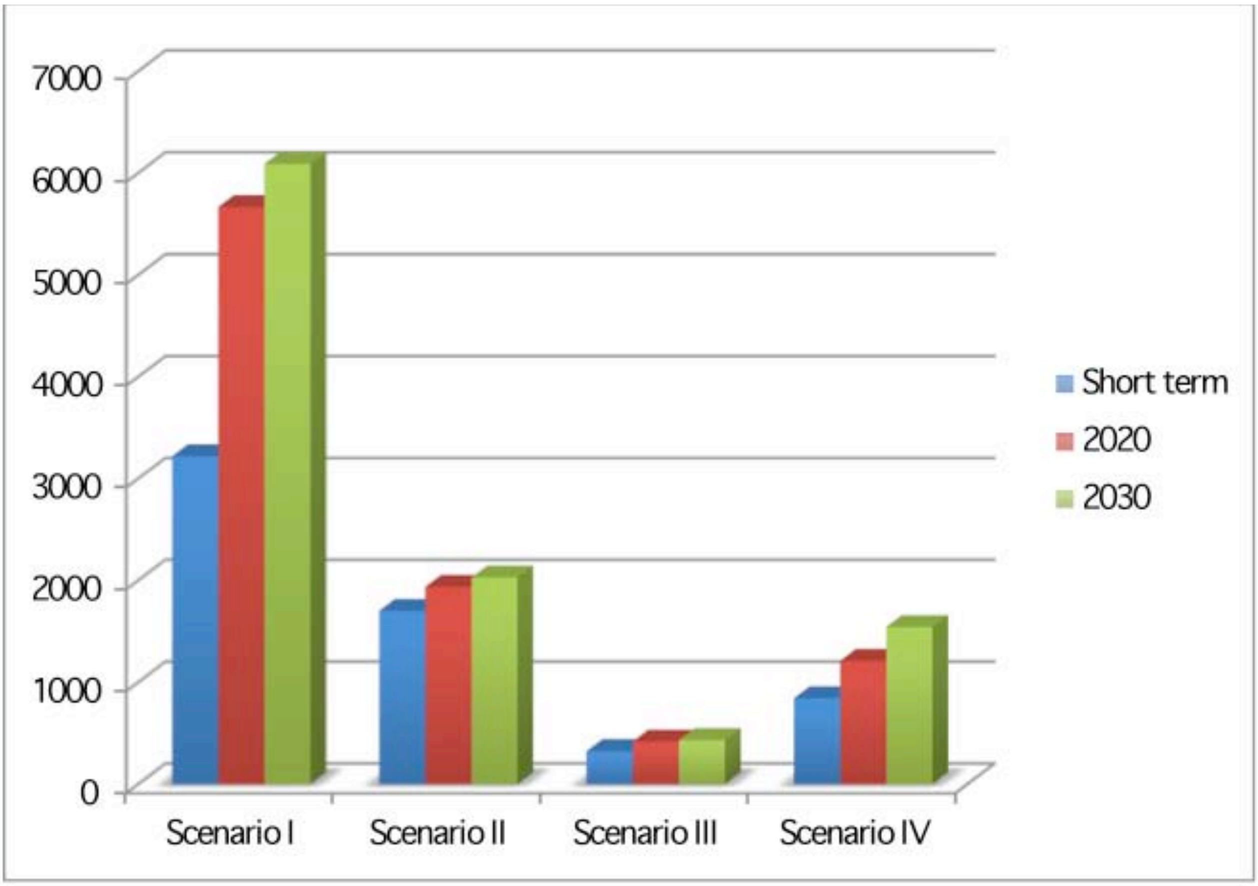
Energy use	Liquid Fuel production				Biogas production					Direct combustion				Promising technologies				
	Vegetable oil biodiesel	First generation bioethanol	Animal fat and recycled oil biodiesel	Fisher Tropsch biodiesel	Anaerobic digestion	Anaerobic digestion sewage sludge	Slaughterhause waste biogas	Landfill gas	Gasification CHP	Waste to Energy	Combustion combined Heat and Power	Combustion boiler	Co-combustion of biomass and coal	Algae options (centered in biodiesel)	Salicornia biodiesel	Lignocellulosic ethanol	Fuel from MSW	Total
Primary energy (GWh)	0	29	142	0	0	140	0	162	442	0	0	273	0	0	0	354	0	**1543**
Final energy																		
Capacity factor					85%	90%	80%	85%	90%	90%	90%	90%	90%					
Electricity (GWh)					0	49	0	57	155	0	0		0					**261**
Electricity (MWe)					0	6	0	8	20	0	0		0					**33**
Heat (ktoe)					0	4	0	5	13	0	0	16	0					**39**
Heat (MWt)					0	7	0	9	22	0	0	28	0					**66**
Transport (ktoe)	0	2	11	0										0	0	27	0	**39**

V.RESULTS AND CONCLUSIONS OF SCENARIOS ASSESSMENT

The scenarios in the previous sections are based on qualitative conjectures (what we have called story lines), and not on econometric relations.

These scenarios provide insights into the possible accelerating or slowing effects that development may likely have on the level of deployment of bioenergy in Lebanon; they can expose opportunities in the future that were not so far foreseen; they can also expose technological, legal and financial barriers to bioenergy market deployment not previously foreseen as well.

Figure 31: Bioenergy potential of bioenergy resource streams for four scenarios over time (in GWh of total primary energy)



V.1 BIOENERGY POTENTIAL

The outlook of the available and deployable bioenergy potential for each scenario is based on the outcomes of the technical potential resource assessment, as analysed in chapter 1, and on the assumptions for each scenario.

Figure 31 shows that most bioenergy will be deployed under scenario I, followed by scenarios II, IV and III. Scenario I represents the scenario where bioenergy is mostly stimulated by the Lebanese government and the private sector. Scenario III is mostly hampered by economic and political unrest and instability in the country.The potential contribution of the various biomass resources differs per scenario, influenced by the various assumptions in the story lines (Figure 32).

Figure 32: Potential contribution of bioenergy resource categories (in GWh of total primary energy) for four scenarios, here only shown for year 2030[8].

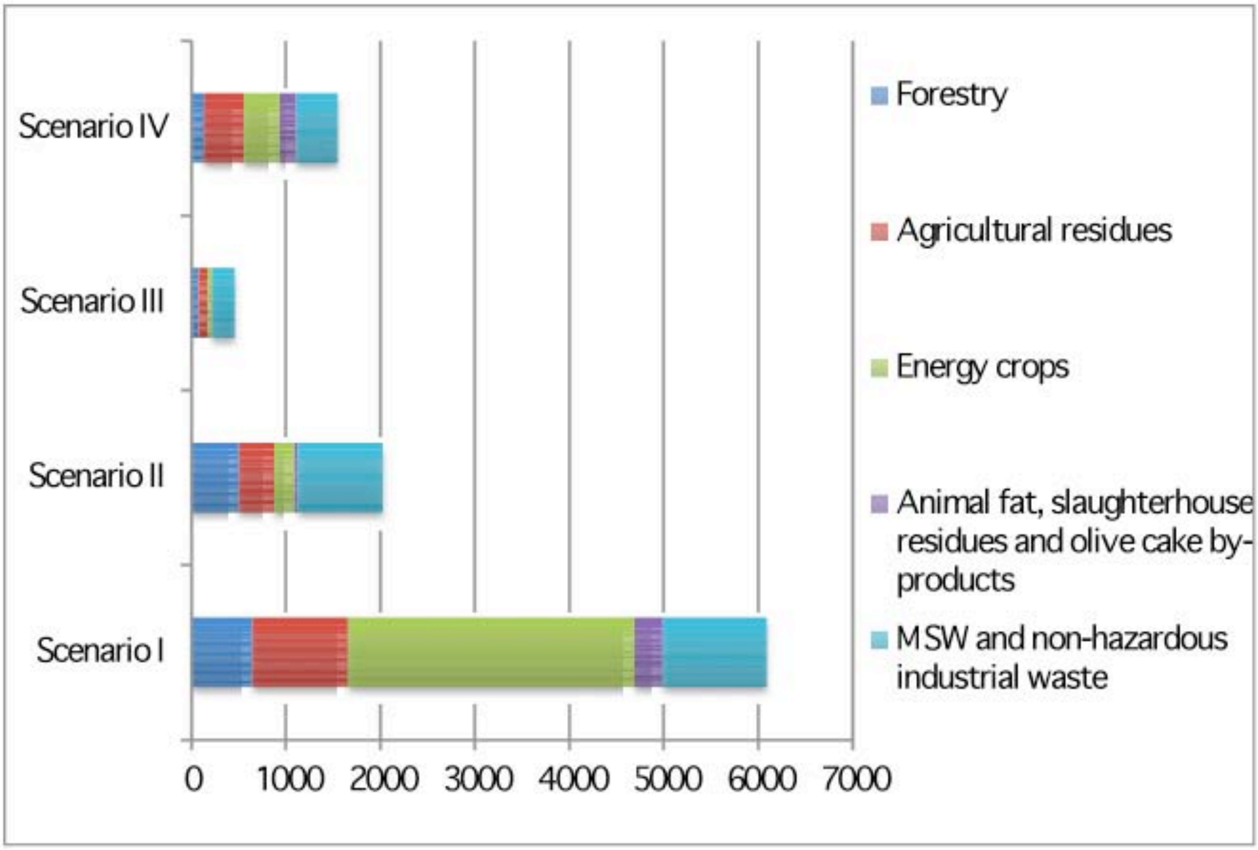
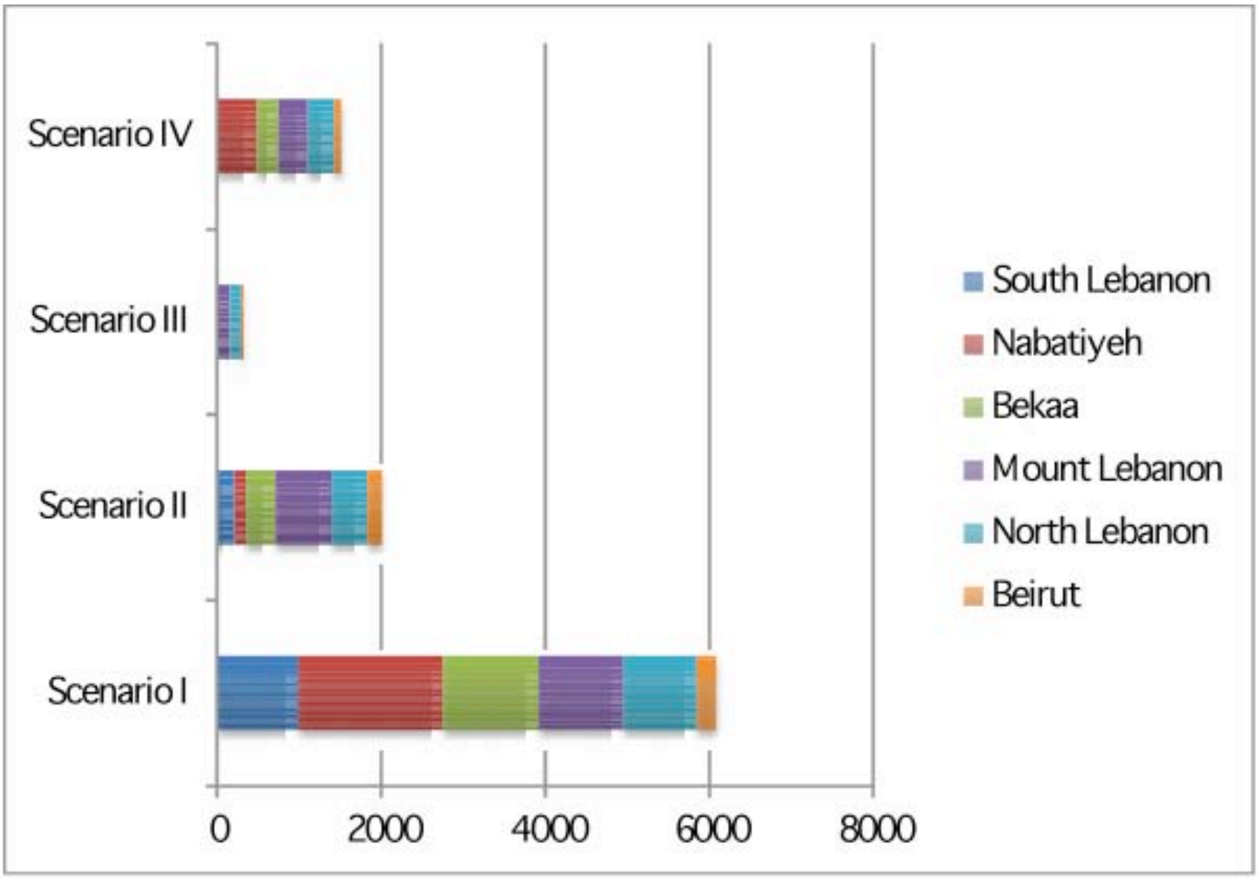


Figure 33 shows the contribution of the mohafazats to the deployment of bioenergy to the four scenarios. Scenario III has excluded three mohafazats for the deployment of bioenergy due to considerations explained in the scenario description which explains the limited bioenergy contribution to this scenario.

[8]The potential contribution of algae as bioenergy source is expected to happen in the world after 2030, therefore it is not included in this assessment. Further attention to the research of algae as bioenergy resource in Lebanon should be given as Lebanon has a long shore line that could exploit it; currently, no studies about its potential for Lebanon have been carried out. An increase of MSW is assumed over time (from 2020 to 2030) as growth in population in the main cities of Lebanon is expected.

Figure 33: Contribution of mohafazats to bioenergy development and deployment (here for year 2030, in GWh primary total energy) for the various scenarios



These results show that all mohafazats, except Beirut, can contribute substantially to the total potential of bioenergy deployment. Excluding one or several mohafazats due to political or socio-economic considerations, has significant impact on the total availability of bioenergy in Lebanon.

The available land for energy crop production is largest in Beqaa, followed by Mount Lebanon, North Lebanon and Nabatiyeh. Considering the option of energy crop production on part of these lands, as assumed for example in Scenario I, enlarges substantially the potential for bioenergy production and deployment in these mohafazats.

V.2 CONTRIBUTION TO ENERGY USE

The deployed biomass streams can be used for a limited number of end-uses as biofuels, biogas, direct combustion (power and heat), each covering a set of possible and potential technologies (see chapter 2).

According to statistics from the International Energy Agency (IEA), the evolution of energy supply in Lebanon has more than doubled in the last 20 years (Figure 34). Electricity generation has grown at a pace of approximately 300 GWh/year, as an average, within this period as well (Figure 35)

Figure 34: Evolution of total primary energy supply in Lebanon. Source IEA[9]

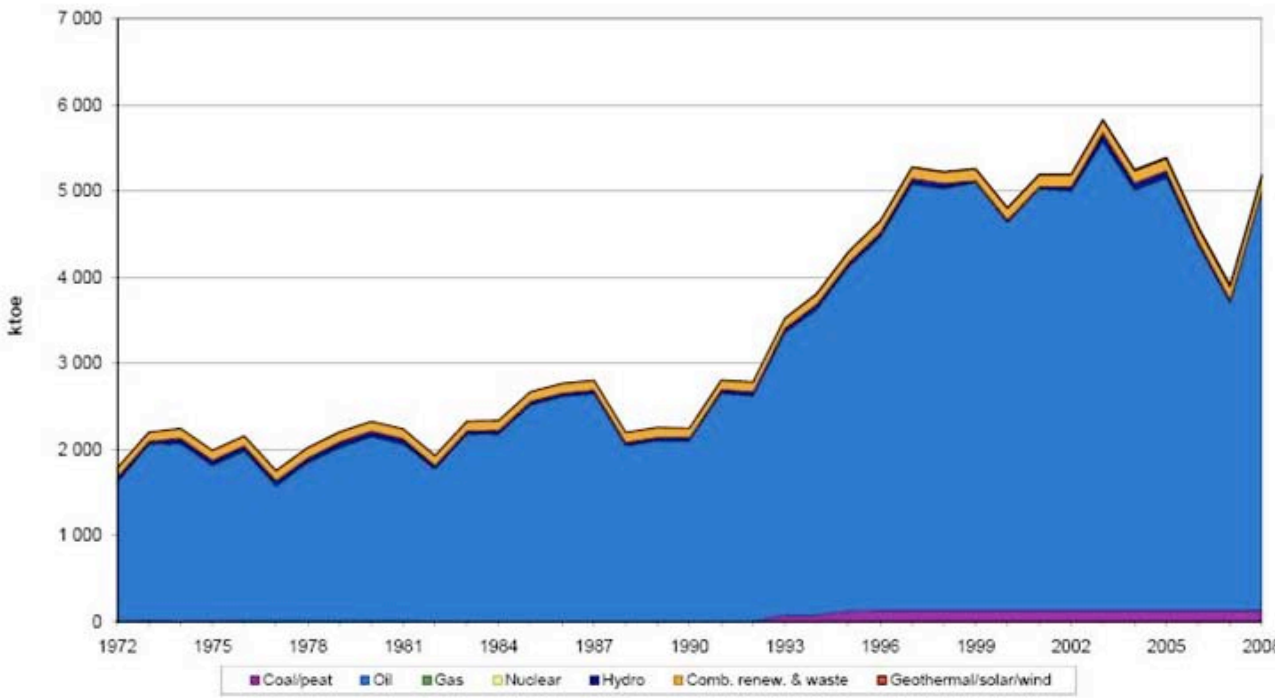
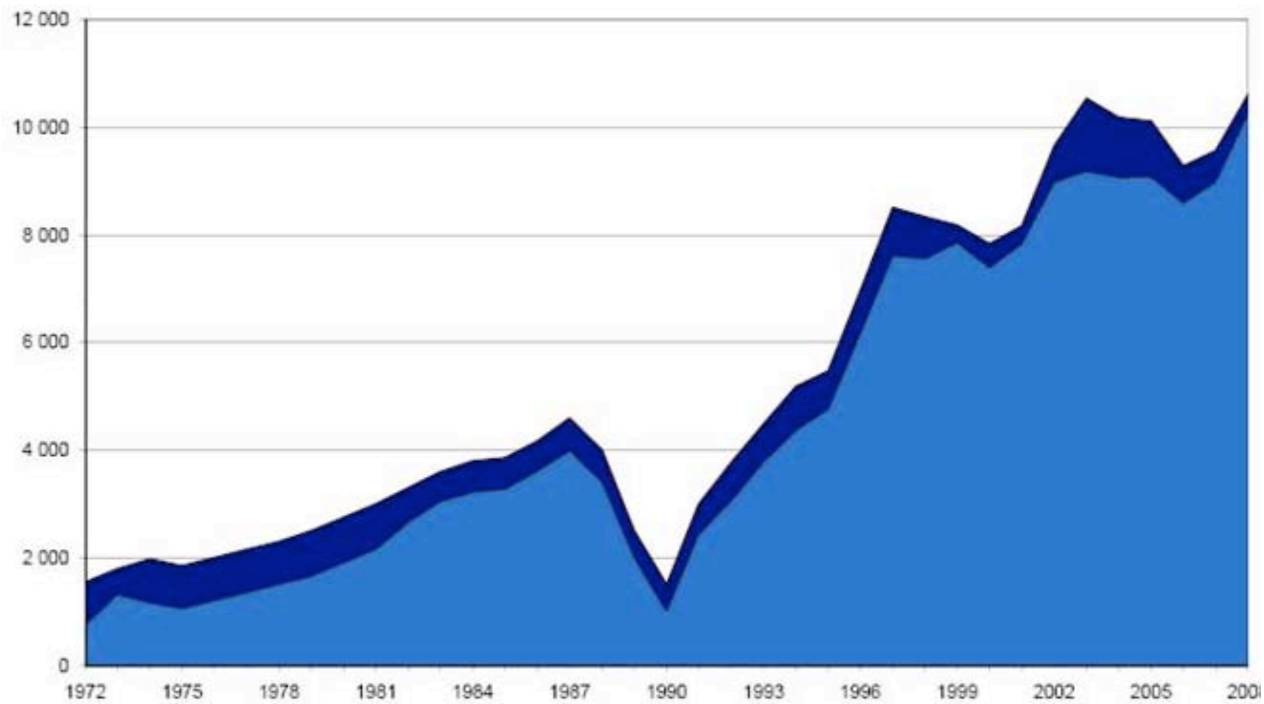


Figure 35: Evolution of the electricity generation in Lebanon. Source: IEA[10]



[9]http://www.iea.org/stats/pdf_graphs/LBTPES.pdf
[10]http://www.iea.org/stats/pdf_graphs/LBELEC.pdf

The energy generation policy in Lebanon is targeting a total installed capacity of 4,000 MW by 2014 and 5,000 MW thereafter (MoEW, 2010). The government of Lebanon aims to have 12% of its total energy needs from renewable energy sources (RES) in 2020. This means roughly the production of 1800 GWh of electricity coming from renewable energy sources (if focus is given on electricity generation only). This amount of energy production leads to 670 MW of installed capacity if we consider an average capacity factor of 30% for all renewable energy plants. The specific required biomass input to meet a share of this expected demand largely depends on the selected technology (and conversion efficiency) and end-use.

When looking at the contribution of the bioenergy potential (in total primary energy[11]) in the various scenarios, we can conclude that only scenario I is able to contribute substantially with about half of the electricity needed to reach the 12% target with a relative small capacity installed of 119 MWe. This is possible because the capacity factor for biomass plants ranges from 80% to 90%, which is much larger than other sources of renewable energies (capacity factors for wind and solar plants range from 15% to 25%).

A more interesting figure though is the potential production of biofuels from lignocellulosic energy crops mostly for the transportation sector. The possibility of producing an important amount of biofuels from lignocellulosic biomass (not from food crops) could help to decrease in a relevant way the dependency on imported fossil fuels. Scenario 1 establishes a potential production of 271 ktoe of biofuels; this represents 18% of current total fossil fuel consumption for transportation.

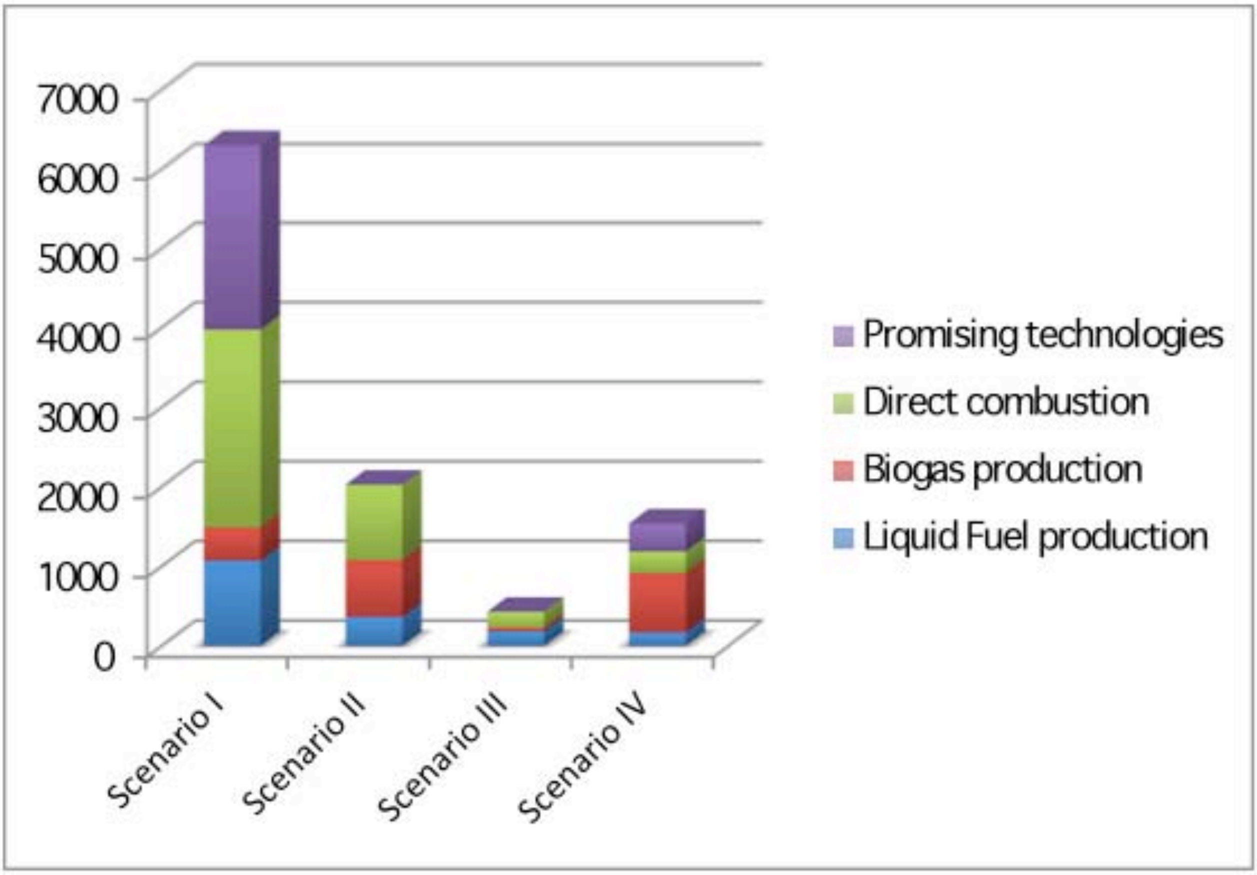
Table 116 and Figure 36 show the contribution of bioenergy to various types of end-use resources, based on the selected technologies from chapter 2.

Table 116: Annual contribution of bioenergy to end-uses, year 2030

Energy use	Scenario I	Scenario II	Scenario III	Scenario IV
Primary energy (GWh)	6305	2029	433	1543
Final energy				
Electricity (GWh)	782	362	43	261
Electricity (MWe)	100	47	6	33
Heat (ktoe)	118	69	11	39
Heat (MWt)	200	118	19	66
Transport (ktoe)	255	28	14	39

[11]The conversion factor from primary energy to electricity produced is about 30% for biomass. For instance, 1800 GWh of electricity would require 6000 GWh of primary energy from bioenergy resources.

Figure 36: Contribution of bioenergy resources to various energy end-uses (in GWh of total primary energy) for the year 2030



Note that energy crops show a potentially large contribution to total bioenergy deployment in Lebanon. Energy crops such as cereals or oilseed crops are interesting resources for biofuel production, though care should be given in its use to avoid any national food security issue. Lignocellulosic energy crops also have the potential to contribute to the supply of resources for biofuels production and power generation as well, as long as heat demand is also proven. Given the reality that local heat for industrial processes and residential uses is low or non-existent, priority is to be given to the deployment of those energy crops for biofuel production.

The promising technologies (as shown in Figure 36) are mainly suitable for the development of biofuels and not for heat and power generation. Although this may be an interesting resource over time, priority should be given first to those technologies that are able to deploy the biomass resources for power generation in Lebanon on the short and long terms.

The most meaningful conclusions from the scenarios are indicated below:

1.Municipal solid waste is an important resource of immediate application for its conversion to electricity and heat in Waste-to-Energy plants. Up to 301 GWh of electricity could be produced from the biomass fraction coming from municipal waste, with a total installed capacity of 38 MWe (only considering the biomass fraction, in case of considering also the non-biomass fractions, the total capacity could reach 70 MWe), if an ambitious waste management master plan is pursued; this is about 2,8% of the current electricity consumption in the country, which could almost immediately contribute to the renewable energy target of 12%.

2.The potential contribution of energy crops for biofuels production fluctuates largely in the various scenarios, depending on i) competition of the land and possible alternative uses and ii) the decision of government and private sector to exploit this opportunity or not. Developing the potential of energy crops for biofuels production under strict sustainable criteria and regulation, would produce up to 271 ktoe of biofuels by 2030. This is about 18% of current fossil fuel use for transport, which creates a large opportunity for reducing dependence from imported fossil fuels. Additionally, the deployment of the biofuels industry brings many other socioeconomic benefits such as work for farmers and crops substitution (drug crops by instance) when properly regulated.

3.Lebanon has the opportunity to leapfrog the learning curve for producing sustainable biofuels by establishing a national action plan for the development of biofuel production from lignocellulosic resources. The international biofuels industry is obliged to do the transition from production of biofuels from food crops to a more sustainable production of biofuels either from lignocellulosic crops or residues and wastes, at a high plants reconversion costs. Technologies are in the stage of becoming fully commercial within five years; energy crops require the development of on-site experience and usually also specific on-site research to adapt correctly and sustainably the species to harvest. These two conditions give Lebanon the right opportunity to step into the market in an orderly way and avoid the costs of transition that the European industry, for example, will have to confront.

4.The potential contribution of agricultural residues is limited for all scenarios; however, the combined contribution of forestry, agricultural residues and waste streams (such as animal fats, slaughterhouse residues and olive cake by-products) also shows fluctuations for the different scenarios, although to a lesser extent. However, their total contribution can still be significant, especially when combined for the production of electricity and heat. About 930 GWh of electricity could be produced, with most of it coming from the combustion of these streams.

V.3 POLICY RECOMMENDATIONS

The scenario study shows that the 12% RES target is difficult to reach by bioenergy alone, even under the most positive scenario. The use of bioenergy should therefore be combined smartly with the deployment of other potential RES such as wind or solar to meet the 12% target in 2020.

Given the increased demand for power generation and industrial heat in Lebanon, priorities should be given to those technologies and bioenergy resources that can produce these end-uses. It is recommended to focus on existing, well known technologies for the generation of heat and power.

All Mohafazats, except Beirut, can contribute substantially to the total potential of bioenergy deployment of bioenergy. Excluding one or several of them has significant impact on the total availability of bioenergy in Lebanon.

Energy crops for bioenergy show an interesting potential for Lebanon. At the same time, their potential is also fluctuating most between the scenarios due to the different assumptions with respect to land availability, sustainability considerations and competition. The possible use of available lands requires proper land use planning and management and the consideration of sustainability criteria for its further deployment (see also chapter 4).

It is recommended to explore energy crop production with those energy crops that are also able to produce heat and power (in the middle to long terms), such as lignocellulosic energy crops.

Catalyzing the deployment of bioenergy through new policies, legislation and incentives to the market (as assumed under Scenario I) is key to reach the deployment of bioenergy in Lebanon.

Examples of the introduction of new legislation or policies to stimulate the deployment of bioenergy are:

- Enforcement of standards for industrial wastewater discharges;
- The development of solid wastewater treatment plans; national master plans favor the valorization of sludge;
- A forest management plan and additional legislative changes are developed that consider sustainable harvesting conditions.

In all cases, it is important not to focus on one single biomass resource or region for the development and deployment of bioenergy in Lebanon. Solutions should be sought in the exploitation of a combination of biomass resources, deployed in various mohafazats. Given the linkages between bioenergy and other sectors such as agriculture, water and forestry, policy makers should coordinate closely for the further development of policies and market initiatives.

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CHAPTER 4

SUSTAINABILITY IMPACT ASSESSMENT

INTRODUCTION

This chapter defines the environmental, economic and social sustainability criteria that Lebanon should aim for. The sustainability criteria to be established in the National Strategy will resemble, as closely as possible, existing standards like the European Sustainability Criteria for biomass and biofuels. In this way, the possibilities of trade of biomass products such as biofuels (ethanol and biodiesel) and solid biomass pellets with European Countries will be possible.

To assess the influence of the sustainability criteria for the scenarios (see chapter 3) analysed for Lebanon, this chapter will perform a sustainability risk assessment for the different types of biomass resources.

The sustainability impact analysis is based on two different sustainability levels. The first sustainability level is based on the compliance to the minimum current EU obligations, as defined under the EU Renewable Energy Directive (EC, 2009). The second sustainability level will include the compliance of most probable additional sustainability criteria. These additional criteria will be based on:

- Identified sustainability implications that are expected in Lebanon in a local context;
- Additional key initiatives[1] that are developed worldwide to establish principles and criteria to guarantee the sustainable production of biomass and bioenergy in a region or country.

The methodology to assess the sustainability performance of selected bioenergy chains in various regions is based on the so-called 'scorecard approach'.

This report outlines the sustainability criteria, threshold values and methodology to be used for the sustainability impact assessment.

II.SUSTAINABILITY LEVEL1: MINIMUM REQUIREMENTS

The sustainability level 1 is defined by the minimum level of sustainability obligations for bioenergy at the European Union stipulated mainly at the EU Renewable Energy Directive; those requirements are stipulated in Table 117.

The Renewable Energy Directive defines (mainly) environmental criteria for biofuels and other bioliquids to ensure that defined targets are reached in a sustainable way. The specific requirements are laid down in article 7 of the regulation (EC, 2009).

The regulation indicates that, irrespective of whether the raw materials were cultivated inside or outside the territory of the Community, energy from biofuels and bioliquids shall only be taken into consideration when a defined set of sustainability requirements are fulfilled for the following purposes (EC, 2009):

- Measuring compliance with the requirements of this Directive concerning national targets;
- Measuring compliance with renewable energy obligations;
- Eligibility for financial support for the consumption of biofuels and bioliquids.

The defined sustainability criteria in the EU Renewable Energy Directive for biofuels and bioliquids are shown in Table 117. Note that the Regulation indicates that biofuels and bioliquids produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need only fulfill the sustainability criterion on the GHG savings (EC, 2009).

[1]Although a wide range of initiatives are under development, maximum number of 10 most relevant initiatives will be taken into consideration.

Table 117: Sustainability criteria in the EU Renewable Energy Directive for biofuels and bioliquids (EC, 2009)

[2] With effect from 1 January 2017, the GHG saving from the use of biofuels and bioliquids shall be at least 50 %. From 1 January 2018 that GHG emission saving shall be at least 60 % for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017. In the case of biofuels and bioliquids produced by installations that were in operation on 23 January 2008, this shall apply from 1 April 2013.

[3] Unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes.

[4] The provisions of this criterion do not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

[5] Unless evidence is provided that the carbon stock of the area before and after conversion is such that the GHG reduction savings would be fulfilled.

[6] Unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously un-drained soil

Good Agricultural Practices (GAP) are "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" (FAO 2003). The four 'pillars' of GAP (economic viability, environmental sustainability, social acceptability and food safety and quality) are included in most private and public sector standards. FAO follows a set of 10 defined GAP principles:

- Soil
- Animal Production
- Harvest and On-Farm Processing and Storage
- Water
- Animal Health and Welfare
- Energy and Waste Management
- Crop and Fodder Production
- Human Welfare, Health, and Safety
- Crop Protection
- Wildlife and Landscape

These 10 GAP principles have strong links with other sustainability criteria mentioned in Table 117. Wildlife and landscape relates, for example, strongly with the exclusion of high biodiversity value areas.

Apart from the requirements as stipulated in Table 117, the Commission will report every two years to the European Parliament and the Council on various other aspects related to sustainability impacts of biofuels and bioliquids including:

- National measures taken to respect the sustainability criteria in Table 117 and for soil, water and air protection;
- Analysis of the impact on social sustainability of increased demand for biofuels;
- Impact of Community biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries, and wider development issues;
- The respect of land-use rights.

The first report will be published in 2012. Countries covered will be member countries from the European Union and other countries that produce and import significant quantities of biofuels and bioliquids to the EU. For analysis, the EC will consider whether the country has ratified and implemented various international conventions and declarations, which are shown in Table 118 (EC, 2009).

Table 118: International conventions considered by EC for sustainability reporting on countries in EU and other countries (EC, 2009)

Conventions and declarations	
Conventions of the International Labour Organisation (ILO):	Convention concerning Forced or Compulsory Labour (No 29);
	Convention concerning Freedom of Association and Protection of the Right to Organise (No 87);
	Convention concerning the Application of the Principles of the Right to Organise and to Bargain Collectively (No 98);
	Convention concerning Equal Remuneration of Men and Women Workers for Work of Equal Value (No 100);
	Convention concerning the Abolition of Forced Labour (No 105);
	Convention concerning Discrimination in Respect of Employment and Occupation (No 111);
	Convention concerning Minimum Age for Admission to Employment (No 138);
	Convention concerning the Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour (No 182)
International biodiversity declarations:	The Cartagena Protocol on Biosafety;
	The Convention on International Trade in Endangered Species of Wild Fauna and Flora

III. SUSTAINABILITY LEVEL 2: STRICTER REQUIREMENTS

The second and stricter sustainability level will be based on:

1. Sustainability implications that are expected in Lebanon in a local context;
2. Additional key initiatives that are developed worldwide to establish principles and criteria to guarantee the sustainable production of biomass and bioenergy in a region or country.

As a starting point, the strict sustainability requirements and levels will be designed according to the requirements in the Lebanese context.

A full analysis on worldwide key initiatives establishing principles and criteria to guarantee sustainable production can be found in the volume "Annexes" of this study, chapter 4, annex I "Key initiatives on sustainability criteria for bioenergy worldwide."

III.1 LEBANON AND THE SOCIO-ECONOMIC CONTEXT

Poverty is a serious problem in Lebanon despite some apparent improvement in the last decade. Poverty estimates place extreme poverty at 8% of the Lebanese population in 2005. This implies that almost 300 thousand individuals in Lebanon are unable to meet their food and non-food basic needs. Around 28.5 per cent of the population is below the upper poverty line, which translates into about US$4 per capita per day (UNDP, 2010).

Regional disparity is also a major characteristic of poverty; while North Lebanon has 20.7% of Lebanon's population; it houses 38% of the poor and 46% of the extremely poor; compared to Beirut that hosts only 1% of the extremely poor and 2.1% of the poor population (UNDP, 2010).

Unemployment rates in Lebanon are high among the poor and the majority of the poor are unskilled workers. Gender also affects unemployment rates; women in poor households are at a greater disadvantage (UNDP, 2010).

The following socio-economic sustainability impacts are of specific concern for the Lebanese context:

- Impact on food production and prices
- Competing uses
- Socio-economic effects
- Employment generation
- Rural agricultural and economic development
- Contribution to poverty reduction
- Land value
- Human health
- Gender
- Added value substitution for non-desired crops

III.2 LEBANON AND THE ENVIRONMENT

Although Lebanon has made considerable progress in protecting its environment since the early nineties, many critical environmental challenges remain. The 2006 July War recently exacerbated some of these. Furthermore, the pressure from economic and social activities on the limited natural resources available in Lebanon is difficult to control (UNDP, 2010).

The 2008 Environmental Performance Index (EPI) ranks 163 countries on 25 performance indicators tracked across ten policy categories covering: Environmental Health, Air Pollution, Water Resources, Biodiversity and Habitat, Productive Natural Resources, and Climate Change. These indicators provide a gauge at a national government scale of how close countries are to established environmental policy goals. The EPI's proximity-to-target methodology facilitates cross-country comparisons as well as analysis of how the global community is doing collectively on each particular policy issue. Table 119 shows the EPI for Lebanon in 2008 and 2010. In both years Lebanon ranked 90th in the list of 149 countries (EPI, 2008), (EPI, 2010).

Table 119: Environmental Performance Index (EPI) for Lebanon in 2008 and 2010

	2008 (max value=100)	2010 (max value=100)
Climatic change	47.1	38
Agriculture	62.3	91
Forestry	98.9	100
Biodiversity	3	3.5
Water (impact on ecosystem)	32.5	56
Air pollution (impact on ecosystem)	45.1	40.5
Water (impact on human)	82	98.9
Air pollution (impact on human)	62	81.6
Environmental burden of disease	66	64.4

Table 119 shows that pressing environmental issues are related to biodiversity loss, climate change (high CO2 emissions), water-related problems (with serious implications on ecosystems present in Lebanon) and high air pollution loads. The latter has, in combination with deficient solid waste management practices, an impact on the environmental burden of disease.

Although annual precipitation is estimated at around 8,600 million m3, water availability remains a critical issue of national importance in Lebanon due to the high demand for water, the large losses in the public water distribution networks and the high level of water pollution (MDG, 2008).

Solid waste in Lebanon continues to be a major environmental problem with more than 700 open dumps used by the municipalities and where, furthermore, 50% of this waste is being burned. This causes major underground water pollution and air pollution (MDG, 2008).

Biodiversity loss and land degradation were further degraded due to the July/August 2006 war. The oil spill crisis had a major adverse impact on environmentally sensitive ecosystems like the Palm Islands protected area. The proportion of terrestrial and marine area that is protected by law in Lebanon shows however a small increase of a little over 21,200 hectares in year 2007 (MDG, 2008).

In the last few years, the Ministry of Environment has successfully initiated the five-year national reforestation plan, which has resulted in the plantation of around 580 hectares of forest; however, at the end of the summer of 2007, devastating forest fires hit large areas of land across the country, destroying more than 2350 hectares of natural forests (MDG, 2008).

Based on this information, the following environmental sustainability impacts are of specific concern for the Lebanese context:

- GHG emission reduction
- Risk on biodiversity loss, and land degradation
- Increased competition on land resources
- Risk for invasiveness species
- Soil conservation
- Water use and quality
- Waste management
- Air and atmosphere (emissions and pollution loads)

III.3 SUMMARIZING LIST OF SUSTAINABILITY IMPACTS FOR STRICT SUSTAINABILITY LEVEL

Table 120 combines the list of sustainability impacts that are relevant to the Lebanese context, with the sustainability concerns, as developed in international initiatives and standards. Based on this information, we can come to a list of sustainability impacts that will be taken into consideration for the "strict sustainability level".

Table: 120: List of sustainability aspects for strict sustainability level

Requirements related to legal compliance (individual) producers
Human and labour rights [1) 2)]
Responsible community relations
Respect customary water rights
Land rights and land use rights
Reducing GHG emissions and energy use
Reducing GHG emissions
Promote national energy security
Economic affordability of energy use
Biodiversity impacts
Carbon conservation: maintenance carbon stocks
Biodiversity conservation: No risk for conservation high biodiversity value areas
Biodiversity conservation: No risk for land degradation by deforestation [3)]
Biodiversity conservation: No risk for invasiveness species
Environmental impacts
Soil conservation: Risk for soil degradation
Soil conservation: Risk for soil health
Water conservation: Risk for water quantity
Water conservation: Risk for water quality
Air pollution shall be minimized [4)]
Socio-economic impacts
Poverty reduction: Contribution to socio-economic development [5)]
Employment generation
Reducing fuel poverty in regions
Competition with food and other uses
Biomass production does not impair food security, which is defined under: • Food availability (reduced food cultivated and land price increases); [6)] • Food access; • Food vulnerability
No endanger on local (non-food) biomass applications [7)]
Good agricultural practices as defined as: [8)]
Crop protection: Responsible use of fertilizers
Crop protection: responsible use of pesticides and chemicals
Responsible waste management
No risk for forest fires
Best management practices

[1]Labour rights include decent work and well-being for workers (e.g. safe working conditions, health), also refers to Good Agricultural Practices as defined by (FAO, 2003).
[2]Labour rights includes no discrimination (e.g. related to gender)
[3] Risk of land degradation by desertification is included under soil conservation
[4]Includes risk of air pollution from burning residues and waste (in open air)
[5]Assumed that profitability of bioenergy chain creates added value and possibility for substitution for non-desired crops). Recommendations for possibilities to replace non-desired crops will also be partly retrieved from outputs under the impact 'community relations'.
[6]It is assumed that increased land prices and decreased cultivated land for food will also lead to a risk for increased competition of land resources. This is not included as a separate item.
[7]Includes competition of co-products
[8]This methodology has covered, under the item Good Agricultural Practices, those aspects that are not explicitly covered under other sustainability principles or aspects. These are: Crop protection: Fertilizer and pesticides use, Waste management and Best management practices including selection of most suitable crops and practices for sustainable management, on-farm processing and storage.

IV.METHODOLOGIES TO ASSESS SUSTAINABILITY PERFORMANCE AND FOOD SECURITY

A full explanation of the methodology developed to assess sustainability performance and the scorecard approach for this study is presented in the volume "Annexes" of this study, chapter 4, annex II "Methodology to assess sustainability performance."

A full explanation of the methodology to assess the risk on food security is presented in the volume "Annexes" of this study, chapter 4, annex III "Methodology to assess risk for food security."

V.OVERVIEW OF EXISTING SUSTAINABILITY PRINCIPLES AND CRITERIA

A full overview of the existing sustainability principles and criteria for biomass and biofuels is presented in the volume "Annexes" of this study, chapter 4, annex IV "Overview of principles and criteria of selected initiatives."

VI.SUSTAINABILITY IMPACT ASSESSMENT

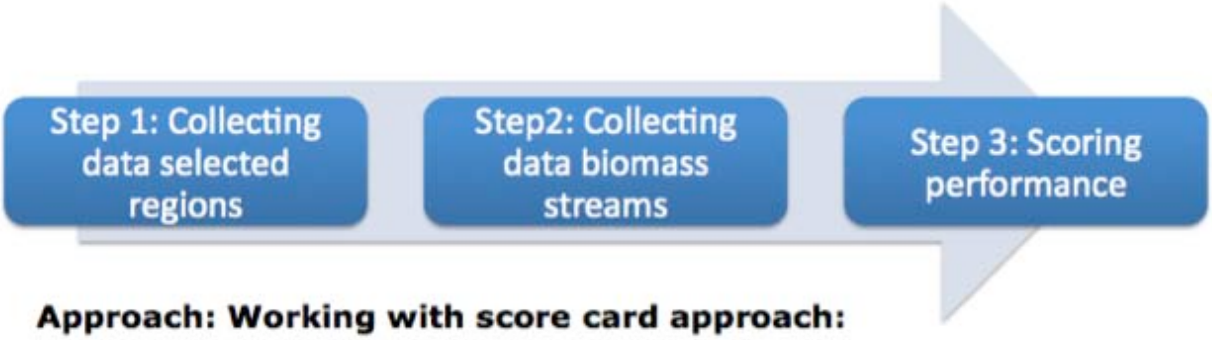
The feasibility of the deployment of promising bioenergy routes not only depends on the available biomass potential and economic performance, yet a condition for a sustainable performance of bioenergy development is to ensure that negative sustainability impacts are avoided. This chapter will therefore look at the expected sustainability impacts of promising biomass resources, as defined in chapter 1.

The sustainability impact analysis is based on two different sustainability levels. The first sustainability level is based on the compliance to the minimum current EU obligations, as defined under the EU Renewable Energy Directive (EC, 2009). The second sustainability level includes the compliance of the most probable additional sustainability criteria, as shown in Table 120.

VI.1 APPLICATION OF THE SCORECARD APPROACH METHODOLOGY

The sustainability impact assessment is based on the scorecard approach. This approach enables to select promising biomass streams per region (for sustainability aspects) and key concerns for sustainability impacts. The scorecard approach is a three-step approach (Figure 37) that basically links the socio-economic and environmental information in the region with the expected impacts of the introduced biomass resources.

Figure 37: Three-step approach for scorecards methodology



The third step links the collected information in the region with the information on the biomass resources. Its performance will be assessed on defined threshold values.
The threshold values are differentiated to the risk of negative impacts when a biomass and bioenergy chain is introduced in a region, distinguishing:

- No to low risk;
- Medium risk;
- High risk

Possible positive impacts are grouped under 'no' to 'low' risks. These positive impacts will be highlighted in the evaluation of the impact assessment.
Table 121 sets the scoring rules that are used in the sustainability impact assessment of biomass resources in each mofahazat.

Table 121: Scoring rules for final performance region – biomass resource combination

Impact	Scoring rule
Socio-economic impacts: Community relations, poverty, employment, fuel security	If the risk in the region is zero to low; then the final impact is expected to be zero or low
Legislative or policy related impacts: Human rights, water rights, land use rights Impacts related to competition of food and other uses Environment related impacts: presence of land with high carbon stocks, presence of deforestation, endemic species, HCV areas, soil conservation, soil health, water quantity and quality, air emissions	If the risk of the resource in the region is zero to low, then the final impact is expected to be zero or low
Energy related impacts: GHG emissions and energy use, energy security	If the risk of the resource is zero to low, then the final impact is expected to be zero or low
Energy related impacts: GHG emissions and energy use, energy security	Risk in region is considered to be equal for all regions (medium). Distinctions in final impact assessment are based on the resource assessment

SELECTED REGIONS

The regional sustainability impact assessment is performed on the level of mohafazats including: North Lebanon, Mount Lebanon, Beirut, Nabatiyeh, South Lebanon and the Beqaa region.

When relevant, more specific information is provided on the caza level.

SELECTED BIOMASS RESOURCES

The selected biomass resources are those resources as selected in the biomass potential assessment of chapter 1.

These include:

• Woody biomass and fellings	• Animal fat
• Residues from fellings	• Slaughterhouse residues
• Wood residues from wood industry	• Olive cake by-products
• By-products from paper industry	• Org. residues & Waste food proc. industry
• Residues of olive trees	• Wastewater& sludge food proc. industry
• Residues of fruit trees	• Biodegradable fraction of MSW
• Residues of Cereals	• Landfill potential
• Manure	• Industrial and commercial waste
• Cereal crops	• Waste wood
• Oil seed crops	• Municipal sewage sludge
• Lignocellulosic energy crops	• Landscape management residues
• Salicornia	• Yellow grease
• Algae	

In chapter 1, the following energy crops are selected for the different mohafazats:

- Jatropha has been selected for the Beqaa region: as the climate of the region is appropriate to grow this oilseed energy crop (precipitation and temperatures);
- Sunflower has been selected for the North Lebanon region as the climate is quite mild and the soil conditions suits its growth;
- Perennial grasses, such as giant reed has been selected for Nabatiyeh region as it fits well with the soil condition and climate of the region;
- Jojoba is another crop that could be of interest for the future; however it is disregarded at this stage due to the high value of jojoba oil in the cosmetics industry.

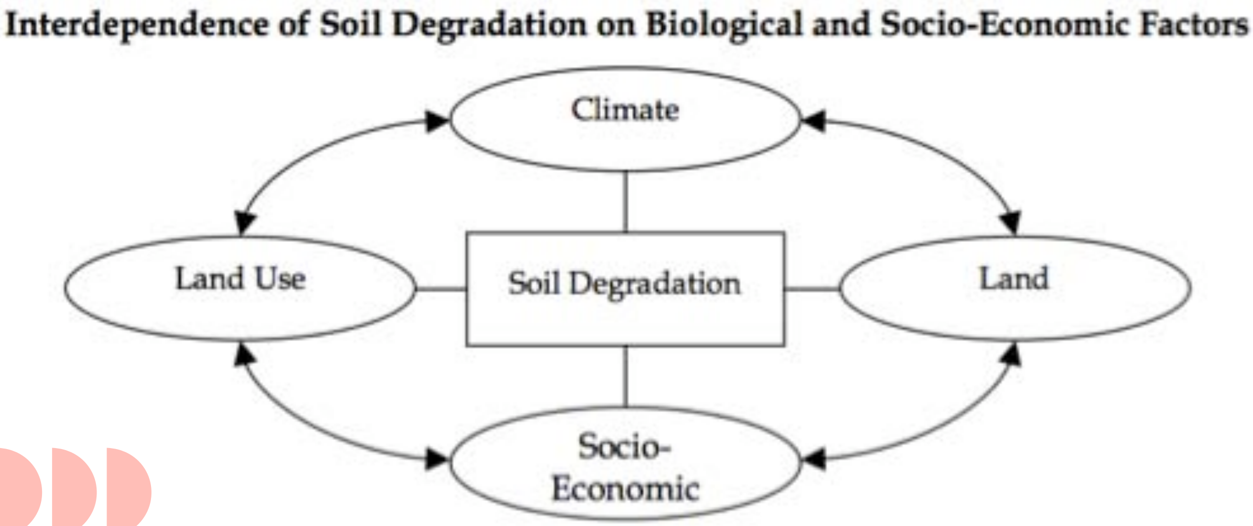
CONSIDERATIONS OF THE METHODOLOGICAL APPROACH

Although the performance of the individual criteria is based on defined thresholds, its interpretation should be seen as a relative scoring of the sustainability performance of the selected region – biomass resource combinations. In other words: the final scoring largely shows which regions – biomass resource combinations are performing better or worse than other ones, filtering the best options for Lebanon in terms of sustainability aspects.

VI.2 INTERRELATIONS AND WEIGHING OF IMPACTS

Several of the sustainability impacts included in the assessment are interrelated to one other. For example, both anthropogenic and natural factors affect soil quality and potentially result in soil degradation. Natural factors may include climate (i.e., rainfall, temperature, wind), and land (i.e., terrain, vegetation cover, parent material and soil type). Anthropogenic factors include land-use systems (i.e., farming systems, use of non-conventional water sources for irrigation, grazing arrangements and intensity, forest management, terracing) and socio-economic factors (e.g. population density, urban encroachment, road networks, industrial zones), as shown in Figure 38 below.

Figure 38: Interdependence of impact soil degradation with other factors



Clearly, the improvement or deterioration of one impact can therefore also highly affect the scoring of other sustainability impacts. The interrelations of the impacts included in the sustainability assessment and the wide diversity of impacts included also mean that the improvement of one impact may result into a deterioration of another. For example, the choice for stimulating bioenergy projects from MSW may on the one hand limit the risk for undesired land use changes but may also minimize (compared to other resources) the opportunities for employment generation in the agricultural sector, and therefore poverty reduction in rural areas. On the other hand, cultivation of energy crops usually creates employment opportunities in the agricultural sector; however they increase largely the risk for land use change through development of additional activities in the chain, however they increase largely the risk for land use change when developed in a non-sustainable manner.

Consequently, the linkage of bioenergy production with many relevant policy areas such as agriculture, energy, poverty reduction or forestry enforces policy makers and the market to make clear choices and priority settings.

Although the performance of the individual criteria is based on defined thresholds, its interpretation should be seen as a relative scoring of the sustainability performance of the selected region – biomass resource combinations. In other words: the final scoring largely shows which regions – biomass resource combinations are performing better or worse than other ones, filtering the best options for Lebanon in terms of sustainability aspects.

The scoring of impacts ranges from high to medium and low impacts (including positive impacts) in relation to a defined threshold. This threshold is in some cases based on existing thresholds in policies (e.g. GHG reduction requirement according to the thresholds in the European RED); in other cases it is based on the author's interpretation and therefore may always include some subjectivity. These thresholds are explained for each individual impact. For example, the threshold for promoting national energy security is:

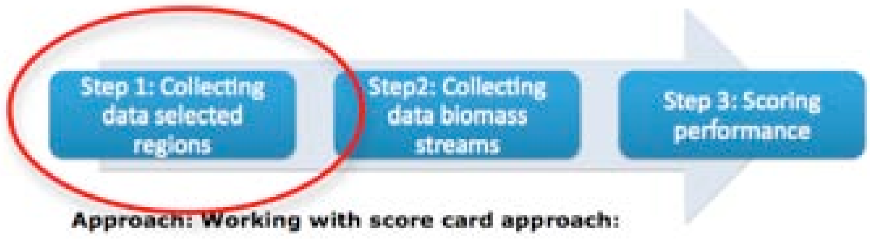
- Low risk: >10% contribution of total renewable energy needs in region
- Medium risk: 5-10% contribution of total renewable energy needs in region
- High risk: <5% contribution of total renewable energy needs in region

It is thus important to keep in mind that a low sustainability performance of a biomass resource is always in comparison with the other biomass resources in the list and compared to the defined thresholds.

VI.3 PRESENTATION OF REGIONAL ASSESSMENT

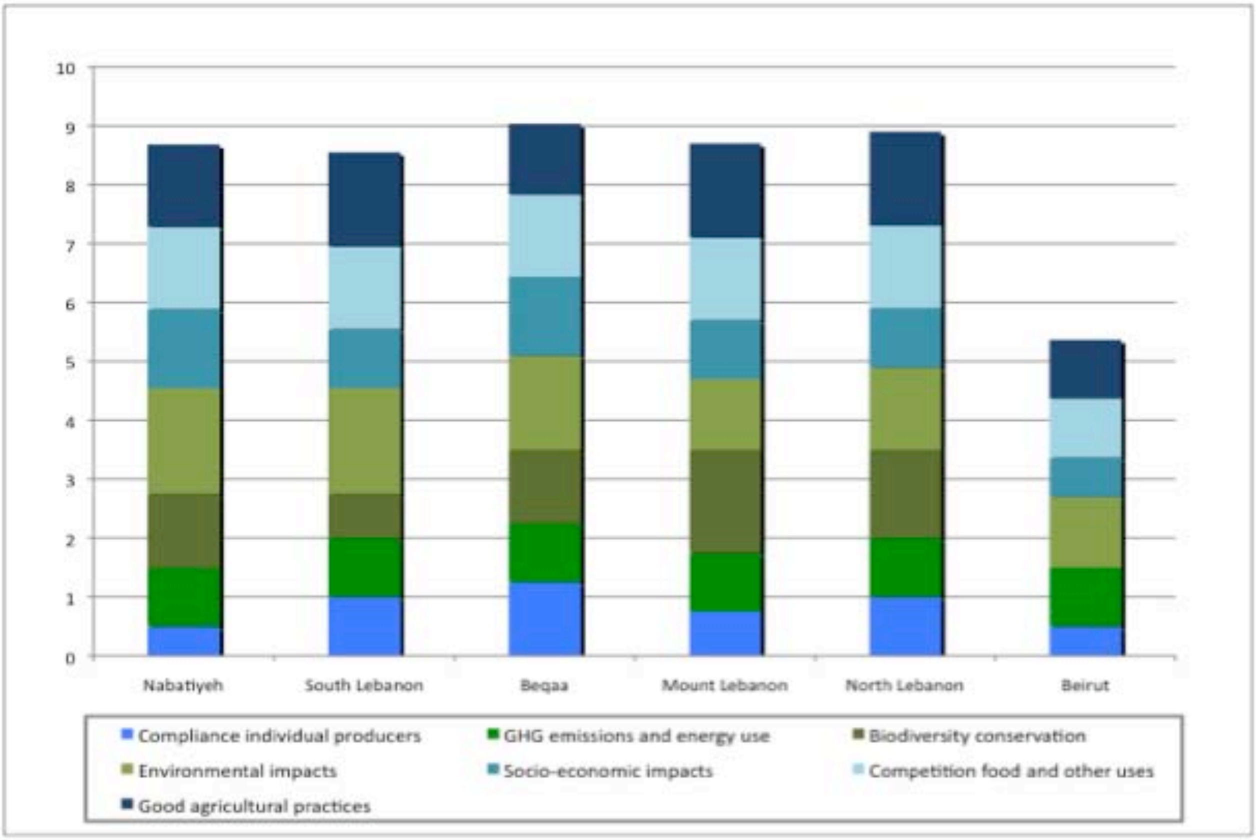
Collecting data for the selected region is the first step of the sustainability assessment (Figure 39).

Figure 39: Step 1 of the scorecard approach



The results of the regional assessment show the first step of the scorecard approach: The vulnerability of the region in terms of sustainability impacts. The results are presented on the mohafazat level. Figure 40 shows the sustainability impact performance for the various mohafazats.

Figure 40: Total scoring and scores of analysed sustainability impacts for the different mohafazats in Lebanon (based on 1:1 weighing score)



The total score for the different mohafazats is based on weighted assessment is shown in Table 122. The score is calculated by summing the individual impacts under one issue (e.g. biodiversity) and dividing them through the number of impacts under this issue (which is 4 for biodiversity).

Table 122: Total score for mohafazats based on weighted assessment

Score with no weighting 1:1	Based on differential weighing (distribution of 7 points)
• Nabatiyeh: 8.7 (3) • South Lebanon: 8.6 (2) • Beqaa: 9.0 (5) • Mount Lebanon: 8.7 (3) • North Lebanon: 8.9 (4) • Beirut: 5.4 (1)	Nabativeh: 9.3 (3) South Lebanon: 8.0 (2) Beqaa: 9.3 (3) Mount Lebanon: 9.6 (4) North Lebanon: 9.3 (3) Beirut: 4.6 (1)

Note that Beirut has a lower score (i.e., better relative score) compared to the other mohafazats. This can partly be attributed to the fact that some of the analysed sustainability aspects (e.g. for High Conservation Value -HCV areas[7]) are simply not present in Beirut.
Although total final differences are limited between mohafazats, the contribution of the various issues to the total score differs per mohafazat. For example: the environmental impacts score 1.2 in Mount Lebanon while this issue scores 1.8 in Nabatiyeh and South Lebanon. Also, North Lebanon scores 1.5 on biodiversity conservation compared to 0.75 in South Lebanon.
It must be noted that all regions show some level of vulnerability to both environmental and socio-economic issues.

VI.4 PRESENTATION OF RESULTS OF THE RESOURCE ASSESSMENT

Collecting data for the selected biomass streams is the second step of the sustainability assessment (Figure 41)

Figure 41: Step 2 of the scorecard methodology

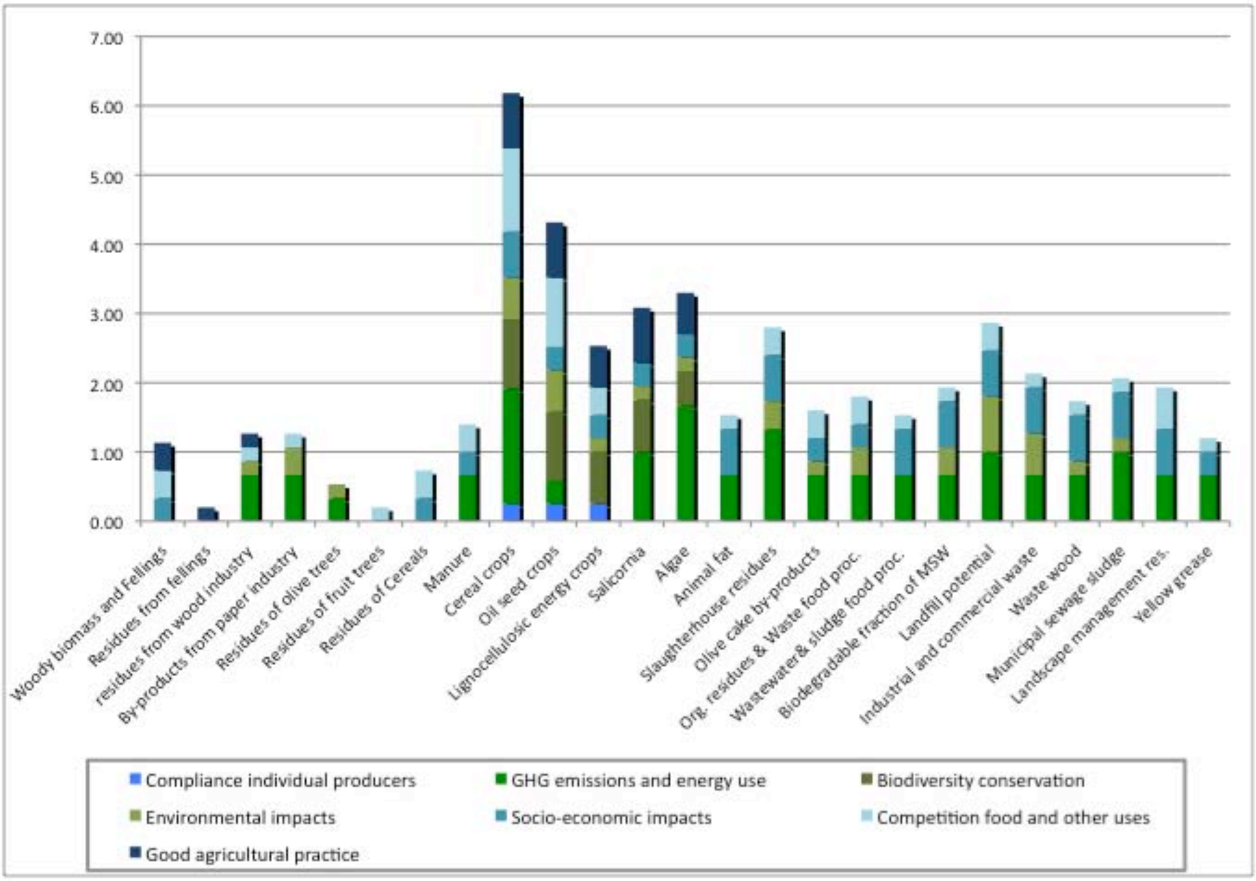
The results of the resource assessment show the second step of the scorecard methodology: The vulnerability of the biomass resources for the sustainability impacts. More specific information can be found in the next section: Assessment of the individual sustainability criteria for Lebanon.

The total score and the individual contribution of the sustainability issues are shown in Figure 42. Note that the method for calculating the total score is based on a 1:1 weighing of the impacts.
Note that some of the criteria are only applicable to a limited number of biomass resources (e.g. responsible use

[7]Definition of HCV areas type: http://bioenergywiki.net/images/b/b3/Env_paper_6_-_HCV_Areas.pdf

of fertilizers), which should be taken into account when interpreting the results. This also largely explains the higher score of energy crops compared to other biomass resources: good agricultural practices or biodiversity issues only apply to land use related biomass resources.

Figure 42: Total score and individual contribution of the sustainability issues to the score for the selected biomass resources.

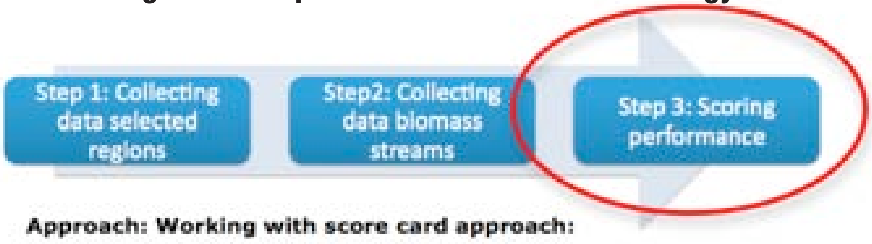


Residues from agriculture and forestry produce the lowest impacts among all biomass streams. Lignocellulosic energy crops are also more sustainable than cereal crops and oil seed crops that are harvested for energy uses. GHG emissions of food crops are usually higher than lignocellulosic crops, due to the use of fertilizers by instance, or due to the non-observation of best agricultural practices. Food crops are also assessed as producing larger sustainability impacts compared with the rest of biomass streams as they may create competition with food. Note though that several of the expected impacts can be mitigated through additional measures (see also section 2d) and through the deployment of a combination of various biomass resources.

VI.5 FINAL ASSESSMENT

The results of the final assessment show the third step of the scorecard approach: Combining the scores from the regions and from the biomass resources (Figure 43). This assessment shows which combination of regions-biomass resources are performing better than others, reflected on a mohafazat level.

Figure 43 Step 3 of the scorecard methodology



Note that this final score is a combination of individual scores and underlying assumptions, as performed under the regional and biomass resource assessment.

Table 123 shows that appropriate combinations of biomass resources – regions can be selected, or a combination of them. For example, the deployment of yellow grease seems to be an appropriate option for Beirut while less attractive for North Lebanon. Also, the development of landfill potentials for bioenergy seems more appropriate for Beirut than for other mohafazats.

Table 123: Results total score of final sustainability assessment for region – biomass resource combinations

Scoring card:	No risk		Medium risk			High risk
	< 1	1.0 - 1.5	1.51 - 2.0	2.01 - 3.0	3.01 - 4.0	4.01 - 5.0
	5.0 - 5.5	> 5.5		Not available		

	Beirut	N Lebanon	M Lebanon	Beqaa	S Lebanon	Nabatiyeh
Woody biomass and Fellings	1,00	1,62	1,49	1,88	1,59	1,63
Residues from fellings	0,53	0,95	0,83	1,12	0,83	0,87
residues from wood industry	1,33	2,05	1,83	2,22	1,83	1,97
By-products from paper industry	1,33	2,15	1,83	2,22	1,93	2,07
Residues of olive trees	0,87	1,38	1,16	1,45	1,26	1,30
Residues of fruit trees	0,53	0,95	0,83	1,12	0,83	0,87
Residues of Cereals	0,80	1,22	1,09	1,38	1,09	1,13
Manure	1,30	1,72	1,59	1,88	1,59	1,63
Cereal crops	3,68	6,32	6,42	6,36	5,99	6,31
Oil seed crops	2,62	5,15	5,25	5,19	4,83	5,14
Lignocellulosic energy crops	1,48	3,44	3,54	3,51	3,14	3,46
Salicornia	1,57	3,75	3,63	3,57	3,23	3,52
Algae	2,07	3,58	3,45	3,82	3,28	3,57
Animal fat	1,17	1,88	1,66	2,05	1,66	1,80
Slaughterhouse residues	2,47	3,18	2,86	3,25	2,96	3,10
Olive cake by-products	1,40	2,22	1,89	2,28	1,99	2,13
Org. residues & Waste food proc.	1,70	2,52	2,19	2,58	2,29	2,43
Wastewater& sludge food proc	1,17	1,88	1,66	2,05	1,66	1,80
Biodegradable fraction of MSW	1,67	2,38	2,06	2,45	2,16	2,30
Landfill potential	2,70	3,32	3,09	3,38	3,19	3,23
Industrial and commercial waste	1,97	2,68	2,36	2,75	2,46	2,60
Waste wood	1,47	2,18	1,96	2,35	1,96	2,10
Municipal sewage sludge	1,80	2,42	2,19	2,58	2,19	2,33
Landscape management res.	1,47	2,18	1,96	2,35	1,96	2,10
Yellow grease	1,00	1,72	1,49	1,88	1,49	1,63

VI.6 MITIGATION OPTIONS AND OPPORTUNITIES

The risk on certain impacts can be avoided through the selection of appropriate mitigation measures. On the other hand, positive benefits from bioenergy production can be further enhanced through highlighting these opportunities.

The individual impact assessment proposes, for every impact, a set of mitigation measures and opportunities to minimize the possible negative impacts and to promote the possible positive impacts. These measures are listed in the table 107 and relate, for example, to management practices or policy measures.

Wastewood being formed in Nabatieh

Table 124: Proposed mitigation measures and opportunities when deploying biomass resources in Lebanon

Issue 1: Requirements related to legal compliance (individual) producers	
Human and labour rights	• Promotion of human rights and responsible labour rights through and with the development of bioenergy projects in Lebanon; • Stimulate gender equality.
Responsible community relations	• Alternative energy crop production could be a socio-economic development option to reduce community conflicts, especially in areas with illicit crop production.
Respect existing water rights	• Constructive cooperation and permanent consultations between local communities, government and related institutions avoid conflicts related to water rights; • Limit water use in newly developed bioenergy projects.
Land rights and land use rights	• Improved land administration systems that harmonize formal and customary land tenure will be required; • The risks for conflicts in land use rights seem to be smaller when managed on a small scale with involvement of the local population.
Issue 2: Reducing GHG emissions and energy use	
Reducing GHG emissions	• When opting for the production of oilseed crops for biodiesel production, Jatropha is preferred above sunflower in terms of GHG reduction performance; • In all cases, the risk for indirect land use change should be taken into consideration (see also impact 6); • At the end, the GHG reduction performance highly depends on the local and case-specific parameters and significant improvements can be made through selection of technology, reference land use, management system, etc…
Promote national energy security	• A combination of resources (e.g. various residues or a combination of waste, residues and energy crop streams) can substantially increase the potential of bioenergy to the RES target in Lebanon; • Even though a biomass resource will not contribute much to the 12% RES target, it may still significantly contribute to the self-generation of energy in some regions that experience power cuts on a regular basis. • The actual contribution of the biomass resource depends on its deployment.
Economic affordability of energy use	• In all cases, the deployment of bioenergy will require financial incentives to become competitive with the production cost of fossil fuel resources; • The subsidies of fossil fuels makes renewable energy sources less competitive and interesting for the consumer; It is recommended to create a level playing field on the market when developing renewable energy resources; • Long-term running economic costs from fossil fuel resources (health impacts) and possible profits from renewable resources (carbon credits) are not taken into consideration here and may drastically change the picture.
Issue 3: Biodiversity impacts	
Carbon conservation: maintenance of carbon stocks	• Good land use planning to avoid the growing of bioenergy crops on lands with high carbon stocks is recommended; • Some level of protection for lands with high carbon stocks is recommended. • Energy crops such lignocellulosic crops create the opportunity to improve soil carbon stocks on degraded land areas.
Biodiversity conservation: No risk for conservation in high biodiversity value areas	• Strict monitoring and enforcement of exclusion and High Conservation Values (HCV) areas for biomass production; • Enlarging the area of natural reserves by including current non-protected HCV areas; • Biomass production can improve biodiversity in certain areas by: i) reforestation of degraded lands by woody biomass or by ii) grassland rehabilitation by lignocellulosic energy crops.
Biodiversity conservation: No risk for land degradation by deforestation [3]	• Effective protection and legislation to protect forests is in place; • Good sustainable land use planning; • Reforestation projects by establishing bioenergy projects from woody biomass.
Biodiversity conservation: No risk for invasiveness species	• Guidance exists for measures at every stage in the supply chain and for governments as well as developers and investors; examples are a weed risk assessment of potential crops or to prevent spread of seeds, pests, etc. during transport and monitor transport corridors; • For more information, see: UNEP (2010).

Issue 4: Environmental impacts	
Soil conservation: Risk for soil degradation	• The risk for soil conservation can be strongly minimized when proper agricultural management such as no-tillage and maintenance of soil cover are practiced; • Use of appropriate residue to product ratios, adapted to the local situation • Local variations to vulnerability of soil erosion should be taken into consideration.
Soil conservation: Risk for soil health	• Guarantee compliance and monitoring of laws to avoid soil pollution; • Requirement of monitoring devices and state-of-the-art technology in installation of processing units.
Water conservation: Risk for water quantity	• To buffer the need for additional water withdrawals from local aquifers, bioenergy feedstock should be chosen with respect to geo-climatic conditions (this includes conditions such as local water availability and rainfall); • Given the current and expected increases in future water demand, irrigation for bioenergy crop production is not recommended.
Water conservation: Risk for water quality	• The sustainable use of wastewater and sludge for bioenergy production has the potential to reduce the discharge of contaminated pollutants in the water; • Ensure the installation of adequate water treatment systems and other initiatives in new bioenergy projects to ensure compliance with national standards.
Air pollution shall be minimized	• Adequate monitoring and enforcement of legislation of air emissions will generally prevent the risk of high air emission levels from bioenergy (and other sources); • The use of olive and cereal residues for bioenergy, instead of burning them in the field, will reduce emissions on the respective agricultural production sites.
Issue 5: Socio-economic impacts	
Poverty reduction: Contribution to socio-economic development	• Biomass production for energy can be used to reduce poverty in rural areas, especially by the economic benefits generated from dedicated energy crop production in currently abandoned or degraded (agricultural) land; • Dedicated energy crop production (from e.g. Jatropha or Hemp) can be used to replace non-desired crops in the Beeka area.
Employment generation	• For many of the stages in the value chain of bioenergy production, there may be opportunities to deliberately involve the unemployed (and poor) in employment generation; • When one includes the jobs created in the production and harvesting of the biomass energy crop, the possibilities for employment generation of biomass energy become apparent; this is especially relevant to generate employment in rural areas.
Reducing fuel poverty in regions	• To reduce the existing impacts of limited fuel security, the promotion and deployment of bioenergy projects for heat and power are preferred above projects for biofuel production; • Those bioenergy projects that can offer local solutions to reduce the impact of power blackouts are preferred.

Issue 6: Competition with food and other uses	
Biomass production does not impair food security (competition)	• Even though suitable land for bioenergy crop production may be available in a region, good land use planning in consultation with local communities is key to avoid unexpected land use changes & conflicts; • Various tools and methods are under development to check in the field the risk on (indirect) land use changes from bioenergy production, see for example: Module 1 of the FAO-BEFS project (http://www.fao.org/bioenergy/foodsecurity/befs) or an overview of existing participatory planning tools on http://www.iapad.org/toolbox.htm
Food availability (reduced food cultivated and land price increases)	• Risk for increasing land prices and tensions in land ownership can be avoided when energy crops are integrated into smaller holder systems; • Risk for increasing land prices and tensions in land ownership can be avoided when energy crops are selected that can be grown on marginal or degraded land.
Food access	• To improve the purchasing power of poor communities, it is recommended to involve the relatively more vulnerable and less well-off groups in the deployment of bioenergy projects.
Food vulnerability	The introduction of new energy crops will lead to further diversification of Lebanon's agricultural production (when produced on small to medium scale). Given current high import levels of agricultural commodities in Lebanon: • The further introduction of cereals and sunflower is only recommended for food purposes; • The production of energy crops is only recommended on those lands that cannot be used for food purposes.
No endanger on local (non-food) biomass applications	• Those resources with a more competitive end-use or with lack of alternative uses, should not be further developed for bioenergy purposes; • In those cases where biomass resources turn out to be more competitive when used for bioenergy deployment, a transition process can assist to avoid sudden price fluctuations in the market or shortages / oversupply of the resource.
Issue 7: Good agricultural practices as defined as:	
Crop protection: Responsible use of fertilizers	• Appropriate rotation and management can restrict the development of secondary soil salinization even when using slightly saline water. • Growing a productive crop requires correct fertilization and adequate rainfall or irrigation (see also good agricultural practices).
Crop protection: responsible use of pesticides and chemicals	• Information, instruction, and training of pesticide-exposed workers should be further promoted, since these activities are fundamental aspects of health protection; • Improved monitoring and enforcement on pesticide use; • Promotion of integrated pest management.
Responsible waste management	The use of the following biomass resources can contribute to solving the increasing pressure on waste disposal and generation in Lebanon: • Residues from the wood industry; • Slaughterhouse residues; • Olive cake by-products; • Organic residues and waste food processing industry; • Wastewater and sludge food processing industry; • Biodegradable fraction of MSW; • Landfill potential; • Industrial and commercial waste; • Waste wood; • Landscape management residues.
No risk for forest fires	• Woody biomass, fellings and residues can be used in the fight against forest fires. • Good land use planning and sustainable management of energy crops to ensure that no increasing land pressure or environmental impacts are created that indirectly may enhance forest fires
Best management practices	• Good agricultural and forestry practices for bioenergy production can be promoted through existing structures, networks and best practices from conventional agriculture and forestry production; • The stimulation of sustainable bioenergy projects could be used to further promote the development of good practices in Lebanon; • Gaining experience in the certification of non-conventional crops as ryegrass or Jatropha is recommended.

VI.7 OUTLOOK TO SCENARIOS

This chapter also provides information on the possible contribution of the mohafazats to bioenergy development and deployment over time for various scenarios;

- Scenario I shows the highest potential for bioenergy development, with a potential high contribution from energy crop production; Contributions from other biomass resources are relatively limited;
- Contributions from the food processing industry on bioenergy deployment are expected to be limited;
- Beirut shows the smallest potential in contribution to bioenergy development and deployment;
- A strict sustainability level is only considered for Scenario I.

Based on the outcomes in the scenario assessment in Chapter 3 and the sustainability impact assessment, the following conclusions can be made:

- The region (Beirut) with the lowest expected impact in terms of sustainability also has the lowest potential in bioenergy development and deployment;
- The biomass resource with possibly the highest potential in terms of bioenergy production also shows the highest risk in terms of sustainability impacts; The full exploitation of available land for bioenergy production may be substantially smaller when all sustainability impacts are taken into consideration;
- Strict sustainability levels are only considered for Scenario I. Given the versatility of possible sustainability risks, this strict sustainability level is also recommended for the other scenarios.

VI.8 DIFFERENT SUSTAINABILITY LEVELS AND POLICY RECOMMENDATIONS

Two sustainability levels have been developed in this Chapter; a soft sustainability level that is largely based on international developments for sustainability criteria of bioenergy and a strict sustainability level, which considers the local environmental and socio-economic situation. Considering the versatility and vulnerability of the Lebanese regions in terms of the environment and the socio-economic situations, the development of a strict sustainability level for bioenergy projects is highly recommended. In all cases, good monitoring and enforcement of these sustainability requirements needs to be ensured.

The development of sustainable bioenergy projects could i) provide best practices for other sectors and ii) mitigate existing environmental problems in other sectors. Some examples are as follows:

- The use of waste for bioenergy production;
- The promotion and development of certification procedures and / or policies for sustainable agricultural and forestry practices;
- Reducing the risk of fire in forest areas;
- Poverty reduction in rural areas.

Energy crop production for bioenergy provides an interesting potential for Lebanon and may provide benefits to rural areas and poor communities. On the other hand, this category of biomass resources also shows potentially the largest risks in terms of sustainability impacts. Key considerations are the water limitations, competition of land and the food vulnerability (in terms of imports) in Lebanon. The deployment of small-scale projects, with an appropriate selection of land use (marginal or degraded lands preferred) and crop, which allow time for learning and risk avoidance, is therefore highly recommended.

In all cases, the deployment of bioenergy projects should consider the local variation in environmental and socio-economic aspects within Lebanon and within the mohafazats.

VII.ASSESSMENT OF THE INDIVIDUAL SUSTAINABILITY CRITERIA FOR LEBANON

The defined individual criteria is discussed one by one. The assessment starts with an analysis on the situation for the specific criterion on the regional level, followed by an analysis on the expected impacts for the defined biomass resources, combining the two results in the final assessment, following the scorecard approach.

Full assessment is presented in the volume “Annexes” of this study, chapter 4, annex V “Assessment of the individual sustainability criteria for Lebanon.”

VIII.GREENHOUSE GAS AND ENERGY BALANCES OF RELEVANT BIOENERGY OPTIONS

In order to quantify some of the most important environmental advantages of Lebanon's bioenergy options, this section will subject some of these options to a LCA-style (Life Cycle Assessment) Greenhouse Gas balance and Energy balance, and existing LCA results on relevant bioenergy options are reported. This will enable a more realistic assessment of the ability of identified bioenergy options to reduce GHG emissions (and other environmental impacts), and to the fossil energy needed to produce a bioenergy-product with its fossil alternative, among other benefits. Bioenergy options are defined here as a combination of an available feedstock with an appropriate bioenergy conversion technology.

Life-cycle assessment (LCA) describes a technique that analyses a product over its entire life cycle, focusing on all required inputs and all outputs generated during production, use and disposal of a product. In the context of bioenergy, two types of results are of specific interest; the Energy balance (or energy gain ratios) and the Greenhouse Gas balance (or GHG savings). A bioenergy product is an energy carrier, but it does not only deliver energy, it also costs energy to produce. The Energy balance results in an energy gain ratio (EGR), which is the total energy the bioenergy product contains, minus the energy cost of creating, transporting and storing this product. Greenhouse Gas balances take this one step further; besides the GHG emissions associated to the energy balance (avoided emissions because of using bioenergy instead of fossil energy, and emissions caused by the energy needed to produce, transport and store bioenergy, GHG balances also account for non-energy related GHG emissions, for instance because of N2O production due to fertilization of the feedstock or changes in carbon stocks due to Land Use Change.

VIII.1 METHODOLOGY SELECTION

Although an ISO standard for LCA exists (14040 and 14044), there is no exact methodology to follow. Therefore LCAs of the same product can have significantly different outcomes if different system boundaries (e.g. include land use change, energy costs of producing equipment), different assumptions (e.g. average transport distance, energy needs of production process), allocation methods to co-products (bioethanol production from corn also produces animal feed. How much of the energy/emissions are attributed to the bioethanol and how much to the animal feed? Total has to be 100%) and per geographical region.

In order to be able to compare different bioenergy options with each other, a unified methodology is needed. The European Commission (EC) has carefully analysed the different options of LCA methodology for liquid biofuels. The choice was made to restrict LCA work to GHG emissions (the EC has imposed other sustainability criteria, but none of these are LCA-style calculations), for which a standardized methodology was laid down in two EU directives, the Renewable Energy Directive (EU-RED) and the Fuel Quality Directive (EU-FQD). Wherever possible and appropriate, this section follows this methodology. This offers the added benefit of being able to compare the result in this section with results reported for the EU, and gives some insight if the Lebanese bioenergy product could have the EU as an export market. Some of the key characteristics of the EU methodology:

- The functional unit is in grams of CO2 equivalent (gCO2eq) per MJ energy content of the biofuel (other options could have been gCO2eq/km or gCO2eq/litre).
- The production of machinery (trucks, factories) is not included.
- Allocation is based on energy content (LHV), this means that the released emissions are divided over co-products relative to their energy content (e.g. bioethanol contains 60% of the total co-product energy content, therefore is responsible for 60% of emissions. Other options could have been, for e.g., allocation relative to market value, weight, emissions needed to substitute co-product). Naturally, no emissions are allocated to waste streams.
- If the feedstock is a waste stream (e.g. manure, animal fat) no emissions are allocated to the "production" phase, it is assumed that this waste would have been produced anyway, and was not produced for the sake of bioenergy production.

While selecting the best sources of all the kinds of different data required for the GHG and energy balances, priority is given to data specific to Lebanon or one of its geographical region. In these are not available reputable data sources have been used in all other cases, giving preference to sources that have used the same or similar methodology as used in the calculations presented here. For GHG and energy balances, transport has a major impact. On this topic, the Lebanese context is important to describe;

- Firstly, no international transport is considered; bioenergy is to be produced and consumed in Lebanon.
- There is no transport over sea, and inland waterways and rail transport currently don't exist in Lebanon, therefore all transport is assumed to be road transport, based on 40t trucks.
- In most cases, multiple transportation steps are needed.
- Transport distances are relatively small because Lebanon is a small country; a radius of 100 km around Beirut almost covers the whole country, see Figure 44.

Figure 44: Example destinations 100 km from Beirut, by road transport

VIII.2 BIOENERGY PATHWAY SELECTION

A bioenergy pathway is a combination of an available feedstock with an appropriate bioenergy conversion technology. Chapter 1 has identified the feedstocks with the highest potential in Lebanon. In chapter 2, 20 conversion technologies have been described, and multiple bioenergy forms can be distinguished; bioelectricity, bioheat, liquid biofuel, biogas and solid biofuel. Therefore, a very large amount of bioenergy pathways are possible, many of which have several alternative configurations within the pathway, with significantly different GHG savings. Figure 45 illustrates an example of the savings for bioheat and bioelectricity from different woody biomass sources.

A total of eight bioenergy pathways are studied in the remainder of this chapter, for three pathways a GHG balance has been produced, and five pathways have been investigated by means of literature research.

The criteria for selection of these eight bioenergy pathways are, in order of importance:

1. Applicability in Lebanon, including considerations regarding the existing energy infrastructure and expected demand for bioenergy forms, and the location of bioenergy consumption;
2. The broadest possible coverage of the identified feedstock. In order to give a representative picture of feedstocks and technologies, each feedstock is selected only once, and combined with other feedstocks where appropriate;
3. Also for all identified bioenergy forms and the main conversion technologies, the chosen spectrum is as broad as possible.

The main topic in this section is GHG savings that can be obtained by a bioenergy pathway, however the maximum GHG saving was explicitly not a criterion for pathway selection.

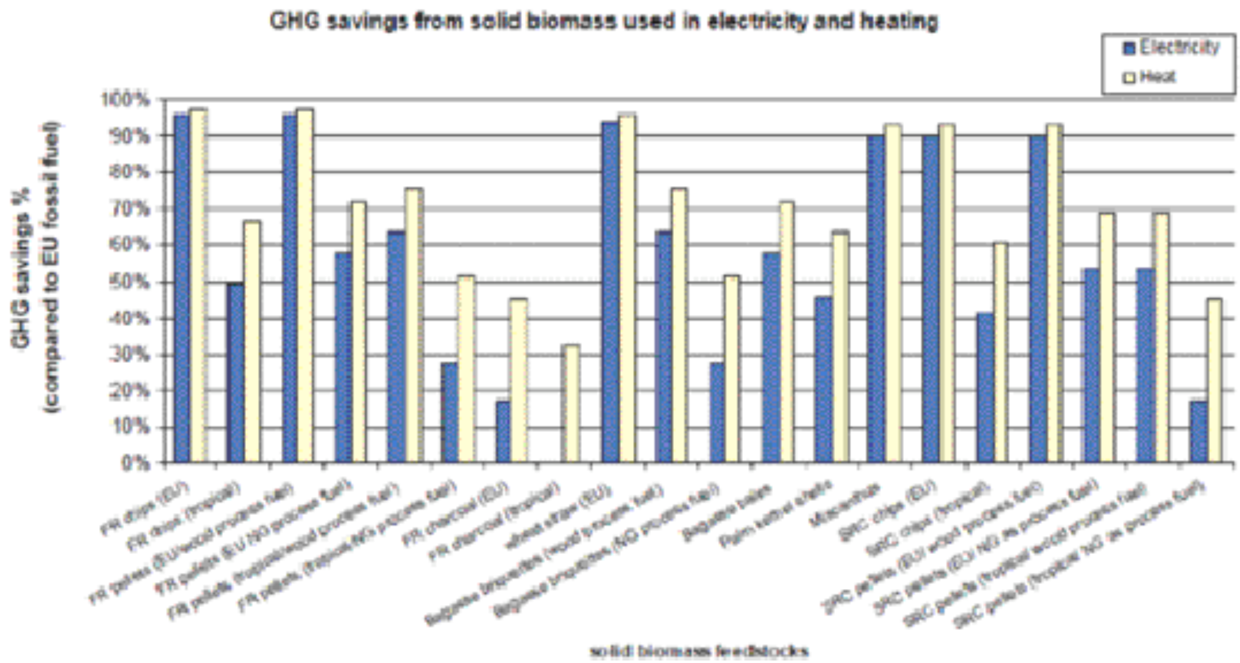
It needs to be noted that selecting a broad range of feedstocks, technologies and bioenergy forms results in bioenergy pathways that are different from each other to a high degree, therefore comparing the resulting GHG balances is limited and should be done with caution.

The results presented (see figure 45) are described in the Lebanese context, but specific projects in Lebanon may have different GHG balances, so a balance should be prepared for an individual project to adequately assess its impact.

Balance calculations are presented for the Lebanese case of:

1. Bioheat and bioelectricity from forestry residues
2. Bioethanol from the lignocellulosic energy crop Giant Reed
3. Compressed natural gas from fruit tree residues

Figure 45: Bioenergy GHG savings from solid biomass (FR = forestry residues, SRC = short rotation coppice (trees) Source: EC (2010)



LCA literature results that are relevant to Lebanon are reported for:

1. Biodiesel from used cooking oil
2. Combustion of straw for electricity generation
3. Biogas from sewage treatment Sludge
4. Municipal Solid Waste
5. Co-digestion of organic waste streams

VIII.3 REFERENCE ENERGY SYSTEM SELECTION

In order to assess how much GHG emissions are prevented by a bioenergy pathway, comparison with a fossil reference scenario is needed. It is important to note that;

- Not only the GHG released during the combustion of a fossil fuel is taken into account, also the GHG expended for the procurement, production and distribution of a fossil fuel is calculated.
- The reference system choice is often debatable:
- For instance, what is actually displaced by a Lebanese biofuel? Gasoline or diesel produced in Syria directly? If so, the indirect consequence may be that Syria produces this fossil fuel anyway and sells it to another country, which otherwise would have bought fuel made from Canadian oil shale, which produces about the double of the GHG of Syrian fossil fuel. Which one should be taken? Here a value based on a mix of fossil oil sources is taken, based on the selection by the European Commission).
- The GHG emissions of heat from biomass sources in Lebanon can differ a lot, sometimes biomass is already the main source, sometimes a highly polluting heavy fuel oil is used (also the efficiency of heat use can vary greatly).
- Indirect effects like economic effects or accidents like oil spills are not taken into account.

Table 125: Reference values for various fossil energy systems (adapted from Elsayed, Matthews, & Mortimer, 2003).
Notes: (a) Based on the net calorific value of the fuel, (b) Per unit of electricity or heat

Conventional Energy Supply	Energy requirement (MJ input/MJ product)	Carbon requirement (kg CO_2/MJ)	Methane requirement (g CO_2/MJ)	Nitrous Oxide requirement (g CO_2/MJ)	Total GHG gas requirement (KG CO_2 eq/MJ)
Diesel [a]	1.26	0.087	0.025	0.000075	0.087
Gasoline [a]	1.19	0.081	0.022	0.000028	0.081
Fuel Oil [a]	1.19	0.087	0.022	0.000028	0.087
Electricity from UK grid	3.08	0.150	0.404	0.006	0.162
Industrial CHP [b]	1.38	0.100	0.027	0.001	0.101
Heat from small scale oil-fired boiler	1.45	0.104	0.029	0.001	0.105

In this report, reference values for fossil energy are shown in Table 125, which uses very similar values for the total GHG emissions of diesel and gasoline as the methodology described by the European commission in its Renewable Energy Directive, but also provides fossil references for other products which don't have an EU defined value. By using this single source of reference values, the usage of the same methodology to calculate these reference values is guaranteed.

IX.THREE HIGH-POTENTIAL BIOENERGY OPTIONS FOR LEBANON

A LCA-style GHG and energy balance is built up for three bioenergy options that are important to Lebanon. First, a brief description of each system is given, than a step-by-step sketch along the entire bioenergy pathways is presented, which culminates in a calculation overview of the complete pathway, including the GHG and energy balances. In the end of this section, the results are compared.

IX.1 BIOHEAT AND BIOELECTRICITY FROM FORESTRY RESIDUES

Residues from forestry were indicated as the top biomass resource in Lebanon. When considering the use of felling and pruning residues, it is clear that retrieving this feedstock is only practical in easily accessible areas with good road connections, and that the need for subsequent transport should be limited. For this LCA, the scale of combustion-CHP plant that consumes 5 Kt of residues per year is modelled. This amount is about 10% of the residues available per year in the total area of Mount Lebanon (or 1/30th part of the national annual potential).

The forestry residues are collected, chipped and transported to a CHP plant that is located in or near industrial consumers of heat and electricity, for example food processing industry on the outskirts of Beirut.

Following the EU methodology, the functional unit is gCO2eq/MJ. In the scenario described here, both bioheat and bioelectricity is produced, the total of these two will be the functional unit in this case.

BIOENERGY PATHWAY DESCRIPTION AND ASSUMPTIONS

This section describes the bioheat and bioelectricity from forestry residues pathway in detail, including the assumptions that have been made. These are used to produce the GHG and energy balance calculations presented in the full-page table in the next subsection. The individual steps in the pathway are numbered, and these numbers are refered to in the overview table.

- Assumption: extraction of felling residues from the forest reduces the risk for forest fires, and therefore reduces GHG emissions. This is not taken into account because it is hard to predict and/or measure.
- Forestry activities require energy input for cutting down trees, pruning and replanting trees. Following EU methodology, felling residues are a waste product of forestry, therefore all energy expenditure is allocated to forestry, and none is allocated to the residues.
- Assumption: during forestry activities such as cutting down trees, pruning or activities performed in an attempt to reduce the risk of forest fires, felling residues are transported to and stored at the roadside (the energy input for this is assumed to be part of forestry activities, and therefore not accounted for in the GHG balance, the balance scope starts from roadside-collected residues).
- Following EU RED methodology, production, construction and maintenance of machinery and facilities is not taken into account.

1a:The branches, trunks (without roots) and tops of the trees are removed from the logs when a forest plantation is clear-cut at the end of its rotation, or small trees removed in

Biogas can be compressed to supply cooking and heating needs

thinning operations. The wood fuel is likely to be stored at the roadside, where some natural drying will take place.

1b:A mobile wood chipping machine transforms the felling residues to wood chips, which facilitates transportation, storage and eventual combustion. Some of the biomass is lost during chipping.

2:An empty truck arrives and transports the wood chips to the CHP plant.

• Assumption: traveling from the north to the south of Mount Lebanon mohazafat by road is roughly 100 km over secondary roads, and therefore an average transport distance of 50 km is taken.

• Assumption: no biomass is lost during transport.

• Assumption: wood chips are stored at the CHP plant; the transfer of chips from truck to storage to CHP plant is done through conveyer belts, it is assumed that the energy expenditure of storage and transport within the gates of the facility is negligible.

3:Wood chips are combusted in the CHP plant, which delivers heat and electricity to neighbouring industrial facilities, minimizing the energy needed for electricity and heat distribution.

• With the combustion of the biomass, CO_2 is released to the environment, but because this CO_2 is not from fossil origin, it is not considered to contribute to the global rise in (anthropogenic) greenhouse gas.

• Low amount of methane and nitrous oxide are formed during combustion; these are newly formed Greenhouse gases, and therefore accounted as such.

• Operating and maintaining the CHP plant also requires a small amount of energy input, this is not accounted for separately, but instead is accounted for in the overall plant (75% in this example).

• Assumption: decreased efficiency during start-up phase and technical problems are negligible.

4: Other than energy and flue gas, the only end product is a small amount of ashes.

• Assumption: the ashes left over after combustion are transported to a landfill 50 km away by truck.

The bioenergy pathway for greenhouse gases emissions and energy balance overview of heat and power from felling residues is shown in Table 126.

Wastewater treatment plant in Tripoli, North Lebanon

Table 126: Bioenergy pathway GHG and energy balance overview: heat and power from felling residues

Datasource	Step / Input data	Calculated values	Value	Unit	Emissions per MJ bioenergy produced: g CO2	mg CH4	mg N2O	g CO2 eq	Energy input per MJ bioenergy produced: Fossil	Bio	Total
	Basic assumptions										
11	Calorific value		18	MJ/kg dry biomass						1.00	1.00
2	Average dry matter content		0.8	kg dry biomass/kg fresh biomass							
	1: Feedstock collection: On-site wood chipping										
3	Diesel input		0.004	MJdiesel/MJbiomass	0.49	0	0	0.49	0.01		0.01
4	Biomass loss during chipping (5%)		0.950	MJ wood chips/MJbiomass						0.07	0.07
	2: Feedstock transport: Transport mode: 40t truck (carries 27t)										
5	Transport distance		50	km, one way full, empty return							
3	Payload		27	tonne chips							
3	Diesel input		25.272	MJ/km							
	->	Transport input	0.003	MJdiesel/MJ wood chips	0.40	0	0	0.40	0.01		0.01
	3: Feedstock conversion: biomass combustion to heat and electricity										
4	Plant overall efficiency		75%	% total							
4	Heat to electricity ratio		4	MJth/MJe							
	->	Input / output total	1.404	MJ wood chips / MJ bioenergy	0	2.81	5.61	1.73		1.40	1.40
	=	Input / output heat	1.123	MJ wood chips / MJ bioheat							
	+	Input / output electrical power	0.281	MJ wood chips / MJ bioelectricity							
	4: Waste disposal										
4	Ash content		0.4	% of dry biomass							
5	Transport distance		50	km, one way full, empty return							
3	Payload		27	tonne ashes							
3	Diesel input		25.272	MJ/km							
	->	Transport input for ash disposal	0.000013	MJdiesel/MJ wood chips	0.00	0	0	0.00	0.00		0.00
				Total for whole chain	0.89	2.81	5.61	2.62	0.01	2.47	2.49
				Reference value (fossil heat+elec)	100.00	0.027	0.001	100.92	1.38		
				% savings comparing this bioenergy chain to its reference value				97.40% Total GHG savings	99.14% Primary Energy Savings		40% Efficiency of Conversion

IX.2 BIOETHANOL FROM THE LIGNOCELLULOSIC ENERGY CROP GIANT REED

Cultivating energy crops on currently unused land was indicated as the 4th best biomass resource in Lebanon. From the energy crops investigated, Giant reed is the most promising, given the little effort, water, fertilizer and maintenance it needs. Giant reed (Arundo donax) is a large (up to 10m tall) perennial grass that is found around the Mediterranean Sea and many other mild, subtropical and tropical parts of the world. High biomass yields of up to 45 ton DM/ha/year (DM = Dry Matter, the weight of the biomass after all water has been removed) are reported in wet, fertile environments, but also on dry, marginal soils yields of 15 ton DM/ha/year are obtained. This is mainly due to its complex root system (see Figure 46), which also provides very good protection against erosion. Therefore this species is indicated for the conservation and restoration of marginal and erosion-sensitive land.

Figure 46: The root system of Giant reed, allowing efficient water use and soil protection
(Williams, Biswas, & Schrale, 2008)

Some of the main features of this energy crop are as follows (note that some of these aspects describe conditions in which the plants will survive and grow, but the growth speed may be reduced under these conditions) (Anderson, Dien, Brandon, & Peterson, 2008; El Bassam, 2010; A Monti, Divirgilio, & G Venturi, 2008; Andrea Monti, Fazio, & Gianpietro Venturi, 2009; Williams et al., 2008);

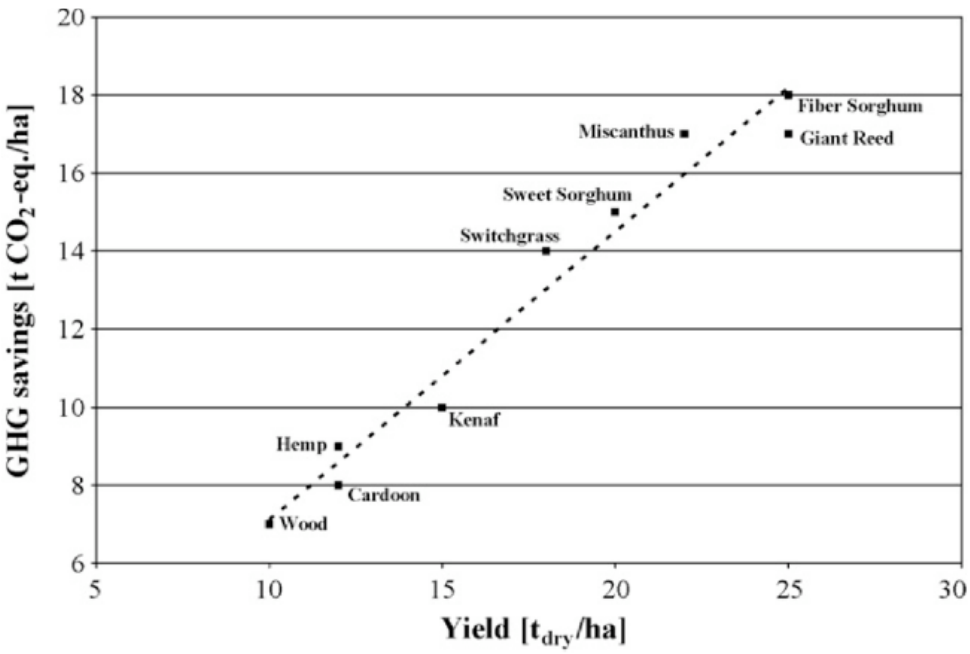
- Requires low inputs, but gives high yields.
- Low labour input; no maintenance, fertilization or pesticides needed.
- It has good storability compared to many other biomass crops. It can be stored outdoors without any shelter protection with minor losses. Storage losses occur mainly in the leaf fraction (blades and sheaths), which represents a small

percentage, about 10 to 15 per cent, of the total biomass production. Stems can be stored with almost no losses.

- It can be grown with fresh water, but is not sensitive to salinity.
- It can be irrigated and fertilized with waste water.
- It is insensitive to drought or frost.
- Even in dry periods, it resists wild fires.
- There is very low risk of weed-behaviour: the plant is sterile, it only reproduces if certain root material is flushed to a new location.
- It offers wind protection.
- Once established, it can be cultivated for many decades without replanting.
- It is highly pest resistant.
- Due to its aggressive growth, it out-competes any other plants by taking up all solar light.
- No tillage is required.
- It can be grown on almost any soil type from very light soils to very moist and compact soils
- Known high GHG savings (see Figure 47).

Figure 47 GHG savings per hectare as a function of lignocellulosic crop yields

(Cherubini, Bird, et al., 2009)



The reed is harvested in autumn each year, at a dry matter content of 40%. If weather conditions permit, it can be dried naturally in the field. 10% to 15% of the biomass is leaves, the rest is stem. Leaves require less processing to break down it's cellulose than stems, thus are an easier substrate for ethanol production than the stems (Anderson et al., 2008).

Following the EU methodology, the functional unit is gCO2 eq/MJ. In the scenario described here, bioethanol is produced, therefore the functional unit becomes gCO2 eq/MJ ethanol and the fossil reference system is gasoline.

BIOENERGY PATHWAY DESCRIPTION AND ASSUMPTIONS

This section describes the bioethanol from the lignocellulosic energy crop Giant Reed pathway in detail, including the assumptions that have been made. These are used to produce the GHG and energy balance calculations presented in the full-page table in the next subsection. The individual steps in the pathway are numbered, and these numbers are refered to in the overview table.

- The establishment of new giant reed cultivation requires energy input, for preparing the land, producing and planting the seeding material, and possible initial fertilization. Following EU methodology, this is not accounted for in the annual cultivation inputs.
- Assumption: Harvesting is the only activity needed.
- Following EU RED methodology, production, construction and maintenance of machinery and facilities is not taken into account.
- Depending on local soil conditions and population, fertilization may not be needed at all or can be achieved with waste water. Conservatively, full replacement of the main nutrients in harvested reed is assumed. No irrigation is assumed.
- A conservative average yield of 20 t dry matter per

Table 127: Bioenergy pathway GHG and energy balance overview: cellulosic ethanol from Giant Reed

Datasource	Step / Input data / Calculated values	Value	Unit	Emissions per MJ bioenergy produced: g CO2	mg CH4	mg N2O	g CO2, eq	Energy input per MJ bioenergy prod: Fossil	Bio	Total
	Basic assumptions									
6	Calorific value	18	MJ/kg dry biomass						1.00	1.00
7	Average dry matter content	0.60	kg dry biomass/kg fresh biomass							
8	Annual average yield	20	ton dry biomass per ha							
	1: Feedstock cultivation and harvest by chopper:									
9	Nitrogen fertilizer input	6.78	g N/kg dry biomass	3.10	9.50	10.56	6.44	0.05		0.05
9	Phosphate fertilizer input	0.38	g P/kg dry biomass	1.06	1.46	0.06	1.11	0.02		0.02
10	Diesel input	55	L/ha	1.40	0	0	1.40	0.02		0.02
8	Biomass loss during chopping	5%	% of dry biomass						0.15	0.15
	2: Feedstock transport: Transport mode: 40t truck (carries 27t)									
8	Transport distance	50	km, one way full, empty return							
3	Payload	27	tonne chopped reed							
3	Diesel input	25.27	MJ/km							
	-> Transport input	0.004	MJdiesel/MJ dry biomass	0.0614	0	0	0.06	0.00		0.00
	3: Feedstock conversion: biomass combustion bioethanol									
3	Chopped giant reed	2.91	MJbiomass/MJethanol						1.76	1.76
3	H2SO4	4.27	g/MJethanol	0.83	2.33	0.02	0.89	0.02		0.02
3	CaO	1.35	g/MJethanol	1.37	0.88	0.01	1.39	0.02		0.02
3	NH3	2.68	g/MJethanol	6.65	21.02	0.02	7.14	0.19		0.19
3	Diesel	0.04	MJdiesel/MJethanol	3.16	0	0	3.16	0.04		0.04
3	*Surplus electricity (generated as by-product)*	*-0.10*	*MJelec/MJethanol*	*-11.99*	*-29.25*	*-0.54*	*-12.83*	*-0.27*		-0.27
	-> Input / output (main)	0.162	kg dry biomass / MJethanol							
	4: Distribution									
3, 1	Truck for 27t ethanol transport (Diesel, 100km)	0.0038	MJdiesel/MJethanol	0.33	0.00	0.00	0.33	0.0044		0.00
3	Road fuel depot (electricity)	0.0008	MJelec/MJethanol	0.10	0.25	0.00	0.11	0.0023		0.00
3	Road fuel filling station (electricity)	0.0034	MJelec/MJethanol	0.41	1.00	0.02	0.44	0.0093		0.01
			Total for whole chain	6.45	7.18	10.15	9.62	0.10	2.91	3.01
			Reference value (gasoline)	81	22	0.03	81.51	1.19		
			% savings comparing this bioenergy chain to its reference value				88% Total GHG savings	91% Fossil Energy Savings		33% Efficiency of Conversion

hectare per year is assumed, with an energy content of 18MJ/kg (Angelini et al, 2005)

1a:During autumn, the fresh biomass is harvested while the resulting nutrient debt is replenished by fertilizer. Fertilizer needs are calculated as 15.7 g N/kg leaves, 5.2 g N/kg stems, 0.803 g P/kg leaves and 0.320 g P/kg stems (Monti et al., 2008), and assuming 15% leaves and 85% stem.

1b:The plants are harvested by a chopper and temporarily stored near a road awaiting collection

2:An empty truck arrives and transports the feedstock to the bioethanol plant

- Assumption: Giant reed plantations are located in Northern Lebanon and the Beqaa valley, some are near the ethanol plant, some a little further away. Average transport distance of 50 km is taken.
- Assumption: no biomass is lost during transport.
- Assumption: chopped reed chips are stored at the ethanol plant; chips are transferred from trucks to storage and to CHP plant through conveyer belts, it is assumed that the energy expenditure of storage and transport within the gates of the facility is negligible.

3:Chips are pretreated, hydrolyzed and converted into ethanol.

- Not all CO2 contained in the biomass is transferred to bioethanol, some CO2 is released to the environment, but because this CO2 is not from fossil origin, it is not considered to contribute to the global rise in (anthropogenic) greenhouse gas.
- The assumed ethanol plant produces its own heat and electricity from the reed. Due to a fixed ratio between heat and electricity production, the plant overproduces electricity, which is supplied to the grid. To compensate for this electricity stream, the avoided emissions are subtracted.
- The energy requirements for operating the ethanol plant are taken as part of the process, so not accounted for separately, 2.91 MJbiomass/MJethanol is taken as overall efficiency of the plant.
- Assumption: decreased efficiency during start-up phase and technical problems are negligible.

4:The produced ethanol is distributed with tanker trucks to fuel depots, where the ethanol is blended with conventional gasoline and transported to filling stations.

- Assumption: The ethanol has to be transported from the ethanol plant in the north to fuel depots all over the country, therefore the average distance of 100 km is taken, the electricity required for the pumping and blending at the depot is accounted for.
- The blended fuel is sold at a filling station, which spends some electricity, which is accounted for

The bioenergy pathway for greenhouse gases emissions and energy balance overview of heat and power from cellulosic ethanol produced with Giant Reed is shown in Table 127.

IX.3 COMPRESSED NATURAL GAS FROM FRUIT TREE RESIDUES

In chapter 1, the top 10 highest bioenergy potential in Lebanon contain various agricultural residues that can be transformed into biogas via anaerobic digestion. For this pathway, a scenario converting fruit tree residues was selected, since it showed the highest potential within the agricultural residues stream. However, the entire pathway would be very similar for any other organic waste stream, only basic parameters like biogas yield and dry matter content would have to be changed.

The produced biogas is only an intermediate product, which can be converted into:

- Bioheat
- Bioelectricity
- Bioheat & bioelectricity (via CHP)
- Synthetic Natural Gas (SNG), a bio-alternative in natural gas systems
- Compressed Natural Gas (CNG), an alternative for gasoline in converted cars
- (Any other product made from natural gas, e.g. methanol)

In the scenario described in this section, the biogas is ultimately sold as CNG in transport fuel filling stations. CNG is gaining popularity worldwide, and is currently produced from fossil natural gas (in the rest of this section, when referring to CNG, Bio-CNG is meant). CNG is produced by compressing methane to less than 1% of its original volume. After compression, the energy content per liter is about 4 times lower than that of diesel.

As a feedstock, fruit tree (olive, grape, orange, lemon, tangerine, apple, cherry, apricot, peach, pear, plum, and banana) residues are assumed. Therefore the anaerobic digester should be located in an area with intense fruit cultivation. The residues are dry enough to be transported with a normal truck. The residues are collected by the fruit producers and sold to the biogas facility, which in turn sells purified methane that is extracted from the biogas to surrounding filling stations, where the methane is compressed into CNG.

Following the EU methodology, the functional unit is gCO2 eq/MJ. In the scenario described here, CNG is produced, therefore the functional unit becomes gCO2 eq/MJ CNG and the fossil reference system is gasoline.

BIOENERGY PATHWAY DESCRIPTION AND ASSUMPTIONS

This section describes the compressed natural gas from fruit tree residues pathway in detail, including the assumptions that have been made. These are used to produce the GHG and energy balance calculations presented in the full-page table in the next subsection. The individual steps in the pathway are numbered, and these numbers are referred to in the overview table.

- Assumption: At present, some fruit producers leave their residues on the ground. On the one hand this returns some nutrients to the soil, reducing fertilizer need and therefore GHG emissions, while on the other hand it may cause additional methane and nitrous oxide emissions. Neither effect is taken into account, following EU RED methodology the GHG accounting starts from the moment of collection of the residues.
- Following EU RED methodology, production and construction and maintenance of machinery and facilities is not taken into account.
- The energy content of the residues varies per tree species. An average conservative value of 12.60 MJ/kg dry matter is assumed (Amane Energy estimate), and the average moisture content is 40%.

1:The residues are picked up at the fruit producers, and hauled to the biogas plant.

- Depending on the size of the biogas plant, the residues are sourced as near-by as possible, to reduce transportation costs as much as possible. An average distance of 25 km is assumed.
- It is likely that these trucks will transport the digestate (solid output of the anaerobic digester, with good fertilizer value) back to the fruit growers, but this is not taken into account.
- Assumption: no biomass is lost during transport

2a:The feedstock is subjected to anaerobic digestion, which produces biogas;

- Assumption: A large part of the organic compounds in the residues are converted into biogas, but not all. The exact percentage depends mainly on the residence time of the residues in the digester. 70% conversion (on energy basis) is assumed.
- Assumption: during step 2, some biogas leaks to the environment (the methane component has a strong global warming potential).
- Assumption: The digestate contains most of the nitrogen that was contained in the residues. This can be used as a biological fertilizer, which displaces some fossil-derived fertilizers and therefore yields GHG reduction, or negative emissions.

2b:Part of the produced biogas is combusted in a gas engine, which produces the heat and electricity needed to operate the plant.

- Assumption: this biogas combustion produces some CH4 and N2O emissions.
- Assumption: the amount of electricity generated is higher than needed for biogas plant operation, the surplus is fed into the grid, resulting in negative GHG emissions.

3:Methane extraction via pressurized water scrubbing.

- The biogas is subjected to a process called pressurized water scrubbing, which removes CO2 and other gases from the biogas stream, yielding pure methane. Assumption: a small part of the biogas energy content is lost due to oxidation.

4:The produced methane is distributed to filling stations, where it is compressed in preparation to fill tanks of converted cars.

- The methane is produced at low pressure. Energetically, the most efficient transportation mode is trough pipelines, so that's the method assumed here. If no gas infrastructure exists (which is generally the case in Lebanon), a pipeline needs to be built from the biogas plant to the filling station. This can become costly, and therefore a scenario where a fleet of trucks or busses is converted to receive all their CNG near the biogas plant could be more effective.
- Alternatively, biogas could also be compressed into the cylinder commonly used in Lebanon as the gas supply for household cooking and heating.
- When available, methane transported through pipelines requires very little energy per km of transport. The official EU value used for 10 km transport is 0.0000 MJ, in other words, it is negligible.
- Assumption: during step 4, some biogas leaks to the environment (the methane component has a strong global warming potential).

The bioenergy pathway for greenhouse gases emissions and energy balance overview of heat and power from biogas produced from fruit trees residues is shown in Table 128.

Table 128: Bioenergy pathway GHG and energy balance overview: Biogas from fruit tree residues

Datasource	Step / Input data / Calculated values	Value	Unit	Emissions per MJ bioenergy produced: g CO2	mg CH4	mg N2O	g CO2, eq	Energy input per MJ bioenergy produced: Fossil	Bio	Total
	Basic assumptions									
7	Average dry matter content	0.60	kg dry biomass/kg residues						1.00	1.00
13	Organic residue Lower Heating Value	12.60	MJ/kg dry							
	1: Feedstock collection and transport: 40t truck (carries 27t)									
8	Transport distance	25	km, one way full, empty return							
3	Payload	27	tonne residues							
3	Diesel input	25.27	MJdiesel/km							
11	-> Transport input	0.0031	MJdiesel/MJresidues	0.54	0	0	0.54	0.01		0.01
	2: Biogas generation and subsequent combustion in gas engine:									
12	Biogas yield	0.70	MJbiogas/ MJresidues						0.60	0.60
12	Elec. input (generated in this step 2, so no emissions)	0.043	MJelec / MJbiogas							
12	Biogas share needed to run gas engine in this step 2	15%	% of biogas generated							
12	Biogas combustion in gas engine	1.7	MJbiogas / MJheat	0.00	11.16	0.00	0.26		0.30	0.30
12	*Gas engine electricity output (rest is heat)*	*-0.08*	*MJelec / MJbiogas*							
	-> Surplus elec. generated	*-0.032*	*MJelec / MJbiogas*	*-3.87*	*-9.43*	*-0.18*	*-4.13*	*-0.09*		*-0.09*
12	Biogas leakages	1.00%	% of biogas generated		204.89		4.71		0.03	0.03
12	-> Nett biogas output	0.51	MJbiogas/ MJresidues							
	Co-product: N-fertiliser	*-0.33*	*g N/ MJbiogas*	-0.94	-2.89	-3.21	-1.96	*-0.02*		*-0.02*
	3: Methane extraction via pressurized water scrubbing									
12	Energy loss during biogas scrubbing to mehane	1.00%	% of biogas energy content						0.03	0.03
12	Electricity input for biogas scrubbing	0.04	MJelec/MJmethane	5.07	12.37	0.23	5.43	0.11		0.11
	4: Distribution and compression to CNG									
1	Methane transport by pipeline	0.00	MJelec/MJmethane	0.00	0.00	0.00	0.00	0.00		0.00
12	Electricity input for methane compression to CNG	0.02	MJelec/MJ CNG	2.66	6.48	0.12	2.84	0.06		0.06
12	Methane leakages	1.40%	% of CNG generated		280.00		6.44		0.04	0.04
			Total for whole chain	3.46	502.58	-3.04	14.12	0.08	1.99	2.07
			Reference value (fossil heat+elec)	81	22	0.03	81.5143	1.19		
			% savings comparing this bioenergy chain to its reference value				83% Total GHG savings	93% Fossil Energy Savings		48% Efficiency of Conversion

IX.4 COMPARISON

All three pathways investigated can reach high GHG savings (under the conditions that were assumed in this section. Unsustainable practices can cause savings to be reduced or ever become negative) (see Table 129). This is not surprising; it is well known that bioenergy from waste gives low GHG emissions. The same applies for the energy crop Giant reed.

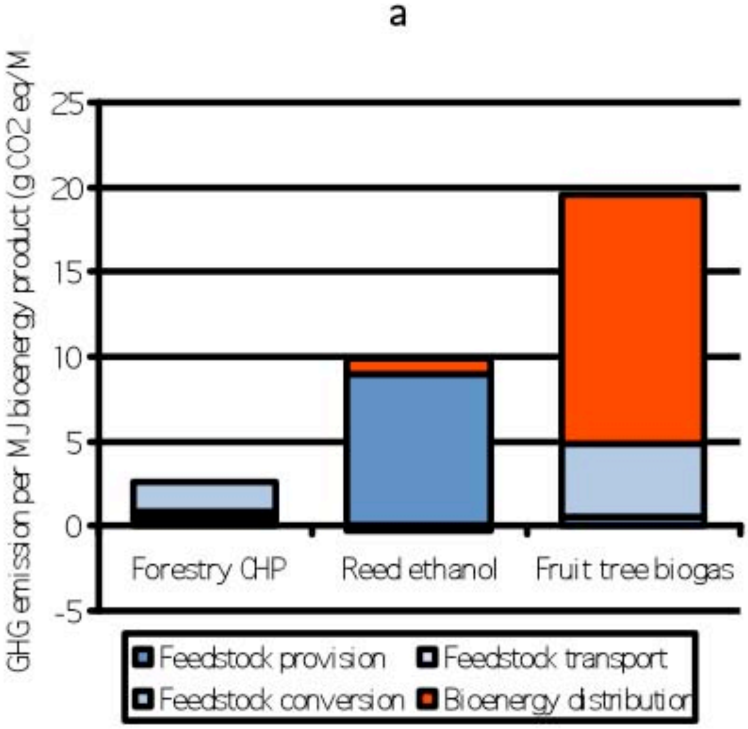
Table 129 Summary of the main results of the GHG and energy balances

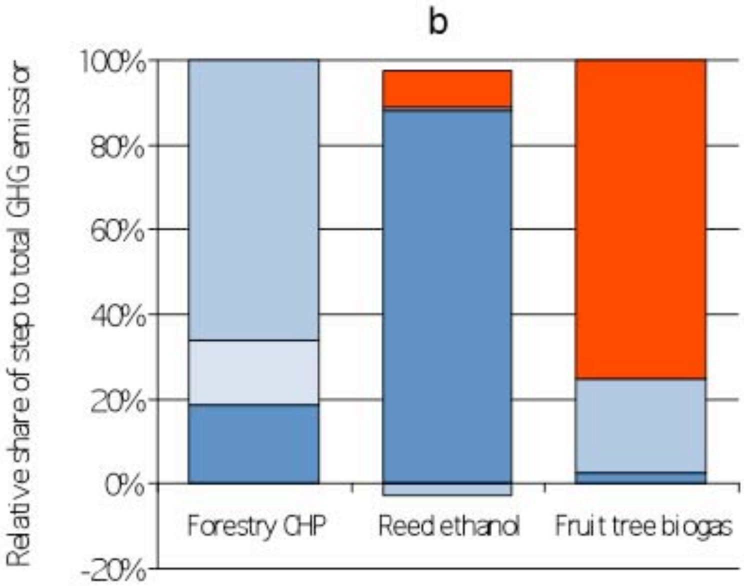
	GHG savings	Fossil energy savings
Forestry CHP	97.4%	99.1%
Reed ethanol	88.2%	91.4%
Fruit tree biogas	82.7%	93.4%

As mentioned in section VIII.2, care has to be taken when comparing the different pathways in Table 129 with each other, because the presented results are based on different technologies, bioenergy forms (Electricity, heat, liquid fuel and biogas) and other relevant assumptions.
Further investigation of the Greenhouse Gas balances shows large differences in the emissions per MJ bioenergy (see Figure 48a), although all numbers are low in comparison to fossil energy. Also the step in the pathway that produces more GHG emissions differs greatly between the investigated bioenergy options, (see Figure 48b) while feedstock conversion for forestry residues produces the most GHG emissions, in the case of bioethanol production from giant reed this step has negative emissions because of the surplus electricity that is generated in this step.
The key message here is that under the assumed conditions, all three investigated bioenergy pathways can achieve high GHG savings. This result is not meant to lead to the selection of the best pathway within the three pathways investigated; all three have high GHG savings, selecting between them should be based on other criteria.

Giant Reed (Arundo donax L.) found in Rouche, Beirut

Figure 48 Calculated GHG emissions per pathway step: (a) Emissions per MJ bioenergy product;(b) Relative share of each pathway step





SENSITIVITY ANALYSIS

This section takes a look at the assumptions that have been made for the three investigated bioenergy pathways, and analyses what the effect of large changes to parameters that could realistically change in the Lebanese context.

- Bioheat and bioelectricity from forestry residues

Using an identical pathway, the only factor that realistically can undergo large changes is the feedstock transportation distance, but even when doubling this, the total GHG emissions rise only 0.4 g CO2eq/MJ to 3.02, the effect on GHG savings is a reduction of only 0.4%. The reason to keep the average transportation distance short is financial, and not due to GHG emissions.

Large differences in GHG savings can be observed if different pathways for woody biomass are followed, as can be observed from Figure 45.

• Bioethanol from the lignocellulosic energy crop Giant Reed

Using an identical pathway, a factor that can realistically undergo large change is primarily the yield per hectare, of which the double of the assumed 20 t/ha have been observed under natural conditions. Increased yield primarily reduces the energy input for harvesting. The overall effect of doubling the yield is an extra 0.9% GHG savings. If stored a long time in an outdoor environment, biomass losses can be a lot higher than the assumed 5% and transport distances could be higher, but doubling either factor minimally influences the overall GHG savings (less than 0.1%).

However, there is one option to achieve significant extra GHG savings: if fertilization with chemical fertilizers can be avoided, e.g., because wastewater can be used, an extra 9% GHG can be saved, lifting the total savings to 97%.

• Compressed natural gas from fruit tree residues

In this pathway, leaking methane is a major risk. Total leakage is assumed at 2.4%, but if this is doubled, GHG savings drop 14% to 67% savings, and if leakage reaches 16.3%, GHG savings drop to 0%.

As mentioned earlier, this pathway could easily be adapted for other organic waste streams. For example, wet manure has a moisture content of 92%. Keeping the rest of the pathway identical, the GHG savings drop 4% due to the extra moisture transported.

X.RELEVANT LCA RESULTS TO LEBANESE BIOENERGY OPTIONS

Relevant Life Cycle Analysis (LCA) on five bioenergy options, with high potential for Lebanon, has been examined in recognised scientific sources. The bioenergy options researched are:

1. Biodiesel from used cooking oil
2. Combustion of straw for electricity generation
3. Biogas from sewage treatment sludge
4. Municipal solid waste
5. Co-digestion of organic waste streams.

The LCA analyses are presented in full in the volume "Annexes" of this study, chapter 4, annex VI "Relevant LCA results to Lebanese bioenergy options".

XI.CONCLUSIONS

While the use of biomass for energy purposes in general impacts the environment much less than the use of conventional fossil fuels, there are still different degrees of sustainability impacts among the biomass streams. These degrees of sustainability impacts depend on a series of conditions such as the soil type, water needed, use of fertilizers, etc. The results of the resource assessment show that energy crops clearly have a higher score compared to several other biomass resources. However some of the criteria, such as responsible use of fertilizer, are only applicable to a limited number of biomass resources, which should be taken into account when interpreting the results.

Several of the sustainability impacts included in the assessment are interlinked. The improvement or deterioration of one impact can also affect the scoring of other sustainability impacts. The interrelations of the impacts included in the sustainability assessment and the wide diversity of impacts included also risks that the improvement of one impact may result in the deterioration of another. Consequently, the linkage of bioenergy production with many relevant policy areas such as agriculture, energy, poverty reduction or forestry enforces policy makers and the market to make clear choices and set priorities.

Considering the versatility and vulnerability of the Lebanese regions in terms of the environment and socio-economic situations, the development of a strict sustainability level for bioenergy projects is highly recommended. In all cases, good monitoring and enforcement need to be ensured.

The development of sustainable bioenergy projects could provide best practices and mitigate existing environmental problems in other sectors.

The final score given in the assessments executed in this study is a combination of partial scores and underlying assumptions, as performed under the regional and biomass resource assessment. Based on this final score, appropriate combinations of biomass resources – regions can be selected taking into consideration as well their impact on sustainability. For example, the deployment of yellow grease seems to be an appropriate option for Beirut while less attractive for North Lebanon. Also, the development of landfill potential for bioenergy seems more appropriate for Beirut than for other mohafazats. This chapter provided information on the possible contribution of mohafazats to bioenergy development and deployment over time for various scenarios. Based on the outcomes in the scenario assessment in chapter 3 and the sustainability impact assessment undergone in this chapter, the following conclusions can be made:

1) The region (Beirut) with the lowest expected impact in terms of sustainability, but it also has the lowest potential in bioenergy development and deployment, unless municipal solid waste is valued for energy purposes under strict sustainability regulation (e.g. waste-to-energy plants combined with effective waste management including recycling of materials).

- Decisions over the management of municipal solid waste and its possible energy valorisation are usually highly complex in any country. From the sustainability point of view, it is necessary to have the following points into consideration; The options for treating municipal solid waste should follow the common sense criterion of applying first the most favoured option: prevention of waste generation, followed by reuse and recycling of materials, energy recovery and finally and as very last option, disposal of waste (eg landfilling). Currently, Lebanon applies mainly landfilling practices, which is the least favoured option (in terms of sustainability) to the management of municipal solid waste, and the option which creates the largest environmental impacts.
- Among the options for energy recovery, the most sustainable option is the combination of effective waste separation practices (for the recycling of materials), with the energy valorisation through Waste-to-Energy plants. This option, according to credible life cycle analysis could produce up to 118% GHG emissions savings when compared to only landfilling waste (current situation); in other words instead of GHG emissions, an 18% GHG capture could happen due to the combination of recycling of materials with energy recovery.
- The second best option for the treatment of waste is the energy recovery in incinerators without previous separation of waste for recycling. This option could produce up to 88% GHG emissions savings compared to current situation. This is still very favourable in terms of sustainability.
- The third option is gas recovery from landfills. This option still produces up to 55% of GHG savings compared to do nothing, however to avoid strong environment damage (especially on soils and underground waters), landfills should be constructed with best practices to avoid the contamination of soils and underground waters. The issue of contamination of underground waters is especially important, as underground effluents may bring this contamination to food crops and water for human use.

2) Energy crops are the biomass resource with possibly the highest potential in terms of bioenergy production and they can be developed in all regions of the country. But they also show the highest risk in terms of sustainability impacts; sustainability criteria should be regulated and enforced in the country for the full development of this bioenergy stream. By instance, lignocellulosic energy crops offer to the future of Lebanon the opportunity of self-producing biofuels reducing the dependence on foreign fossil fuels, and with very little impact on sustainability.

Energy crops production for bioenergy indeed provides a very interesting potential for Lebanon and may provide many benefits to rural areas and poor communities. This potential is even higher when this bioenergy stream is combined with available forestry and agricultural residues streams.

On the other hand, this category of biomass resources also contains potentially, the largest risks in terms of sustainability impacts. Key considerations are the water limitations, competition of land and food vulnerability (in terms of imports) in Lebanon. The deployment of small and medium scale size projects, with an appropriate selection of land use (marginal or degraded lands preferred) and crop, which allows time for learning and risk avoidance, is therefore highly recommended. In all cases, the deployment of bioenergy projects should consider the local variation in environmental and socio-economic aspects within Lebanon and within the respective mohafazat.

3) Strict sustainability level is only considered for Scenario I. Given the versatility of possible sustainability risks, the sustainability criteria used in this level are recommended to be developed into Lebanon's legislation and enforced no matter the scenario pathway occurring in the country.

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CHAPTER 5

BARRIERS TO BIOENERGY DEVELOPMENT

I.INTRODUCTION

An evaluation of each biomass stream is required to identify the potential barriers to recommended bioenergy options.

A number of recommendations are suggested for the realistic and effective implementation of bioenergy options in Lebanon. These recommendations touch the technological, logistical, legal, economic, financial and commercial spheres, amongst others, in order to overcome constraints to suggested projects.

The chapter will follow a five-step approach:
Step 1. SWOT analysis of feedstocks and technologies
Step 2. Definition of barriers to study and assessment of their impacts and mitigation actions
Step 3. Opportunities for bioenergy business in Lebanon
Step 4. Analysis of the regulatory framework and financial perspectives
Step 5. Adapted innovative financial mechanisms

STEP 1. PREVIOUS SWOT ANALYSIS OF ALTERNATIVES

A SWOT analysis is a strategic planning tool used to evaluate Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T) involved in a business venture.

The objective of this SWOT analysis is to illustrate regional strengths and uncover the opportunities that could help Lebanon to achieve its energy goals.

The results will provide an overview of the advantages and disadvantages of the five different streams, helping to take advantage of the projects strengths and defends against threats. Furthermore, the awareness of the need of more energy independence and the environmental threats of climate change, allows the preparation of a response plan.

STEP 2. DEFINITION OF BARRIERS TO THE STUDY, ASSESSMENT OF THEIR IMPACTS AND MITIGATION PLANS

Based on the preliminary SWOT matrixes, the main barriers detected are further analysed to minimize hazards, including the following factors:

- Natural conditions.
- Prevailing experience, technological experience, rural sector structure, production of biomass.
- Technology/infrastructure factors: logistic chain, distribution, energy safety/efficiency/demand, technology vulnerability, innovation and research of technology, maturity of technology, etc.
- Resources: accessibility, collectability, land availability, etc…
- Economic, financial and legal factors: prices, market demand, economic situation in the country, legislative support.
- Social factors: social attitude toward ecology, knowledge about the sector, trained staff in the country, installation and supply companies in the country, job generation, training opportunities, etc…
- Other factors: institutional barriers, lack of information, organisational capacity, etc.

STEP 3. OPPORTUNITIES FOR BIOENERGY BUSINESS IN LEBANON

The third step covers, in depth, the potential and opportunities of bioenergy for the Lebanese energy, electricity and transport sectors. The specific benefits of these opportunities are also analysed (including, among others, environmental, agricultural, social, political, etc., aspects).

STEP 4. ANALYSIS OF REGULATORY FRAMEWORK AND FINANCIAL PERSPECTIVES

This step includes an analysis of the institutional and regulatory policy barriers to develop and implement the bioenergy streams in Lebanon. Financial support will be needed for the establishment of the strategy.

STEP 5. ADAPTED INNOVATIVE FINANCIAL MECHANISM

In the last step, the existing financing mechanisms available for the development of bioenergy in Lebanon will be proposed and analysed. This will result in a list of possible bank financing instruments that could help facilitate the implementation of the strategy.

It is essential to note that a confluence of macro, governance, organisational, capacity, and implementation problems raise certain questions about the interest of donor agencies to make a contribution to the local development in Lebanon. According to the OECD, Lebanon is classified as an "Upper Middle Income Country" which results in a decrease in allocations to the country and possible ineligibility to certain funds.

The objective of analysing the entire supply chain of the different bioenergy streams selected, from feedstock extraction to final conversion of energy and wastes produced, is to find the barriers to their development. The outcome of this activity is also to suggest solutions to overcome the limitations encountered.

I.1 STEP 1: SWOT ANALYSIS OF FEEDSTOCK AND TECHNOLOGIES

GENERAL CONSIDERATIONS

The five most promising biomass resources as determined in chapter 1 are;

1)Residues from forestry felling
2)Residues of olive and fruit trees
3)Residues of cereals
4)Energy crops
5)Olive oil cake

Table 130 summarizes their quantities, energy potentials, as well as their possibilities regarding current legal framework and competition with other uses.

Table 130: Ranking of most important biomass resources for Lebanon

	Biomass resources	Quantity* (Tons)	Energy Potential (GWh)	Other uses	Accessibility	Legal framework	Ranking
Forestry	Residues from felling	150	[460 -600]				1
Agriculture	Residues of olive trees	[100,000 - 120,000]	[230 - 270]				2
	Residues of fruit trees	[240,000 - 300,000]	[500 - 750]				
	Residues of Cereals	180	[580 - 750]				3
Energy crops	Sunflower		[51-82]				4
	Giant Reed		[552-883]				
	Jatropha		[136-847]				
Food processing industry	Olive oil cake	[27,500 - 64,500]	[127.7 – 300.8]				5

* Wet Basis
Color code:
High potential
Medium potential
Low potential

Considering these biomass streams, the most relevant technologies for Lebanon are:

- Combustion-CHP, with a feedstock of residues from forestry felling.
- Anaerobic digestion with residues of olive and fruit trees.
- Combustion boiler coming from residues of cereals.
- Production of lignocellulosic bioethanol from energy crops.
- Anaerobic co-digestion of olive oil cake and other organic wastes.
- Each one of the five biomass streams, has one or more technologies that could be potentially applied to them. However, not every technology linked with a biomass stream is suitable to be carried out in Lebanon.

According to chapter 3, Future Scenarios for Bioenergy in Lebanon, various topics need to be studied in more depth to plan a solid infrastructure and market regarding a bioenergy industry in the country. Four main concerns were established:

- Security of feedstock supplies.

- Economies of scale and other logistical factors.
- Public and non-governmental organisations acceptance
- Competition with other renewable and non-renewable energy sources, as well as, competition with other current end uses.

Some of these topics could turn into risks or barriers that should be mitigated and are described in more details below.

Security of feedstock supplies

Price and quality variations on feedstock as well as its seasonality are all issues that could impact the continuous availability of biomass stocks for bioenergy plants. To proceed in the assessment of barriers to bioenergy projects in Lebanon, the parameters mentioned are studied for each stream pegged to certain assumptions;

1.Residues from forestry felling

- No relevant price variations. The main variation in the feedstock price would be attributed to its transport costs due to difficulties in logistics and fuel consumption.

2.Residues from olive and fruit trees

- Price variations are not likely to occur.
- Seasonality is an important factor to consider when the biomass required depends on harvest of fruits and olives trees. Both of them are collected during specific seasons, depending on the fruit species. Even if seasonality has an indisputable influence on each specific crop and hence, on their residues, crop variability in Lebanon and rotation allows a continuous supply over the year.

3.Residues from cereals

- Price variations are possible due to competitive uses (animal feeding purpose).
- With respect to the seasonality factor, it has to be stressed that Lebanese crop variability and rotation assures continuous supply of cereals over the year, instead that only during specific seasons, depending on their species.,

4.Olive oil cake

- Price variations are possible due to its competitive uses (domestic inefficient heating, and export products).
- Variations on the quality of olive oil cake exist as its generation depends on several industrial factors and processes applied to produced olive oil.

Public and NGO's acceptance and competition with other end uses

These two factors will be treated in the same section as public opinion usually supports other end uses, especially if these are related to human and animal needs.

1.Residues from felling

- It is assumed that using residues from felling for energy purposes will have non-governmental organisations and public acceptance. The reason stems from the lack of competition of this biomass with human food or other end uses.

The next paragraphs show a summary of the SWOT analysis performed on most relevant biomass resources and applicable technologies. A full description of these SWOT analyses is presented in the volume "Annexes" of this study, chapter 5, annex I "SWOT analysis biomass resources and applicable technologies."

SUMMARY SWOT ANALYSIS OF MOST RELEVANT BIOMASS RESOURCES

Table 131, Table 132, Table 133, Table 134 and Table 135, show the strengths, weaknesses, opportunities and threats of every selected raw material concluded from prior tasks.

Table 131: SWOT analysis residues from forestry felling

	Helpful	Harmful
Internal factors	Strengths - High calorific value (14 - 17 MJ/kg) - Low moisture content (average 20%) - Prevents fires - Not a seasonal resource - Low water footprint	Weaknesses - Low accessibility to raw material (higher collection, handling, storage and transportation costs) - Depends on regional availability
External factors	Opportunities - Legislation allows pruning of forests - Pruning of trees is not current practice - Economic performance of the feedstock with other competitive markets	Threats - Possible loss of nutrient if the techniques used are not controlled. - Sustainable forest management issues.

Table 132: SWOT analysis residues from olive and fruit trees

	Helpful	Harmful
Internal factors	Strengths - Calorific value (12.6 – 13.2 KJ/kg) - Appropriate moisture content (40%)	Weaknesses - Extraction, handling and transportation costs - Depends on regional availability
External factors	Opportunities - Development of organised harvesting programs - More efficient use of residues from olive trees	Threats - Residues from olive trees uses for heating purposes - No legal framework supporting harvesting activities

Table 133: SWOT analysis residues from cereals

	Helpful	Harmful
Internal factors	**Strengths** - High calorific value (average of 14.4 – 17.1 MJ/kg) - Moisture content from 11% (depending on the crop)	**Weaknesses** - Transport costs - Depends on regional availability
External factors	**Opportunities** - Energy valorisation adds value to residues burned directly on the fields or left on the ground	**Threats** - Presence of competitive uses (animal feeding purpose). - Opposition likely to be faced by NGOs and public opinion

Table 134: SWOT analysis Energy crops

	Helpful	Harmful
Internal factor	**Strengths** - High calorific value (15 – 39.62 MJ/kg) - Moisture content (32 - 49%) - Reduces soil erosion and land degradation (directly linked to water scarcity) - By products can be reused for biogas production, soil amendment activities and animal feeding. - Economic profits - Diversity of energy crops allows a continuous and regular supply	**Weaknesses** - Transport costs - There is not relevant experience on energy crops in the country.
External factor	**Opportunities** - Added value to unused lands (the surface of uncultivated use is around 104,900ha.) - Energy crops can be cultivated with minimal inputs and labour	**Threats** - Market stimulation by solid incentives needed - Sunflower: competition with market for human consumption. - Opposition likely to be faced by NGOs and public opinion - Modern agricultural practices must be considered in order to obtain a competitive product

Table 135: SWOT analysis olive oil cake

	Helpful	Harmful
Internal factors	**Strengths** - Calorific value (average 14 MJ/kg) - Moisture content (depending on production of olive oil; 25 - 60%). This feedstock is accumulated in olive mills making its transport to bioenergy plants much easier and less costly	**Weaknesses** - Quantity of feedstock applicable only to small scale, combination with other bioenergy sources needed. - Variable nature of olive oil production and generated residues: seasonality and variability of residues. - Depends on regional availability
External factors	**Opportunities** - Opportunity of enriching three different and centralized locations (North Lebanon, Mount Lebanon and Nabatiyeh)	**Threats** - Competition with other uses: heating and exported product

SUMMARY SWOT ANALYSIS TECHNOLOGIES

Table 136, Table 137, Table 138 and Table 139, show the strengths, weaknesses, opportunities and threats of every selected technology option.

Table 136: SWOT analysis combustion CHP

	Helpful	Harmful
Internal factors	**Strengths** - Mature and reliable technology (savings, avoidance of risks). - Higher efficiency than separate generation - Suitable for base-load service - Double product generation: power and heat. - Remaining steam can also be used for industrial purposes in the bioenergy plant or exported to other installations - Low production of ash (around 1-2% of the biomass input)	**Weaknesses** - Drying needed: energy-intensive process - High sensitivity to chlorine and alkali (on a prior stage of operation, the construction tasks usually requires long mobilization time and supplies) - Power production is cost effective depending on the subsidy scheme implemented due to the potential high cost for heat distribution - Combustion of forestry residues for electricity is inefficient. It requires a continuous demand of the heat produced.
External factors	**Opportunities** - To create known-how and qualified labour force in CHP technology - Large scale applications entail lower investment costs and less dust and NOx emissions	**Threats** - Lack of knowledge and experience in Lebanon - Equipment not available locally - Large scale applications face logistical challenges (due to potential insufficient feedstock supply)

Table 137: SWOT analysis combustion boiler

	Helpful	Harmful
Internal factors	**Strengths** - Technology widely proven - Simple to operate and maintain - Little need for qualified labour - Low production of ash (around 1-2% of the biomass input) - A number of feedstock available in Lebanon can be used in the combustion boiler technologies	**Weaknesses** - Drying needed: energy-intensive process. Indeed, the majority of the raw biomass materials may require some form of processing (conditioning of particle size and shape) - Pellets are the preferable use for small scale which means possibly an additional pelletization pretreatment to be considered - Dust and NO_x emissions needs to be carefully controlled - Biomass heating systems require physical handling mechanisms for transferring fuel from where it is stored to where it is combusted
External factors	**Opportunities** - Investment cost much lower than combustion-CHP - Possibility of combining small and large scale (combining benefits of both scales)	**Threats** - More expensive than traditional fossil fuel technologies (incentives needed) - Importation of technology and spare parts needed - Heat is the single product generated, which is applicable just for local usage, as it is difficult and expensive to transport

Table 138: SWOT analysis lignocellulosic bioethanol

	Helpful	Harmful
Internal factors	**Strengths** - Independence of traditional fuel importation requirements - Both effects involve their subsequent environmental, economic and political positive impacts on society and environment - Technology simple and applicable in countries with no current habits - No need for storage or transport of intermediates. Also, feedstock and bioethanol storage can be located on-site or off-site - Production of lignocellulosic bioethanol entails a lower consumption of water than the generation of biodiesel	**Weaknesses** - Currently available only under financial and economic support from subsidies - Production and use of bioethanol is not a current practice in Lebanon - Energy crops may entail a significant water consumption
External factors	**Opportunities** - Different capacities can be spanned if needed. This versatility is not common to every emergent/emerging technology (an advantage to be valued) - Forecasts made on long terms point out a significant decrease on operational costs (foreseen to reach less of the half of the actual cost)	**Threats** - Imports of technology needed. Diversity of suppliers is always an advantage as the best choice could be selected depending on market prices and distances - International standards of biofuel must be considered in order to obtain a competitive product

Table 139: SWOT analysis anaerobic digestion

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal factors	**Strengths** - Lack of required pretreatments: possibility of operation near the waste generation points (savings for avoided transportation and storage needs) - Does not need prior drying processes - Co-digestion of combinations with other raw materials (such as organic waste) is also applicable - The fertilizer output of AD displaces the requirement for artificial fertilizer	**Weaknesses** - Anaerobic digestion depends on a number of biological factors to achieve a stable process: starting up an anaerobic digestion plant could take longer times than other bioenergy processes - The technology has low overall energy conversion efficiency in comparison with other conversion options
External factors	**Opportunities** - Wide range of scale that it can cover (feasible from farm scale to regional scale) - It is foreseen economic feasibility of anaerobic digestion and wider applicability - The majority of the waste streams provided is not toxic to the methanogenic bacteria - Biomass streams with high water content can be applied to this technology, while other conversion options cannot use them. Usage of the most useless waste - Potential management of municipal organic waste implementing the use of this raw material to co-digest with other biomass streams	**Threats** - Anaerobic digestion could imply higher investment and operational costs than combustion boiler or CHP techniques - Importation of technology needed. Diversity of suppliers is always an advantage as the best choice could be selected depending on market prices and distances - Biogas produced needs prior treatment to transport (clean, purified and compressed). These quality standards and consequent treatment are much more strict in the case of a potential injection into a future national grid - Even if anaerobic digestors work with very wet streams, they usually require a second dried feedstock

I.2 STEP 2: BARRIERS AND MITIGATION OPTIONS

This section focuses on the main barriers needing further research to promote bioenergy developments in Lebanon. Summary tables of found barriers and their mitigation options are presented in the next tables (Table 140, Table 141, Table 142, Table 143 and Table 144). A full analysis of these barriers and mitigation options is presented in the volume "Annexes" of this study, chapter 5, annex II "Barriers and mitigation options for bioenergy development in Lebanon."

Table 140: Summary of barriers and mitigation options: Combustion-CHP from forestry felling

Barriers	Mitigation options
Pre-treatments required	- Selection of most feasible alternatives according to the heat source. - Financial support.
Corrosion due to extreme operational conditions and sensitivity of alkali	- Usage of feedstock with low contents of potassium and chlorine with this technology. Using the residues from felling as feedstock.
Lack of current collection practices	- Implementation of collection activities into governmental fire-fighting and forestry cleaning initiatives
Lack of technology suppliers in Lebanon	- Research of suppliers overseas with closer headquarters and study of market prices. - Establishment and stimulation of technological industry in Lebanon. - Stimulation of technological industry in Lebanon. - Importing exemptions for equipment
Lack of accessibility of raw material	- Analysis of the strategic location of the combustion-CHP plant. - Recollection regulation, best agricultural practices - Proper development and maintenance of road infrastructure
Consumption of water (see also table145)	- The treatment processes of forestry residues will be optimized to reduce the consumption of water to the minimum possible. The global water footprint related to fibres and vegetal origin biomass is 3537 m^3 per ton of biomass treated (Mekonnen M.M, Hoekstra A.Y., 2010). This figure results from the following additional data found about consumption of water: 163 m^3/ ton which is the blue water footprint and 3375 m^3/ ton of green water footprint. No gray water footprint is considered for forestry fellings

Table 141: Summary of barriers and mitigation options: Anaerobic digestion from olive and fruit trees residues

Barriers	Mitigation options
Variety in the quality of feedstock	- Forestry management
Land, supply & storage availability	- Enforcement of regulation frameworks (Law 462 & Law 85) - Integration of Solid waste management strategies and energy policies
Labor & staff expertise	- Capacity building - Memorandum of Understanding between Central Bank and UNDP for technical cooperation - Awareness raising and promotion of social acceptance
Local conditions of the production chain	- Flexibility in raw materials - Improvement of logistics for distribution
High investment costs	- Grants for clean energy development - Tax exemptions of imported bioenergy equipment
Legislative policy framework	- Regulation frameworks (Law 462 & Law 85) - Coordination between ministries
Technology maturity in Lebanon	- Investigating technology feasibility - Set up of small scale pilot plants - Stimulation of technological industry in Lebanon
Consumption of water (see also table 145)	- The treatment processes of residues from olive and fruit trees will be optimized to reduce the consumption of water to the minimum possible. - The water footprint related to residues from fruit depends on the specific sort of fruit; however, some general data found about cereals points to a global water footprint of 967 m^3 per ton of biomass treated (Mekonnen M.M, Hoekstra A.Y., 2010). This figure results from the following additional data found about consumption of water: 727 m^3/ ton which is the green water footprint for this biomass, 147 m^3/ ton is the blue water footprint and 93 m^3/ ton the grey water footprint. - As for residues from olive trees, the total water footprint reaches 3015 m^3/ ton and the equivalent additional data is as follows (Mekonnen M.M, Hoekstra A.Y., 2010): 2470 m^3/ ton of green water footprint, 499 m^3/ ton of blue water footprint and 45 m^3/ ton of grey water footprint.

Table 142: Summary of barriers and mitigation options: Combustion boiler with residues from cereals

Barriers	Mitigation options
Additional transportation costs	- Development/improvement and proper maintenance of road infrastructure - Analysis of the strategic location of the plant. - Improvement of connecting roads infrastructure
Competition of residues from cereals with other end uses	- Research of the accurate percentage of feedstock available with energy purposes (collection trials of the feedstock left on the ground and the biomass directly burned).
Small scale size limitations	- Dissemination of the environmental advantages of using combustion/boiler technologies instead of burning the biomass directly. - Governmental subsidies, incentives and financial mechanisms to cover combustion/boiler expenses and make its use affordable on the domestic level. - Capacity building by workshops, trainings and provision of benchmark information.
Lack of technology suppliers in Lebanon	- Research of suppliers overseas with closer headquarters with consideration of market prices and rural population's purchasing power.
Consumption of water (see also table 145)	- The treatment processes of residues from cereals will be optimized to reduce the consumption of water to the minimum possible. General data found about cereals points a global water footprint of 1644 m^3 per ton of biomass treated (Mekonnen M.M, Hoekstra A.Y., 2010). This figure results from the following additional data found about consumption of water: 1232 m^3/ ton which is the green water footprint of this biomass, 228 m^3/ ton is the blue water footprint and 184 m^3/ ton the grey one.

Table 143: Summary of barriers and mitigation options: Bioethanol from lignocellulosic energy crops

Barriers	Mitigation options
Competition with other end uses	- Choosing a feedstock that with the least competing end uses and highest sustainability criteria.
Additional collection, handling and transportation activities	- Improvement of transportation networks between available and suitable agricultural areas where energy crops would be cultivated. - Identification of a strategic location for the establishment of the lignocellulosic ethanol plant.
Identification and negotiation of grasslands, unused lands and cannabis plantations	- Identification of most adequate and accessible lands (administratively and geographically. - Awareness rising within the farming communities of rural areas, namely in Nabatiyeh. - Capacity building
Intensive physical and chemical pretreatment	- Governmental subsidies, incentives and financial mechanisms to cover plant expenses and make commercially profitable the bioethanol production.
Water consumption with irrigation purposes	- Choosing a feedstock with little water requirements and highest sustainability criteria. Perennial grasses and other lignocellulosic crops are a viable option under adapted technology.
Lack of technology suppliers in Lebanon	- Research of suppliers overseas with closer headquarters with consideration of market prices and rural population's purchasing power.
Consumption of water (see table 145)	- The treatment processes of lignocellulosic energy crops will be optimized to reduce the consumption of water to the minimum possible. Depending on the type of energy crops studied, the water consumption of their treatments varies. In general terms, it is found a total water footprint of 1193 m^3 per ton of biomass treated (Mekonnen M.M, Hoekstra A.Y., 2010): 982 m^3/ ton which is the green water footprint, 109 m^3/ ton corresponds to blue water footprint and 102 m^3/ ton to the grey one. The figures provided on this section have been calculated according to the average values of all energy crops suggested (Mekonnen M.M, Hoekstra A.Y., 2010).

Table 144: Summary of barriers and mitigation options:
Anaerobic co-digestion of olive oil cake and other organic residues

Barriers	Mitigation options
Feedstock accessibility and variety of quality	- Stimulate collection of residues in cooperatives with the help of subsidies, grants or funds
Land availability, supply & storage	- Storage of raw materials in cooperatives - Provide distribution lines
Local use of feedstock	- Promote not only global distribution but also personal uses
Labor & staff	- Capacity building: workshops, training, benchmark information - Promoting public acceptance in renewable energies
Local conditions production chain	- Flexibility in raw materials as there are different feedstock
High investment costs	- Financial incentives and regulations for renewable energy
Legislative policy framework	- Provide incentives for bioenergy - Define tariff regulations for electricity - Legal policy to support market
Technology maturity in Lebanon	- Small scale units or pilot plants - Investment and development of local technology
Market absence	- Legal framework to ensure entrance in the energy grid - Legal opening of the market to privatization - Feed-in tariffs for bioenergy options
Lack of a Master Plan specifically for Organic Municipal Waste	- Building and controlling of landfills - Municipal collection waste system - Implementation of a fee to get rid of waste in order maintain the collection system and landfills installations - Workshops and public training about the importance of the correct management of waste in areas where there have not been previous habits of controlled dumping.
Consumption of water (see also table 145)	- The treatment processes of this biomass stream will be optimized to reduce the consumption of water to the minimum possible. The water footprint associated to olive oil cake depends on the production of olive oil as the cake is a by-product of this process. The total water footprint reaches 14431 m^3 per ton of virgin olive oil produced (14726 m^3/ ton for refined olive oil) (Mekonnen M.M, Hoekstra A.Y., 2010). From these quantities: 11826 m^3/ ton corresponds to green water footprint (12067 m^3/ ton for refined olive oil), 2388 m^3/ ton to blue water footprint (2437 m^3/ ton for refined olive oil) and 217 m^3/ ton to the grey one (221 for refined olive oil).

* Green Water Footprint: Rainwater consumed to produce the product
* Blue Water Footprint: Refers to the volume of surface and groundwater consumed as a result of the production of a good
* Grey Water Footprint: Refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

To summarize the information about water consumption above, the next table is presented:

Table 145: Water footprint of raw materials

Raw Material	Green Water Footprint (m^3/ton)	Blue Water Footprint (m^3/ton)	Grey Water Footprint (m^3/ton)	Total Water Footprint (m^3/ton)
Fibers (vegetal origin)	3 375	163	300	3 837
Fruits	727	147	93	967
Olives	2 470	499	45	3 015
Cereals	1 232	228	184	1 644
Energy Crops	982	109	102	1 193
Virgin Olive Oil	11 826	2 388	217	14 431
Refined Olive Oil	12 067	2 437	221	14 726

I.3 BENEFITS OF DEPLOYING BIOENERGY IN LEBANON

The worldwide concern for the security of fossil fuel supply in the long-term and the environmental damage caused by irresponsible use of energy sources available, are shifting energy policies towards more sustainable pathways. The MENA region is a potential future hub for clean energies, not only for its domestic consumption but also as a supplier to the EU markets. The Lebanese energy sector is heavily reliant on fossil fuel imports (at least 97% of total primary energy) and therefore exposed to international oil price fluctuations. The transport sector leads this primary energy consumption (28% of total) according to the latest statistics of the International Energy Agency (2008)[1] .

Lebanon is not a fossil fuel producer (at least at present) and its economy is mainly based on the service sector; its high energy intensity (see Table 146) is not justified. Therefore, there is a large potential for reducing Lebanon's energy intensity and the dependence on fossil fuel consumption. For the latter, bioenergy is a promising option.

Table 146: Energy intensity in Lebanon and other regions

	Energy intensity (toe per $1,000 of GDP, 2005)
Lebanon	0.20
Region's average	0.18
World's average	0.13
OECD's average	0.11

[1]http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=LB

The most important benefits of deploying bioenergy in Lebanon are presented in the following paragraphs.

• **Security of supply**

A more balanced mix of energy sources including bioenergy are appropriate for security of supply and improve sustainability.

• Regulation of the electrical generation

The regulation reform of the electricity sector in Lebanon is still pending. According to the MoEW Policy Paper of 2010, the failure to reform the electricity sector is causing an annual deficit of 1.5 billion dollars on the public purse and losses on the national economy estimated at not less than $2.5 billion dollars per year. This crisis is caused by the lack of worthy investments, high imported fossil fuel bill, the operating status of power plants; high technical and commercial losses in transmission and distribution, and wrong tariff structure and low average tariff among others. The future reform of the electricity sector regulation is actually an opportunity to promote investment on sustainable energy sources such as bioenergy. These reforms could very well focus on promotion on reducing the dependency on imported fossil fuel and on a proper tariffing system that pays back properly the investments in renewable energies.

• **GHG emissions reduction**

Implementing the exploitation and use of bioenergy in Lebanon reduces fossil fuel needs and their associated GHG emissions.

• **Political benefits**

The difficulties resulting from the current structure of the electricity sector is the centre of several political confrontations and consumer complaints. Providing the proper institutional framework, by gradually introducing the appropriate laws and unbundling regulations (established in Law 462 and its amendment, Law 775), and permitting private sector participation would allow to by-pass some of these obstacles and enhance consumer's and investor's confidence.

• **Domestic fuel for the transport sector**

The Lebanese transport sector is a large contributor to GHG emissions and consumption of fossil fuels. Development of policy statements and regulations are needed to consider biofuels as a viable alternative. The transport sector is the largest in terms of energy consumption, with a substantial growth in recent decades, and the second largest sector in terms of greenhouse gas (GHG) emissions. A displacement of fossil fuels by biofuels implies large greenhouse gas emissions savings when sustainability criteria are applied, as well as certain independence from traditional fuel importation requirements. Both effects involve their subsequent environmental, economic and political positive impacts on society and the environment. With over 1.6 million vehicles registered and 87% of the Lebanese population living in urban areas, the benefits of using biofuels seem obvious.

In order to reach this purpose, actions as a governmental targeting of its use, obligatory blending, and the creation of a legal framework that gives fiscal benefits for biofuel production are recommended. In addition, the adoption of international technical standards is recommended in order to obtain a competitive product.

• **Heat uses in the industry or district heating**

The combination of CHP from biomass with heat uses in some Lebanese cities with new planning developments could be an opportunity and a subject for further study. This scheme is therefore most effective when serving a variety of heat customers, to guarantee a relatively constant heat load. It is common practice to identify key anchor loads such as industrial processes or community uses (hospitals, universities, leisure centres, public buildings, prisons or schools) with constant hot water needs and in some cases also space heating requirements.

The combination of cogeneration and heat uses is very energy efficient. A simple thermal power station can be 20-35% efficient, whereas a more advanced facility with waste heat recovery can reach nearly 80% of total energy efficiency. District heating is a long-term commitment due to the high investments needed (some estimations can be consulted on Table 147).

Table 147: Costs of district heating for homes in the UK (Faber Maunsell AECOM & Poyry, 2009).
Average exchange rate 1 USD = 0.641 British pounds

Dwelling Type	DH mechanical and civil costs of distribution pipework Cost	DH Branch mechanical and civil costs of distribution pipework Cost	Heat Interface Unit (HIU) and Heat Meter Cost	Total Cost
Small terrace	£2,135 Based on outline network design and costing	£1,912 Based on outline network design and costing plus additional costs for HIU and metering.	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£6,347
Medium / Large terrace	£2,135 Based on outline network design and costing	£2,255 Based on outline network design and costing plus additional costs for HIU and metering.	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£6,690
Semi-detached	£2,719 Based on outline network design and costing	£2,598 Based on outline network design and costing plus additional costs for HIU and metering.	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£7,617
Semi detached	£2,719 Based on outline network design and costing	£3,198 Based on outline network design and costing plus additional costs for HIU and metering.	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£8,217
Converted flat	£712 Assumes that infrastructure costs for a 3-story converted terrace are split between 3 flats.	£752 Assumes that branch costs for a terrace are split between 3 flats with an HIU and heat meter for each flat.	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£3,764
Low rise flat	£1,500 Estimate	£1,500 Internal pipework	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£5,300
High rise flat	£1,000 Estimate	£1,500 Internal pipework	£2,300 (includes £1,600 HIU, £200 for heat meter, and £500 for installation)	£4,800

• **Added value for residues used as feedstock**

Considering the well-known cost of end products, turning residues into biogas or biofuels is an important added value.

• **Forest management**

The Lebanese Ministry of Environment launched several initiatives in order to mitigate fires in forest zones. Those movements entail the removal of wastes from forests however they act more in the direction of cleaning activities rather than collection of residues from felling. Although it is not exactly a residues collection, the existence of this practice is helpful as potential measures could be further adopted to develop an organised cleaning activity with relatively little effort and investments. These governmental efforts would be preliminary steps towards a proper forestry management system, including the mitigation of forest fires.

• **Waste management**

The National Strategy for Bioenergy could contribute effectively in the design of the new Master Plan for MSW by identifying potentials and impacts of the use of waste for energy generation.

• **Added value to unused lands**

Important added value to unused lands can be obtained through the cultivation of energy crops. Unsuitable lands for other crop plantations are ideal locations for the activities recommended in this National Bioenergy Strategy.

• **Prevention of soil erosion**

Setting lands aside for energy crops reduces soil erosion and therefore land degradation. Soil erosion and land degradation are phenomena directly linked to water scarcity and therefore energy crops may assist in water management.

• **Added value for by-products**

Several by-products generated as a consequence of biomass processing can be reused and contribute to other energy conversions such as biogas production, or to soil amendment activities (charcoal or compost production) and animal feeding. Each of these activities provides the energy crops chain with increased economic profits.

• **Conservation of soil nutrients**

The plantations of energy crops could contribute to soil conservation as sowing the ground is an appropriate practice to maintain physical and chemical properties of soils. However, the maintenance of these properties will not arise if harvests are not developed under good agricultural practices. Respecting sustainable practices in agriculture is indispensable. Bearing in mind these good practices, sowing will benefit lands rather than leaving them neglected.

• **Employment generation and reduction of poverty**

Bioenergy projects contribute to social welfare through employment generation. Both a qualified and a non-qualified labour force are needed for the technological transformation of residues from felling, cereals, olive and fruit trees, and also for their collection, handling and transport activities. The generation of employment is a very significant factor in terms of reduction of the poverty in regions where these residues can be easily extracted.

• **Rural development**

Many of the Lebanese rural populations live in relative poverty due to the major problems facing agricultural production. The deficiencies of this production in the country is mainly due to the small size of agricultural lands, high operating expenses, and the lack of regulation and specialized economic subsidies. Hence, bioenergy projects are aimed to enhance economic stability of the less wealthy areas in Lebanon.

• **Spreading of knowledge in specialized fields**

Awareness and knowledge about bioenergy in Lebanon requires more effort or dissemination. This factor is the basis for acceptance and interest. The necessary human capital can only be built up gradually, as there is a lack of specialized labour at the onset of such markets. The spreading of knowledge and technical know-how will allow individual consumers and firms to overcome existing barriers.

• **Clean technologies and entrance to carbon markets**

Technology transfer that implies the encouraging and development of bioenergy in Lebanon would encourage the country entering the clean technologies and carbon markets.

One of the markets derived from the implementation of green and renewable energy in Lebanon is the carbon market. Although Lebanon has ratified the Kyoto Protocol, there are no stable initiatives concerning clean energy resources, a fact hindering the development of these types of projects. As a consequence, there is just one CDM project in the validation stage in Lebanon.

• **Promotion of private investments**

Public and governmental supports are not enough to start and maintain the bioenergy strategy. Encouraging the private sector in investing in the bioenergy sector and related activities is fundamental for the success of a national strategy. The legal framework needs to establish not only technical, environmental, safety and other regulatory aspects for private power production, but also provisions allowing private power producers to sell electricity.

- **International and regional cooperation**

The surge in interest in bioenergy sources has led to increased investments in the MENA region by the EU, the US and international organisations such as The World Bank, as well as by public and private stakeholders in the region. The aim of these initiatives is to achieve a critical mass of investment to jump-start these markets in the region within the next few years. Similar conditions are desirable for Lebanon.

II.ANALYSIS OF REGULATORY FRAMEWORK

Lebanon ratified the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol respectively, in 1994 and 2006. Referring to the Kyoto Protocol, Lebanon is among Non-Annex I countries that do not have to take any binding commitments to reduce greenhouse gas emissions. In addition, Lebanon joined the International Renewable Energy Agency (IRENA) in 2009, becoming the 81st country to do so. On the regional level, Lebanon is a part of the Euro-Mediterranean Energy Partnership which has adopted three energy policy objectives: security of supply, competitiveness of the energy industry, and environmental protection (Kangiannas Argyris, 2003). While Lebanon is following every international trend toward cleaner energy and environmental protection, on the local level, the country is suffering from the absence required policies to improve the energy situation.

Lebanon's electricity sector was nationalized in the 1960s (it was formerly private with local and international ownership), and since then it ended the policy of interfacing with various electricity concessions throughout the country. Forty years later in 2002, the next crucial energy policy decision occurred when the Lebanese parliament decided to reopen the energy market to the private sector. Lebanon has never had any type of renewable energy policy and even the energy law that Parliament passed in 2002 is yet to be implemented. Law 462 initiates a platform for an energy restructuring in Lebanon based on two major decisions: the establishment of a regulatory authority and the recognition of independent power producers (IPPs). Although it is an essential step toward the renovation of the electricity sector in Lebanon, more comprehensive legislations and regulations are needed for development of renewable energy in Lebanon.

II.1ELECTRICITY LEGISLATION IN LEBANON

The Lebanese Ministry of Energy and Water (MoEW) is responsible for to the country's electricity sector. Electricité du Liban (EDL) is under the supervision of the MoEW. Electricity legislation in Lebanon is limited to a small number of laws and decrees. The absence of a regulatory authority to follow and update the issues in the sector is one of the main reasons why there are no plans to find practical solutions to the electricity shortage. Energy plans are most often adapted to international donors and the conditions of their funds, rather than to national planning. Law 462 from 2002 has not been implemented; the current electricity regulation in Lebanon is still based on Decree 16878 from 1964 which established a monopoly for the generation, transmission and distribution to EDL. This issue has been partially overcomed by the MoEW Policy Paper of 2010 which has recommended initiating the process of revising Law 462 with all involved parties in light of the consensus on this matter, and introducing the necessary amendment on Law 462 to correct deficiencies and contradictions and start its process of implementation.

LAW 462

Law 462 was issued on September 2nd, 2002 and aimed to implement a structural change in the electricity sector in Lebanon. The law provides the legal framework for privatization of the electricity sector and the implementation of the Electricity Regulatory Authority (ERA) as the regulator of the electricity sector. Moreover the law focuses on the unbundling of the sector by separating the generation, transmission and distribution activities. Based on the law 462, the creation of one or more public corporations responsible for generation and distribution is anticipated. While corporatization is the first level of privatization of these two sectors, transmission would remain a public monopoly.

Law 462 came at the request of the World Bank (Abisaid, 2010) and Paris III chartered the roadmap for donor countries to provide funds for Lebanon.

II.2 WOOD FOREST PRODUCTS LEGISLATION

In Lebanon, wood does not constitute a major product due to the structure, cover and distribution of forests. No value is given to the commercial growing stock as timber harvesting is forbidden. Wood is only used as fuel and charcoal in limited quantities. Several rural communities still depend on fuel-wood and charcoal production for their livelihoods. Controlled exploitation of charcoal is legally allowed by the Ministry of Agriculture.

Lebanon has two overlapping forest laws:

- The Forest Code of 1949 and;
- The Law on Forest Protection, Law 85 of 1991 then amended by the Parliament in 1996.

While the Forest Code regulates forest activities including pruning, thinning and charcoal making, the law on Forest Protection imposed severe restrictions on forest activities, and a total ban on harvesting resinous trees including pine (Calibrian, Aleppo and Stone pines), Lebanese cedar, juniper, cypress and fir. The Forest Code recognizes three types of forests based on land ownership (private, municipal and state) and therefore continues to provide the basis for the management of forests by the Ministry of Agriculture.

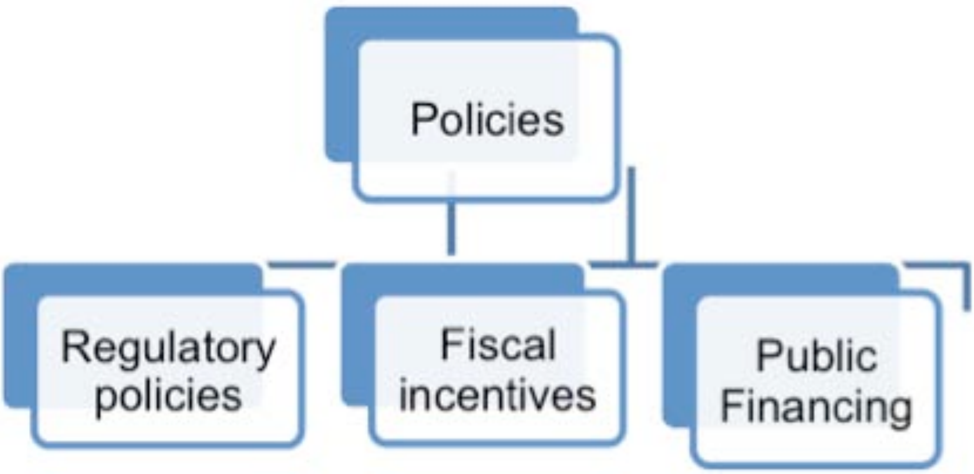
II.3 RENEWABLE ENERGY SUPPORTIVE SCHEMES IN THE WORLD

Policy design for the support of renewable energy should reflect four fundamental principles:

- The removal of non-economic barriers, such as administrative hurdles, obstacles to grid access, poor electricity market design, lack of information and training, and the tackling of social acceptance issues;
- The need for a predictable and transparent support framework to attract investments;
- The introduction of transitional incentives, decreasing over time, to foster and monitor technological innovation and move technologies quickly towards market competitiveness;
- And the development and implementation of appropriate incentives guaranteeing a specific level of support to different technologies based on their degree of technology maturity, in order to exploit the significant potential of the large basket of renewable energy technologies over time.

Governments have a number of different options that they can use to promote bioenergy. Often, a mix of instruments is the key to their success. Direct support instruments can be categorized into 3 groups outlined in Figure 49.

Figure 49: Legal instrument for bioenergy promotion



REGULATORY POLICIES

Feed-In Tariffs

Feed-in tariffs (FITs) are the most widely used policy in the world for accelerating renewable energy deployment, accounting for a greater share of renewable energy development than either tax incentives or renewable portfolio standard (RPS) policies (REN21, 2009). Countries such as Germany and Spain, in particular, have demonstrated that FITs can be used as a powerful policy tool to drive renewable energy deployment and help meet combined energy security and emissions reductions objectives.

The Feed-in Tariff system sets a price that is guaranteed over a certain period of time at which power producers can sell renewable electricity into the grid. Some policies provide a fixed tariff while others provide fixed premiums added to market- or cost-related tariffs. Feed-in tariffs are expressed in national currency per kWh or national currency per MWh.

These purchase agreements are structured with contracts ranging from 10-25 years. In order to tailor FITs to a range of policy goals, the payment level can be differentiated by technology type, project size, resource quality, and project location. FIT policies typically include three key provisions:

- Guaranteed access to the grid;
- Stable, long-term purchase agreements (typically, about 15-20 years);
- Payment levels based on the costs of RE generation (Mendonça 2007). In countries such as Germany, they include streamlined administrative procedures that can help shorten lead times, reduce bureaucratic overhead, minimize project costs, and accelerate the pace of renewable energy deployment (Fell 2009).

One of the most important elements of FIT design is the guarantee of reliable revenue streams (Klein et. al. 2008). In addition, the guaranteed contract terms enable project developers to finance a larger proportion of the project with debt financing, as opposed to equity, which puts further downward pressure on the cost of capital (de Jager and Rathmann 2008).

Most successful European FIT policies, which resulted in quick and substantial RE capacity expansion, have FIT payments structured to cover the RE project cost, plus an estimated profit (Klein 2008).

Because each renewable energy generation project is unique, differentiation of FIT payments to account for these differences can ensure that a variety of technologies and project sizes come online. Many European FITs provide an equal opportunity for small, medium and large scale projects.

In addition, European policies typically extend eligibility to anyone with the ability to invest, including – but not limited to – homeowners; business owners; federal, state, and local government agencies; private investors; utilities and nonprofit organisations (Mendonça 2009). Experience from Europe is also beginning to demonstrate that properly designed FITs may be more cost-effective than renewable portfolio standards (RPS), which make use of competitive solicitations.

Feed-in tariff regulations have been introduced in both developed and developing countries, among them are most of EU member countries, Japan, South Korea, Thailand, South Africa, Uganda, Kenya, etc., and are cited as the primary reason for the success of the German biogas market.

Utility Quota Obligation

Utility quota obligation or more generally known as Renewable Portfolio Standard (RPS), renewable obligations or quota policies, require electric utilities to provide renewable electricity to their customers, typically as a percentage of total energy use. It does this by establishing the proportion of electricity supply that must be produced from eligible renewable energy sources. The obligation is typically imposed on electricity producers. The implementation of an obligation system usually involves a penalty for not complying with the obligation. RPS relies almost entirely on the private market for its implementation.

The United States of America is the main applicant of RPS in the world with the highest number of states that have applied RPS policy.

Often quota systems incorporate a tradable certificate system with certificates which can then be sold. The interested parties in a trading scheme can either choose to fulfil the quota by renewable energy generation or purchase certificates in order to meet the obligation. The prices of these certificates are determined by the level of quota obligation, the size and allocation of penalty charges, and the duration of the eligible credits.

Net metering

A variant of renewable electricity systems support scheme based on electricity pricing is net metering. This mechanism allows homes or businesses to sell renewable electricity they generated in excess of their use at wholesale or retail prices. Customers pay only for the net electricity used.

Net metering is limited in its capacity to expand the generation of renewable electricity. Compared to FIT system, price paid for excess electricity in net metering is not high enough to attract investment in renewable electricity facilities. Also many net metering schemes have participation limits and grid connection standards which act as obstacles for expanding the renewable market.

In addition to the main policy instruments for stimulating renewable energy discussed above, the following accompanying measures are sometimes used to achieve the objectives set for specific renewable energy technologies.

FISCAL INCENTIVES

This category constitutes policies which are focused on cost reductions and improvement of the relative competitiveness of RE technologies in given markets: they may include capital grants, third-party finance, investment tax credits, property tax exemptions, production tax credits, sales tax rebates, etc. Some of these measures can be well applied to Renewable Energy Technologies (RET) invested by the users themselves. Taxes on fossil fuels also improve the competitive position of renewable energy. Specific regulatory policy instruments are tax incentives such as investment tax credits, production tax credits or reductions in sales, energy, carbon, VAT, etc.

Investment/production tax credits provide the investor with an annual income tax credit based on the amount of money invested in that facility or the amount of electricity that it generates during the relevant year. It allows investments to be fully or partially deducted from tax obligations or income. Reductions in sales, VAT, energy or other have in common a reduction in taxes which is applicable to the purchase (or production) of renewable energy technologies.

PUBLIC FINANCING

The tendering scheme

Tendering scheme is a system in which government encourages deployment of renewable electricity systems through providing competitive bids for power purchase agreements for bioenergy projects. Government accepts the lowest priced bids until the point that targeted level of generation is reached. This system also contains an element of a pricing law, in that the winners of the bids are guaranteed to sell their generated electricity to utilities at the price proposed by the winning bids. By encouraging competition between utilities the goal of the tendering system is to reduce the price of supplying renewable energy. Many tendering initiatives have been unsuccessful so far, which can be attributed to several reasons. Some of these tenders have been unreliable, which created uncertainty on the side of the developers. Some suggest that complexity of the bidding process as an obstacle. In certain cases, the plans drafted for these bids turned out to be too costly, and were unable to receive financing as a result.

Tendering systems have been used in U.K, Ireland, France, the U.S, and China.

Financial Subsidies

Bioenergy power plants are often capital intensive. Hence, governments may offer financial subsidies for renewable electricity technologies in terms of specific $/kW grants, or grants set as a percentage of total investment. Investment subsidies are the oldest (and yet still a very common) type of support mechanisms. This may be explained by the fact that such systems are often politically feasible and easy to administer.

II.4 IMPLEMENTATION OF FEED-IN TARIFFS FOR BIOENERGY PROMOTION IN LEBANON

European experience with renewable energy legislations, specifically with quota systems and pricing laws such as FITs has shown that latter is the preferable policy in terms of effectiveness, efficiency, and the amount of risk involved. Countries that implemented FITs have observed more installed capacity, improved technologies, a strengthened manufacturing and job market. The conclusion among many scholars on the renewable energy policy planning is that the feed-in mechanism has the most proved advantages over the other renewable energy support policies. It has been shown that FIT is the fastest and cheapest way toward RE deployment (Mendonca, 2007). Comparing the certain period of time that renewable energy supportive policies are enacted, and then their outcomes, FIT works at an optimum level.

The arguments in favour of a FIT policy are primarily economic in nature. These include the ability to:

- Offer a secure and stable market for investors;
- Stimulate significant and quantifiable growth of local industry and job creation;
- Only cost money if projects actually occur;
- Provide lower transaction costs;
- Distribute costs and development benefits equitably across geographic areas;
- Settle uncertainties related to grid access and interconnection;
- Enhance market access for investors and participants;
- Tailor the policies using a range of design elements that will achieve a wide range of policy goals;
- Encourage technologies at different stages of maturity, including emerging.

Due to the Lebanese local conditions, FIT is recognized as the most appropriate renewable policy for Lebanon that could mitigate the electricity problem in the country. Non-economic barriers can significantly hamper the effectiveness of policies and drive up costs, irrespective of the type of incentive scheme. Hence, Lebanon has to set a well-designed FIT legislation that meet local objectives, social aspects and electricity sector characteristics of the country.

It is to be noted that bioenergy supportive scheme should not be considered separately from other RE. Policy goals have to be defined to encourage a well-balanced distribution on the Lebanese territory and to meet the local and resources context. Renewable energy specific differentiation allows policymakers to select the portfolio of renewable energy technologies that is most suitable to their area, available resources, policy goals, etc., and to offer each a tariff amount that is consistent with cost recovery for each technology type.

LEGISLATION

Implementation of bioenergy sources in Lebanon is linked to electricity policy and legislation.

Even though Lebanon has a significant biomass potential, and advanced bank, financial and insurance systems, it still lacks a clear regulatory framework and credible regulatory authority to implement FITs.

Before starting any formal action toward implementation of Feed-in Tariff mechanism, Lebanon has to implement the pending law 462 which is fundamental for the future. Introducing new policies, setting detailed renewable energy targets, giving guidelines to ministers and setting electricity tariffs, are all part of the mission of the future Electricity Regulatory Authority. Moreover it will have the legal ability to promote renewable energy and presents supportive policies.

The first step is the participation of the private sector in electricity generation and the recognition of independent power producers.

The law has to support renewable energy power producers against conventional power producers and should ensure the grid connection of RE power producers. Renewable energy power producers must be differentiated from the conventional power producers. The purchase tariff has to be attractive enough to encourage investments in renewables, and should bring some level of advantages over the conventional power producers.

TARIFF MECHANISM

FIT policy designers can structure FITs to offer payment levels that are adjusted for different technology types, project sizes, resource qualities, and project locations. Lebanese specific barriers to bioenergy development determine the fundamental design options to implement Feed-in Tariff successfully.

The adequate tariff provides a financial interest in the sustainable growth of RE sources (Mendonca, 2009). If the feed-in tariff is too high, the number of installation will quickly increase and the government will not be able to sustain them any longer. Yet, if the tariff is low, it would be unattractive to investors.

The role of the payment period in FIT structure is significant because it protects the long-term investment against market fluctuation. The tariff is guaranteed for a certain number of years that may vary for different types of RE technologies, usually 15 to 20 years to cover the average lifetime of RE facilities and long-term loans.

Inflation Rate

In 2009, Lebanon struggled with a 10 % inflation rate (consumer prices) that was two times higher than the rate for the previous year. Therefore, if the inflation rate remains high and the country sets a fixed FIT, the FIT would rapidly catch the conventional electricity price up.

Policy designers use different approaches to adjust for changes in the Consumer Price Index. Some jurisdictions adjust the full tariff price to the annual changes in the CPI, while others peg only a portion of the tariff price to track these changes. Both methods protect the value of project revenues from changes.

This inflation adjustment provides added security for investors, by protecting the real value of renewable energy project revenues from changes.

Resource quality differentiation

As presented in chapter 1, the biomass resource is not distributed evenly over all the Lebanese territory. Therefore the FIT should respect the abundance of the resource in each region.

Differentiating FIT by bomass resource offers differentiated payments to projects in areas with a different cost of production (Klein 2008). It is done to encourage development in a wider variety of areas, which can bring a number of benefits both to the grid and to society.

First, differentiation by resource quality can encourage deployment in a wider geographic area. Second, this design option can help avoid excess remuneration at the best quality sites and finally it can make it easier to site projects away from areas where land-use conflicts are likely to be greatest. The tariff could support the Beqaa valley region, for instance, rather than the dense coastal areas along the Mediterranean Sea with a higher purchase tariff; it could encourage biogas power plants to be implemented closer to agricultural lands and investments in a less developed region such as Hermel.

Size differentiation

To promote small and medium scales, the FIT has to be differentiated by project size, represented in terms of total installed capacity. The lowest payment level is offered to the largest plants, reflecting the gains that result from economies of scale. The goal of such a structure is to approximate about the same rate of return, no matter the size of the project.

Bonus Payment Options

In addition to the FIT policy design options recommended for bioenergy in Lebanon, it is also recommended to add specific bonus payments to encourage certain kinds of technologies, as well as certain behaviours by plant operators:

- High-efficiency systems for highly efficient biomass generators using combined heat and power
- Use of specific bioenergy streams: These differentiations can target specific streams that are in abundance from different agricultural (Olive-oil cake, residues of fruit trees and cereals), forestry (residues from felling), or other industrial operations (Slaughterhouse waste, Wastewater sludge) and can allow a diversity of operators (farmers, industries, public entities) to profitably participate in generation of renewable electricity.

Orchard in Akkar

III.ANALYSIS OF FINANCIAL PERSPECTIVES FOR BIOENERGY DEPLOYMENT

III.1 SOURCES OF FINANCING

This section provides an assessment of financial mechanisms from where bioenergy developments can benefit. This includes international sources of financing such as multilateral and development banks and national initiatives as well.

NATIONAL FIT POLICY FUNDING

A FIT policy takes money to operate successfully, both in terms of policy administration, as well as paying for the FIT payments to eligible projects. The type of funding used for the renewable energy law can impact investor security, and have significant impacts (positive or negative) on market growth. If the policy is perceived to be vulnerable, growth in renewable energy markets could be compromised because investors factor in the added regulatory risks. The stability and longevity of the policy are fundamental to its success.

When implementing feed-in tariffs in developing countries, certain special design options have to be considered. Most jurisdictions that have successfully implemented FITs for emerging countries have considered not just the common factors of implementation for developed countries (previously mentioned), but also additional factors (Mendoça, 2009).

1) Common factors to implement FITs for developed and developing countries:

- -Avoidance of windfall profits for producers and contribution to a stable investment framework
- -Clear definition of the eligible technologies and plants
- -Mapping of the regional or national potential
- -Promotion of both firm and renewable energy technologies with specific support for each renewable energy technology (FITs should be calculated based on the generation costs of each technology)
- -Demonstration of a clear and transparent tariff calculation methodology by responsible policy makers and legislators

2)Specific and additional factors to implement FITs for developing countries:

- -Financing the tariff payment by distributing costs amongst all rate-payers but coverage of additional costs by a national fund for renewable energy deployment
- -Limit the installed renewable capacity to control costs for the final consumer

Due to the combination of a tariff payment and the obligation of purchase, FITs can be suitable mechanisms also for monopolized and oligopolised commercial systems. This combination provides a stable scheme for independent producers (Mendoça M, 2009). Thus, FITs schemes might be a financial option for the majority of the electricity market legislations including, the Lebanese current situation.

INTERNATIONAL SOURCES OF FUNDING

World Bank:

The World Bank is a vital source of financial and technical assistance to developing countries around the world. The World Bank is made up of two unique development institutions owned by 187 member countries: the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA).

The World Bank provides low-interest loans, interest-free credits and grants to developing countries for a wide array of purposes that include investments in education, health, public administration, infrastructure, financial and private sector development, agriculture and environmental and natural resource management.

Projects currently implemented in Lebanon in the Energy sector focus on broad on reform programs at the institutional level rather than on projects requiring capital investments.

The currently on-going Emergency Power Sector Reform Capacity Reinforcement Project for Lebanon (expected completion in 2012) aims at accelerating the implementation of electricity sector reforms and restructuring of Electricite du Liban (EdL). Additional initiatives remain a function of the Government's will to engage with the bank on directions as per the currently adopted energy policy.

European Union (EU)

In its efforts to improve the efficiency and effectiveness of service delivery and financial sustainability in the Lebanese infrastructure sectors (water, energy and land transport), the EU is currently developing the Support Programme for Infrastructure Sector Strategies and Alternative Financing Project (SISSAF). The project targets the 3 ministries with the ultimate aim of developing master plans for their respective sectors. Implementation ought to be financed by the Neighborhood Investment

Facility (NIF).

Also, the European Union has signed grant contracts with Banque du Liban (BdL) and Kafalat for the implementation of an energy efficiency financing window targeting Lebanese small and medium-sized enterprises (SMEs) that want to invest in energy savings and renewable energies technologies. The grant to BDL and Kafalat is to make their loan and guarantee schemes more attractive for environmental oriented investments. The project is on-going and can be extrapolated to promote bioenergy investments in equipment.

EIB (European Investment bank) and FEMIP

Created by the treaty of Rome, the bank shareholders are the member states of EU. They borrow on capital markets to finance "sound business projects" especially in Europe but also in other neighbouring regions and developing countries. The FEMIP is an emanation of the EIB and has been created to assist the economic development and the integration of the Mediterranean partner countries. The total investments have reached 10 billion euro between October 2002 and December 2009. FEMIP encourages the modernization and opening-up of the economies of the Mediterranean partner countries. They propose different tools:

- Loans
- Technical Assistance
- Guarantees
- Venture Capital
- Microfinance

EIB is promoting sustainable, competitive and secure energy sources.

The EIB is financing the implementation of Kesrwan Water and Wastewater Project that will improve sanitation services to a densely populated and touristic region and preventing sea water pollution at discharge. Also, the EIB finances the rehabilitation and expansion of the sewerage system of Tripoli area, which comprises the municipalities of Tripoli, El Mina and El Bedawwi.

In cooperation with the Agence Française de Développement (AFD), the EIB is currently undertaking discussion with the Lebanese Center for Energy Conservation (LCEC) for the financing of a project aiming at the promotion of Renewable Energy and Energy Efficiency in the country.

Neighborhood Investment Facility (NIF)

The NIF supports heavy infrastructure projects mainly in the energy, transport and environment sectors in countries neighbouring the European Union. It allocates grants to support lending operations piloted by public European financial institutions. The Kesrwan water treatment plant is the first project in Lebanon to benefit from this innovative tool, in support of Lebanon's investment priorities.

KfW Entwicklungsbank

German Development Bank finances national and international projects. The export bank is focused on financing projects in various sectors including the energy sector in order to promote the German and European industries in foreign developed countries markets. Financing projects are examined principally for their environmental and social relevance. They propose different financial products:

- Export Finance
- Project Finance
- Structured Finance
- Investment Finance
- Trade Finance

Among other things, KfW operates in the field of Energy and Climate Change. KfW is involved in the project "Sewage disposal in Al Ghadir", which was already agreed in 1999.

BMZ (German Federal Ministry for Economic Cooperation & Development)

Founded in 1961, the Ministry works to encourage economic development within Germany and in other countries through international cooperation and partnerships. It cooperates with international organisations involved in development including the International Monetary Fund, the World Bank, and the United Nations.

The priority areas of cooperation of BMZ in Middle East are water and sanitation, renewable energies and energy efficiency, and sustainable economic development.

In addition to the on-going Environmental Fund for Lebanon (EFL), the BMZ finances the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE) dedicated to the promotion of renewable energies and energy efficiency. RCREEE formulates and disseminates policies in support of RE and EE and provides a platform for the regional exchange on policy issues and technological questions. In addition, RCREEE encourages the participation of the private sector in order to promote the growth of a regional industry of RE and EE. Projects implemented in Lebanon revolve around capacity building initiatives undertaken in close collaboration with the Lebanese Center for Energy Conservation (LCEC). However, these projects do not specifically target bioenergy potential.

AFD (Agence Française de Développement)

French development agency supports projects especially in developing countries and has a large variety of financing tools:

- Sovereign and non-sovereign Loans
- Guaranties
- Private equity (Proparco)
- Subsidies

AFD is involved in many projects in Lebanon: wastewater treatment plants, energy efficiency, etc.

Arab Fund for Economic & Social Development

The Arab Fund for Economic & Social Development is a regional institution financing public and private investment projects in Arab countries. It currently operates with a $ 8.5 billion resource fund.

In Lebanon, the Arab fund for Economic & Social Development is involved in projects in the following sectors: agriculture, energy (Electricity network, rehabilitation of electricity installations, power stations, etc.), social services, transport and water and sewage.

USAID (United State Agency for International Development)

The United States Agency for International Development (USAID) is the United States federal government agency primarily responsible for administering civilian foreign aid. USAID delivers foreign aid in two different ways: technical assistance and financial assistance.

- Technical assistance: Technical assistance includes technical advice, training, scholarships, construction, and commodities, which are contracted or procured by USAID and provided in-kind to recipients.
- Financial assistance: Financial assistance supplies cash to developing country organisations to supplement their budgets. USAID also provides financial assistance to local and international NGOs who in turn give technical assistance in developing countries.

USAID develops and implements programs in the energy field that seek to:

- Support the construction and rehabilitation of infrastructure to restore basic services in post conflict and conflict-prone states;
- Improve enabling environments, including policy, legal, regulatory, and commercial reforms, to boost energy sector performance and increase private sector participation and investment;
- Enhance operational and commercial performance of public and private sector institutions, including utilities
- Promote increased energy trade and regional power pools;
- Help countries reduce their overall carbon emissions and address climate change through clean energy and energy efficiency projects.

In Lebanon, USAID has, among other projects, completed a number of wastewater treatment facilities in the country.

GET FiT Program (Global energy Transfer Feed-in Tariffs for Developing Countries)

GET FiT is a renewable energy financing program to support both renewable energy and energy access in developing countries through the creation of new international Public-private Partnerships. GET FiT combines a fund of public money directed for renewable energy incentives with risk mitigation strategies and coordinated technical assistance to address project developments and financing barriers.

GET FiT would partner with developing countries to financially support policy structures that appropriately adapt best practices to national contexts. National governments, development banks and international climate-related funds are the sources of funding. GET Fit contribution has three main fields shown on in Figure 50.

The challenges addressed by the GET FiT Program are summarized below (DB Climate Change Advisors of Deutsche Bank Group, 2010):

-Support of payments to many existing policies that do not offer sufficient payment levels to generators

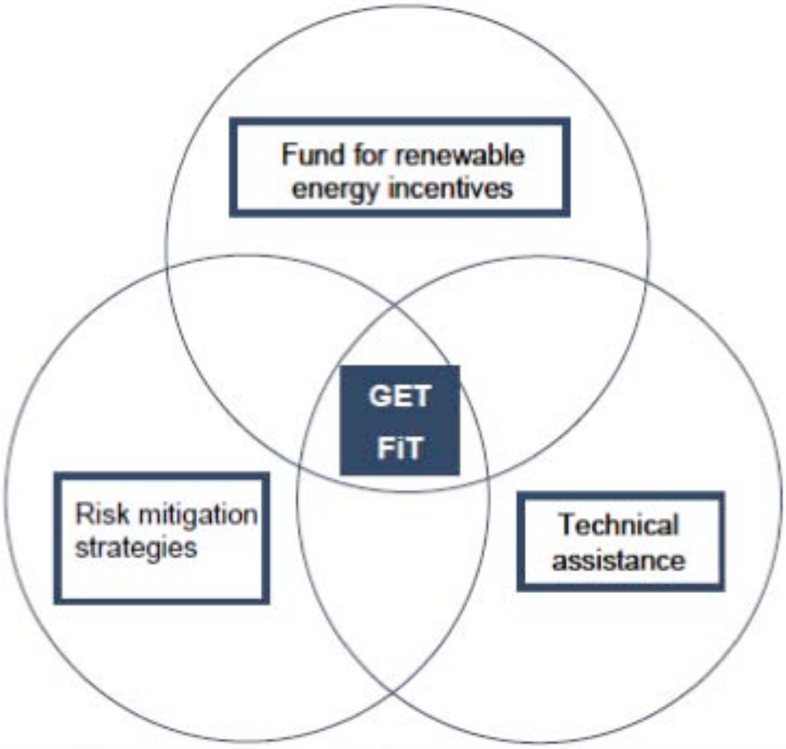
-Work with governments that face grid or other renewable energy integration constraints on their expansion

-Mitigate risks for developers, financiers and investors to avoid trouble accessing affordable capital

-Aggregation and coordination of energy-related capacity building efforts of public and private institutions to solve technical, regulatory, legal and political barriers to renewable energy deployment where the design of a policy cannot be a solution just by itself

-Develop of off-grid solutions in remote areas of developing countries

Figure 50: GET Fit contribution fields



IV.RECOMMENDATIONS ON ADAPTED INNOVATIVE FINANCIAL MECHANISMS

This section presents several innovative financial mechanisms to give support for the establishment of the bioenergy strategy implementation. The main existing barriers are analysed as well as the Lebanon's legal and regulatory policies. Because Lebanon requires funding to enable the climate change solutions, some possible procedures are provided.

IV.1 INSTITUTIONAL AND POLICY FRAMEWORK

Most climate change mitigation solutions are only effective when there is a major legislation covering them. The Law 690/2005 states the inclusion of climate change in the Ministry of Environment, under the Service of Environmental Technology. Also Law 359/1994 and Law 738/2006 are linked to climate change, with the ratification of the Kyoto Protocol. Other laws refer to climate change mitigation solutions such as the reduction of air pollution from transport (Law 341/2001), or energy efficiency standards. Main institutions that are involved in climate change mitigation solutions are:

- **Public sector**
    - Ministry of Environment. One of the most important institution in climate change issues and the activities related with the Kyoto Protocol. It is responsible for the implementation of the Clean Development Mechanisms (CDM), reforestation and the regulations related with environment and climate change, such as emissions standards, waste disposals
    - Lebanese Center for Energy Conservation (LCEC) affiliated to the Lebanese Ministry of Energy and Water (MEoW). The LCEC is the technical point of reference specialized in energy conservation issues within the structure of the MEoW and the Lebanese Government
    - Conseil National de Recherche Scientifique (CNRS) working in conjunction with international actors and national academic institutions on various topics (Soil, water and air)
    - Institut National Agronomique Libanais (IRAL) conducting research in conjunction with the World Bank on adaptation and mitigation of climate change techniques
- **Local NGOs**
    - GREENLINE
    - The League of Independent Activists (IndyACT)

works in climate change issues. They coordinate with the Ministry of Environment

- The Lebanese Cleaner Production center
- Lebanese Solar Energy Society
- The Lebanese Association for Energy Saving & for Environment (ALMEE). Dedicated to energy saving technologies, it promotes technical methods for a better energy management focusing in renewable energies, industrial processing, and generation of electricity.
- Industrial Research Institute. Conducts industrial research in Clean Development Mechanisms.

- **Academic institutions and research groups**
  - American University of Beirut
    - Energy Research Group
  - Notre Dame University
    - Water and Energy Research Center (WERC)
  - Universite Saint Joseph:
    - Centre Regional de l'Eau et de l'Environnement (CREEN) of the Ecole Superieure des Ingenieurs de Beirut (ESIB) working on energy consumption in the transportation sector and on climate change impact on water resources
    - Faculte des Sciences and Faculte des letters conducting research on atmospheric chemistry and physics

IV.2 UNIED NATIONS FLEXIBLE MECHANISMS

The Kyoto Protocol committed the Annex I and Annex II countries that ratified it to a legal binding commitment to reduce their emissions. To meet these commitments the signatories had to develop national measures and also they were offered three market-based mechanisms whose implementation is overseen by the UNFCCC:

-Emissions trading

-Clean development mechanism (CDM)

-Joint implementation (JI)

CDM is one of the three market-based mechanisms that Annex I Parties can use in order to cost-effectively realise their emission reduction targets. As such, these projects serve also as a vehicle for investments in sustainable energy technologies in industrializing/developing countries. The most popular projects (sectors) for investment, according to the CDM-pipeline, are: hydroelectricity, energy efficiency in industry, wind power, landfill gas and fossil fuel switch. For these projects types several methodologies are developed and transaction costs are relatively low.

Lebanon ratified the Kyoto Protocol in November 2006 and possesses substantial potential for the implementation of CDM projects linked with bioenergy:

-Fuel switch and energy efficiency in power generation

-Fuel switch in industry

-Reforestation/biomass/agriculture

-GHG abatement

-Transport

However, the country has not achieved successful implementation of these types of projects. Different types of barriers can impede the development of CDM projects. These include (Jane Ellis, OECD & Sami Kamel, Unep Risø Centre, 2007):

-National-level barriers not related specifically to the CDM such as the policy or legislative framework within which a CDM project operates, e.g. electricity-related regulations that constrain generation by independent power producers;

-National-level CDM-related barriers such as institutional capability/effectiveness or lack of awareness about CDM potential.

-Project-related issues including availability (or not) of underlying project finance, or other country or project-related risks that render the performance of the project uncertain;

-International-level barriers such as constraints on project eligibility (e.g. on land use and forestry projects), available guidance and decisions (e.g. with respect to the inclusion of one project), etc.

Policy and legislative framework

The policy and legislative framework within a country is a very important factor for potential investors and will therefore also have an impact on CDM activity within a country. The policy and legislative framework within a country may therefore enable domestic and foreign investments to different extents. A favourable investment climate would also encourage the CDM projects development (domestic and foreign).

Tax/incentive framework

The availability of subsidies can either encourage or impede CDM project developments. For example, providing direct subsidies for fossil fuels will reduce the economic attractiveness of renewable sources of energy – including from CDM projects. Maintaining electricity tariffs below production costs will reduce incentives for private, small-scale renewable electricity providers.

Countries wanting to increase CDM interest may wish to examine the level/format of such subsidies.

Barriers in the electrical sector

The legislative/policy framework can also impede renewable energy and bioenergy development, particularly by limiting the role of independent power producers by not allowing them to feed electricity to the grid.

FINANCING OF CDM PROJECTS

The costs completing the entire CDM project cycle have a strong fixed element (PDD preparation, validation, verification, etc.). Furthermore, CDM revenue is only generated once the project's methodology has been approved, the project registered and credits issued. Due to this, projects with less than 10,000 CERs per annum have difficulties in recovering these transaction costs (Flamos et al., 2007). This can be a burden for small-scale projects, despite of its replicability and sustainable development benefits for the local population.

Depending on the specific projects characteristics and Lebanon context, a specific form of CDM (unilateral, bilateral, multilateral or programmatic) might be the best option for projects development purposes in order to minimize the transaction costs and to optimize the CER revenue.

Small scale projects

A case by case approach for each project within a category is generally considered to gain capacity building experience in the CDM host country. Unilateral CDM scheme can be applied and the host country walks through the entire project cycle. International Financing Institutions (IFIs) seem reluctant to invest in these small scale projects. It is possible to implement an alternative scheme by developing projects with similar characteristics within the same sector. This strategy could be linked with a GHG emission reduction standard. This "programmatic" investment strategy results on lower transaction costs per individual projects and require coordination between the host country and the investor (public or private entity).

Large scale projects

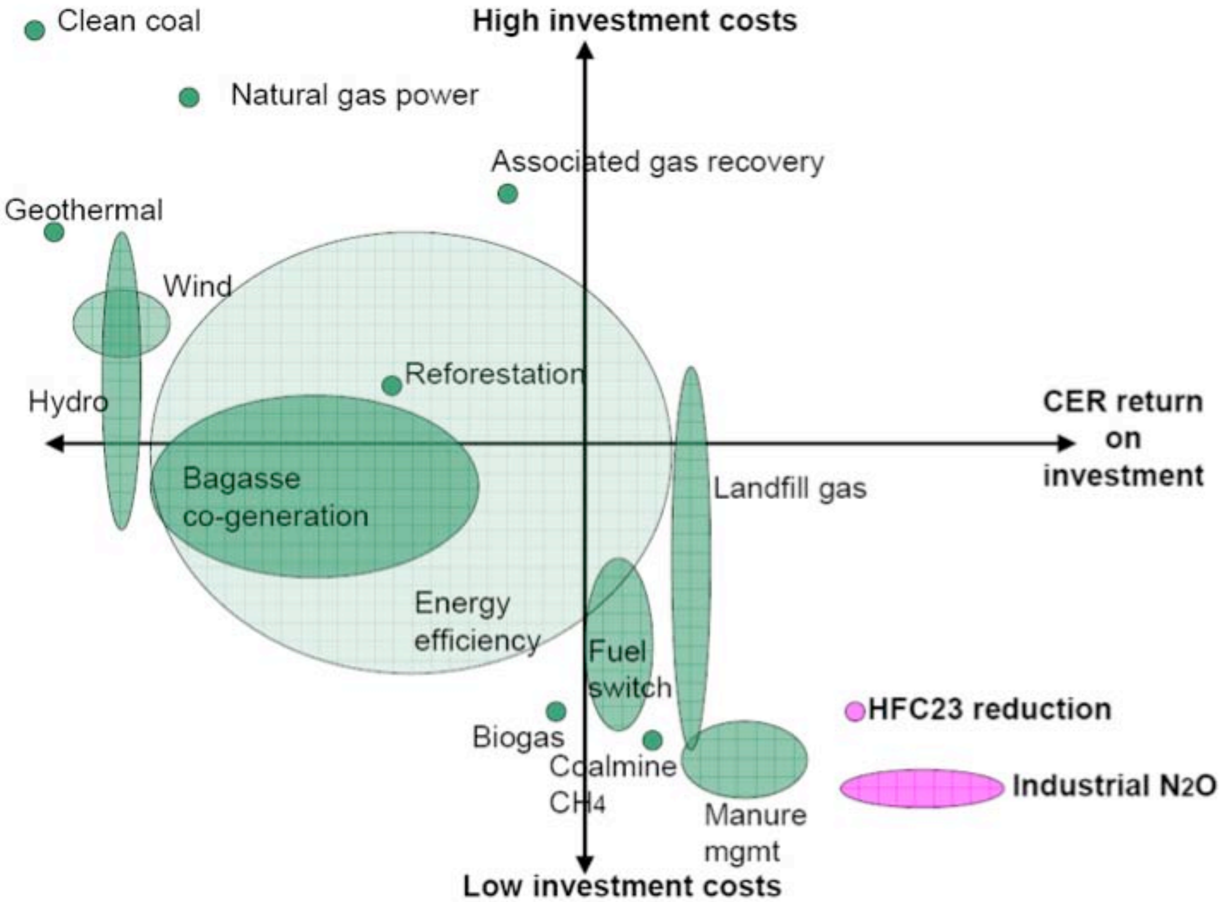
When there are some important GHG emissions abatement options, this investment strategy is also recommended. The national and local governments have a substantial role to play. In this category, projects such as sectorial fuel switch programs can be included.

Some emission reductions buyers, especially large institutional or national carbon funds, have been offering different types of in-advance payments to project developers in order to assist project developers to overcome the burden of the project's transaction cost. One model involves offering this advance payment as a grant, separate from the funds used by the buyer to purchase emissions reductions. Another model is to pay part of the price for the purchased CERs in advance before the project's inception. Some key actions for national government can be recommended in order to encourage investment, such as:

- -Ensure that laws are stable and enforced to allow investors to continue to generate CERs into the future (the lifetime and crediting period of CDM project activities can exceed the lifetime of a parliament by several years);
- -Provide an appropriate tax/incentive framework for investments, including CDM investments. For example, by exemption of import tariffs;
- -Develop a clear policy on CDM-relevant issues, such as the impact of national legislation on the eligibility of proposed CDM projects and the ownership of CERs;
- -A proper coordination between all the stakeholders.

Figure 51 shows the investment costs and expected CER returns on investment for selected CDM projects. Building CDM capacity in relevant CDM stakeholders, financial and lending institutions through structured, hands-on technical training on CDM project identification and development, could encourage the development of this type of projects.

Figure 51: Investment costs and expected CER returns on investment for selected CDM projects
(Jane Ellis, OECD & Sami Kamel, Unep Risø Centre, 2007)



IV.3 INTERNATIONAL FINANCING MECHANISMS

In this section the main financing mechanisms are cited with a brief description of their goals with a detailed analysis of their financial solutions for bioenergy streams options such as donors, funds and grants.

Some of the agencies that conceive donors for projects related with climate change mitigation solutions in Lebanon are the following:

- European Union
- World Bank
- United Nations Environment Program (UNEP)
- United Nations Development Program (UNDP)
- United Nations Industrial Development Organisation (UNIDO)
- US Agency for International Development (USAID)
- International Labor Organisation (ILO)

It is essential to note that a confluence of macro, governance, organisational, capacity, and implementation problems raise certain questions about the interest of donor agencies to make a contribution to local development in Lebanon. Although considered as a medium-level country in terms of development indicators, such a classification does not take into account how allocated resources are distributed, in terms of sectors and regions leaving little effect on the social conditions.

The principal funding instruments further developed are multilateral funds, national initiatives and foundations:

- Global Environmental Facility
- Kyoto Protocol Adaptation Fund
- EUEI- Intelligent Energy COOPENER
- IFAD-ICRISAT Biopower strategy
- REEEP Program Call
- ADB Asian Development Bank
- Development Finance Facility
- DOF: Daey Ouwens Fund
- KfW Bankengruppe-Carbon Fund
- FACT Foundation
- Bill and Melinda Gates Foundation

The above financial mechanisms are fully discussed in the volume "Annexes" of this study, chapter5, annex III "Financial funding mechanisms."

IV.4 CREDIT LINES FROM THE FINANCIAL SYSTEM

Lebanon has 54 commercial banks, 12 banks specializing in the provision of short term loans. Lebanon also has branches of ten foreign banks, and sixteen other foreign banks have representation offices in the Lebanese territory.

The foreign entrepreneurs can open accounts in Lebanese banks and operate at market interest rates. The council for Development and Reconstruction manages the funding of projects in Lebanon. In 2006 the financial resources exceeded 6000 million dollars divided in concessional loans (45%), donations (15%) and export and trade credits. Major financial contributions come from World Bank (14%), the European Investment Bank (14%), the Arab Fund for Development Economic and Social (13%), the Kuwait Fund (11%), Islamic Development Bank (10%), Saudi Arabia (7%), Italy (6%), France (6%) and commercial banks (Jane Ellis, OECD & Sami Kamel, Unep Risø Centre, 2007) .

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