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Final Report

Climate Action Pathways for Island Transport (CAP-IT) Project

24 July – 18 December 2023

From
the People of Japan

Final Report

Feasibility Study for Samoa on Low-Carbon Maritime Transport (Activity 3.2)

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Introduction

While Samoa's contribution to global Greenhouse Gas (GHG) emissions is negligible, climate change mitigation remains a critical government priority in light of the already felt and predicted increases in the frequency and intensity of extreme weather events. The transport sector in Samoa, which is entirely dependent on fossil fuels, is the country's largest emitter of CO_2, accounting for 27.4% of GHG emissions (based on Samoa's National GHG inventory, 2020). Reliance on energy-dense fossil fuels is expected to render decarbonization of the transport sector particularly difficult. Transport demand has grown in parallel to economic development, and with structural changes, it grows faster than that of other sectors. Whilst some interventions to decarbonize the transport sector in Samoa have been initiated, efforts remain fragmented due to a lack of investment and coordination across ministries, agencies, development partners, financial entities, private businesses, and individuals. In order to meet Samoa's Second Nationally Determined Contribution (NDC) target to reduce national GHG emissions by 26% from 2007 levels by 2030 (equivalent to 91 Gg CO_{2e}), the rapid decarbonization of both land and maritime transport systems is fundamental. Research-based evidence, best practices and lessons learned globally indicate that several interventions can catalyse the paradigm shift required to decarbonize the transport sector, including electrification of transport systems, along with supportive policy and business model innovations to catalyse systemic electrification. Decarbonizing maritime transport in the context of the Pacific area has been addressed by different actors before and it is, therefore, paramount to build up on existing research and projects not to duplicate the work and to ensure the best solution for Samoa.

The objective of this report is to propose a sustainable long-term solution that will benefit CO_2 reduction at a national level. The solution may include the technical recommendations together with other suggestions, such as policy and regulation changes, the societal impact of the solutions, and if relevant, a phased plan for implementation based on the global availability of technologies. The project Climate Action Pathways for Island Transport (CAP-IT): Accelerating the Decarbonization of Samoa's Land and Maritime Transport Sectors, funded by the Government of Japan, aims to promote urgent and inclusive transformation of the maritime transport sectors towards decarbonization by accelerating the uptake of low-carbon outboard motors and/or propulsion system in support of the achievement of Samoa's enhanced NDCs for the energy and transport sector by 2030. This will be achieved by introducing and piloting **low-carbon outboard motors for Samoa's maritime transportation** through a gender-sensitive grant mechanism for local fisherfolk and a training scheme on installation, operation, and maintenance. A feasibility study on the available low-carbon outboard motors for fishing and transport vessels including a cost-benefit analysis (CBA) needs to be conducted and prepared. Based on the results of this feasibility study, the United Nations Development Programme (UNDP) Project Management Unit (PMU) with support from UNDP Information Technology Management (ITM) unit will pilot the recommended low-carbon outboard motor solutions for Samoa's small vessels and fishing fleet. The technology will be then introduced to fishermen and small boat operators through a gender-sensitive grant mechanism for local fisherfolk and vessel operators, and a training scheme on installation, operation, and maintenance.

Acknowledgements

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The UNDP task team responsible for the production of this report was composed of Vladimir Kalinski, Peter Lusis, Malin Anderberg and Irantzu Sadaba.

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Acronyms

AC	Alternating Current
AU$	Australia Currency/Dollar
BAU	Business-as-Usual
BMS	Battery Management System
CapEx	Capital Expenditure
CAP-IT	Climate Action Pathways for Island Transport
CBA	Cost-benefit Analysis
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
EEZ	Exclusive Economic Zone
FADs	Fish Aggregation Devices
FAO	Food and Agriculture Organisation
GHG	Greenhouse Gas
FESA	Fire and Emergency Services Authority
hp	Horsepower
ICE	Internal Combustion Engine
IMO	International Maritime Organisation
ISO	International Organisation for Standards
ITM	Information Technology Management
kg	Kilograms
km	Kilometres
kWh	Kilowatt hour
kWp	Kilowatts peak
LA	Lead Acid
LI	Lithium ion
l/h	Litres per hour
m	Meters
mm	Millimetres
MPPT	Maximum Power Point Tracking
MEL	Monitoring, Evaluation and Learning
MWTI	Ministry of Works, Transport & Infrastructure
NDC	Nationally Determined Contribution
nm	Nautical miles
NZ	New Zealand
NZ$	New Zealand Currency/Dollar
OpEx	Operational Expenditure
PICs	Pacific Island Countries
PFH	Parametric Fast Hull
PMU	Project Management Unit
PV	Photovoltaic
RD&D	Research, Development and Deployment
R&D	Research and Development
SPREP	Secretariat of the Pacific Regional Environment Programme
TOR	Terms of Reference
UN	United Nations
UNDP	United Nations Development Programme
US	United States
US$	United States Currency/Dollar
VHF	Very High Frequency
WAM	Waan Aelõñ in Majel
WST	Samoa Currency /Tala

A. Objective and Scope of Work[1]

The Terms of Reference (TOR) for this report was "to carry out a feasibility study that provides a comprehensive assessment of the different low-carbon solutions available for domestic small recreational, transport and fishing vessels in Samoa. The feasibility study should include recommendations for the most cost-effective and sustainable technology for Samoa's context based on a cost-benefit analysis. The report should also include the minimum technical requirements of the proposed technology that will help the UNDP ITM unit to formulate the TOR for the procurement of low-carbon solutions for small fishing vessels in Samoa."

The initial literature review identified the current global transition toward shipping's decarbonisation but highlighted the lack of research and development (R&D) being undertaken into small-vessel transition of relevance to the current Samoan scenario. The status of current options and their availability within a Pacific context was summarized[2]. Via reiterative team meetings, the scope of the objective was progressively narrowed, as discussed below, to a pilot electric outboard ("e-outboard") powered replacement package of some 10-20 vessels for the local small-vessel transport fleet – known in Samoa as Alia – primarily due to the energy constraints imposed by the fishing fleet and the practical time constraints for delivery of the project imposed by the associated funding conditions attached to this project.

Within the narrowed scope, a replacement package for the current vessel fleet was proposed, comprising newbuild hulls of a modified, improved-efficiency Alia design coupled with electric outboard motors supplied by a 48-volt lithium-ion battery pack charged via onboard photovoltaic (PV) 48-volt charging supplemented by 230-volt shore supply from the national grid.

A conventional CBA was not available for this initiative, as discussed in Section D, below. The comparison is between an entrenched business-as-usual (BAU) operational model of low/nil capital expenditure (CapEx) – largely based on donor replacement following intermittent disaster response – with low operational expenditure (OpEx) for maintenance and recurring fossil fuel costs, versus an experimental introduction of completely new technologies and operations with substantial CapEx and initial investment and low OpEx and ongoing costs. Given this is an initial and experimental proof-of-concept project with elevated risks and additional R&D and programming costs that would not normally be incurred, a conventional comparative analysis is not appropriate.

In theory, the long battery life and minimal operational and maintenance costs means that the high initial cost outlay is offset over the operational life of the vessels. In practice, this will largely depend on the success of the technology through knowledge transfer to the operators and passengers, and the ongoing attention to protecting the integrity of the vessel and its power system components to avoid unwanted tampering or damage. To this end, recommendations on the associated oversight needed for assembling the new vessels and then their introduction and monitoring over time have been made. These reflect the lessons learnt from previous programmes in Samoa in the 1970-1990s which saw successful uptake of the then new outboard and aluminium hull technologies. Well-structured government-led programmes at the time saw the necessary servicing and training support in place to ensure a smooth technology uptake in that era and similar challenges are now faced with the introduction of this next generation technology.

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[1] Terms of Reference DocuSign Envelope ID: 6BE45244-90D7-4A2C-A06A-F1938F556257.

[2] Nuttall, P., Newell, A., Rojon, I., Milligan, B. and Irvin, A. (2021) "Pacific Island domestic shipping emissions abatement measures and technology transition pathways for selected ship types", Marine Policy Volume 13 2, October 2021, https://doi.org/10.1016/j.marpol.2021.104704.

B. Samoan Domestic Outboard Powered Small-vessel Fleet

Compared to other Pacific states, Samoa has a smaller domestic small-vessel fleet of outboard powered boats, probably even less than 100 regularly active vessels[3]. This reflects the geography (predominance of fringing reefs, few embayment and reef passages and only two large and five smaller islands with a constrained exclusive economic zone (EEZ) and local fishery), a declining offshore fishery and societal change in Samoa[4].

The small-vessel fleet (less than 15 meters, outboard-motor driven vessels) comprises:

1. Alia class vessels[5] powered with a 40 horsepower (hp) 2-stroke outboard internal combustion engine (ICE) motor used for:
    a. Fishing (which can be sub-grouped as export, domestic, and cultural). The majority of these vessels are concentrated in the capital, Apia; and
    b. Transport (primarily short runs between the islands of Manono and Apolima and to the small island of Namua).
    c. Emergency response vessels:
        i. Fire and Emergency Services Authority (FESA) possesses three vessels with one 25hp outboard motor, one 40hp and one x 200hp.
        ii. The Police possess a new rigid rib with a 200 hp outboard motor.
    d. Recreational vessels (small game fishing launches with motors from 40-400hp). A small number of privately-owned recreational vessels used mainly game fishing. These vessels are powered by a range of motor types and makes, primarily centred on the game fishing club and small marina on the Apia waterfront. These vessels have not been considered further in this study.

The project is housed under a wider Japanese-funded Samoan programme of electric-mobility ("e-mobility") and implies that the focus of this study should be a transition to electrically powered vessels.

Petrol outboards were introduced in numbers to Samoa in the early 1970s, accompanied by successful government and United Nations' (UN) programmes for training operators and mechanics and establishing government maintenance workshops to service and ensuring a reliable logistic supply of both motors and spare parts. Over time this has morphed into a fully private-sector supply chain now operating under a monopoly Yamaha franchise[6]. The Yamaha Enduro 40hp 2-stroke ICE engine is the almost universal propulsion motor in use currently. There is no previous use or literacy of e-outboards prior to this project in Samoa and the introduction of both motors and their energy storage and charging

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[3] A separate component of this programme is reviewing the Samoan domestic vessel registry which should provide accurate data on the small-vessel fleet.

[4] By comparison, Marshall Islands with a population of quarter the size is thought to have in excess of 650 such small vessels https://www.mcst-rmiusp.org/index.php/reference-library-main/download/28-pacific-shipping/887-governance-narrative-twg-working-paper-4.

[5] See Alia history below at Annex 2 for more detail. Alia class vessels are 9-11.5m aluminium catamaran's, originally designed under a Food and Agricultural Organisation (FAO) project in the 1970s and the main small vessel type for fishing and transport today. A separate part of this project is assembling the domestic registry, but the current fleet is thought to be less than 100 vessels with about quarter of the fleet based on Manono Island used primarily for transport and the fishing fleet centred mainly on Apia. Most of the vessels are fitted out for longline or bottom fishing.

[6] A full history of the successful introduction of both ICE outboards and aluminium catamarans to Samoa since the 1970s was presented in the literature review undertaken at the commencement of this contract.

will require a comprehensive induction and training component on introduction and then ongoing project support if it is to be successful.

The current Alia fishing fleet is active on up to 3-day offshore trips, either longlining, trolling or bottom fishing. Informal discussions with Apia-based fishers suggest there is little fishing being undertaken for export with this scale of vessel and most effort is concentrated on supplying the domestic market with falling catch rates and increased fishing effort being considered the norm. In this environment there appears little immediate appetite for private financial investment in upgrading this fleet.

Given the fishing vessels work up to three-day voyages of over 100 miles, with speeds of 12-13 knots required at times, an e-outboard option is not viable given the range and energy constraints imposed by this type of fishing. The battery capacity to maintain the distance and speed necessary to harvest skipjack and albacore for extended voyages will require either battery storage or onboard recharging beyond the capacity of the vessels to operate effectively.

These barriers are potentially overcome by introducing a new vessel design that incorporates greater hull efficiency combined with a wind-assist rig, electric and/or highly efficient ICE outboard motors. Determining the best vessel package design for this facet of maritime work in a Samoan context, requires careful consideration of the economics and sustainability of the coastal and offshore fishery sector. Such analysis and the subsequent generation of design solutions will require greater time than allowed in this project for R&D and for consequential training for both boat builders and operating crews. E-outboard motors, charging and battery technology is a fast-developing field, and it can be expected that increased options, efficiencies in terms of storage capacity, weight and price will emerge over time.

The future options for the offshore component of the existing Alia fleet will be heavily influenced by the market economics of the export and domestic fishery. Greater productivity can be achieved with a fleet of the most effective fish harvesting vessels. However, previous fleet expansions in both numbers of vessels and overall size of vessels, combined with the introduction of new long line and bottom fishing technologies over the last two decades, has demonstrated that sustainable limits for harvest were overrun with the introduction of such new technologies resulting in overall increases in effort for reducing returns, ultimately resulting in the rapid decline of the size of the fleet to current levels.

Given these limitations and following preliminary discussions with the UNDP ITM project team, government partners and other relevant stakeholders, it was agreed early in the project planning phase to focus on the smaller sub-sector of small-vessel transport and leave the fishing challenge for the time being.

Three Primary Small-vessel Transport Routes

The following primary small-vessel transport routes were identified as part of the scoping mission:

1. Between Upolu and Savai'i across the Apolima Strait:

Primarily servicing the islands of Manono (population of approximately 811[7]) and Apolima (population of approximately 88[8]) from the Apolima-uta landing on Upolu. The majority of trips are from the mainland to Manono with a smaller number serving the island of Apolima. From time-to-time transport

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[7] See https://whc.unesco.org/en/tentativelists/5091/.

[8] See https://whc.unesco.org/en/tentativelists/5091/.

services are also needed from Upulo to Savai'i (e.g., when larger ferry services are not operating). These vessels might also undertake limited fishing tasks. The longest expected return voyage is expected to be less than 50kilometers (km) (and reported as occurring very rarely) with most voyages less than 5km return (See Figure 1). 60% of the Manono fleet also engage in fishing activities in the surrounding waters[9].

Figure 1. Route between Upolu and Savai'i across the Apolima Strait.

2. Muiatele (Upulo) to Namua Island:

A popular day tripper small island with a return voyage of 2km. Currently serviced by a single Alia (with a reserve vessel available) making up to 6-8 return trips in a busy day. Also used to offer half-day and overnight fishing trips to tourists to the back of the island (See Figure 2).

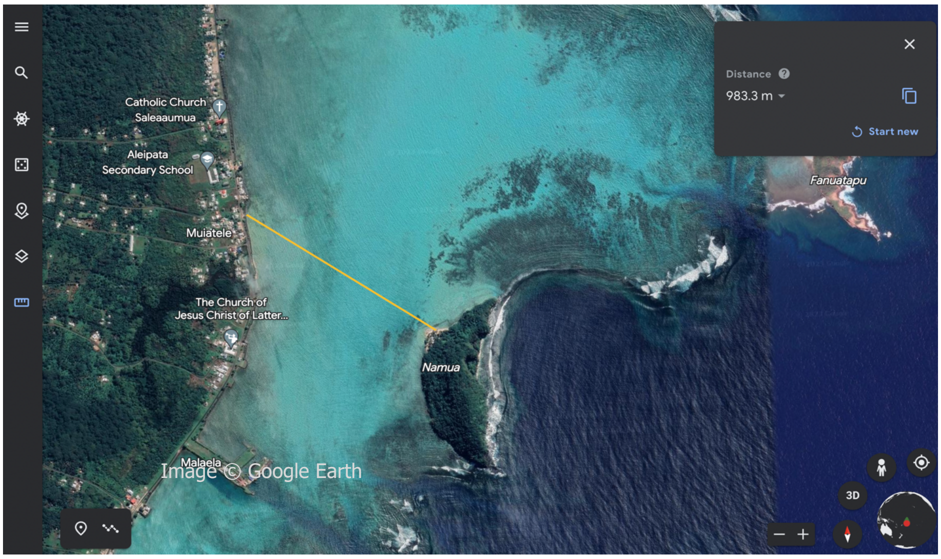

Figure 2. Route between Muiatele (Upulo) to Namua Island.

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[9] The Survey Form is available at Annex 1 of this report.

Image © Google Earth

3. Ports Authority Harbour Workboat (not considered further in this study):

The Samoa Port Authority currently has no vessel for general port work between a small aluminium dinghy and tugboats. This vessel would not have high mileage usage and a daily workload of less than 20km can be expected (See Figure 3).

Figure 3. Ports Authority Harbour Workboat.

Manono Island Alia Operators Written Survey

A written survey[10] of local Manono-based Alia operators in Samoan was undertaken, ably assisted by staff from the Maritime Division of the Ministry of Works, Transport & Infrastructure (MWTI), to determine the transport work done by this fleet. Operators were asked a range of questions concerning their vessels, their regular transport work, income, fuel consumption and operational costs. A total of 30 responses were received. While there are obviously some human errors and inconsistencies, the survey provides a reasonable overview of the transport work and operational costs of the Manono transport fleet. The following are the key survey findings (note: all prices refer to WST):

1. There were 30 respondents, 29 of whom were male, and one female.
2. Each respondent, it could be inferred, had just one Alia. The Survey was meant to be filled for every Alia a person owned. The survey, thus, accounted for 30 Alia.
3. There was 25 Alia that were more than 10 years old. The other five were in the 7-10 years range.
4. 29 respondents noted a purchase price/cost for their Alia with an average cost of WST 19,683[11].
5. The respondents noted several ways they use their vessels, including family, social and commercial uses. These are summarized in Figure 4.

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[10] The Survey Form is available at Annex 1 of this report.

[11] One respondent said that his Alia was gifted to him. While it would have still cost someone something, that value was not noted.

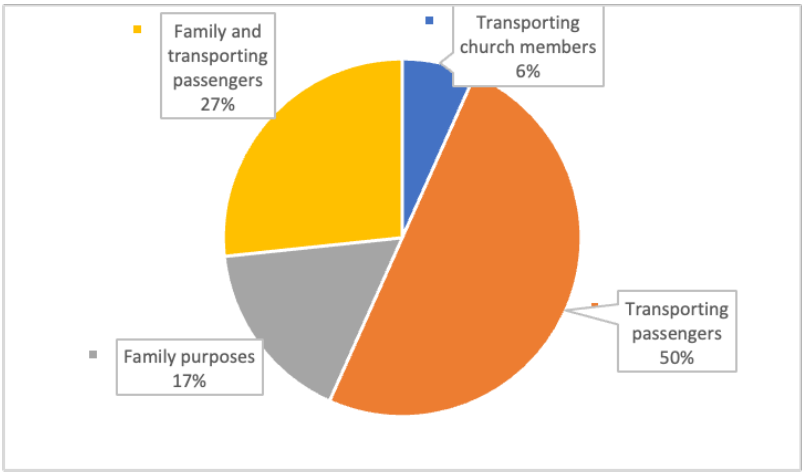

Figure 4. Survey results - Purpose of the trips.

6. 12 out of the 30 (40%) said that they did not use their Alia for any type of fishing. 18 (60%) only used their Alia for fishing when they were requested to or if they felt like it. The survey does not reveal the distance covered or duration of such fishing trips.
7. From the responses, 25 said that they ferried passengers to and from Manono Island, and the number of trips varied from three times a day at the minimum, to seven times a day at the maximum. Standard charges were WST 2 for children, and WST 5 for adults. All respondents responded with "mixed" when asked about gender composition of passengers. 11 said that their normal passenger load was 16-20 people; while 13 said they carried 8-15 people; and four said their load exceeded 20. One did not answer that question.
8. With respect to their charges, two said that they would charge more if fuel prices increased considerably. Some charge extra for cargo, some do not charge extra at all, while those who use the Alia to travel to and from church, or for religious purposes, would accept whatever it is that was handed to them at donation – whether it be cash or fuel.
9. Traveling to Apolima or Savai'i was a rarity. No respondent indicated otherwise.
10. One respondent – a Reverend at a church – said his Alia was fitted with a 40hp Bould Head engine. Two respondents said they had Yamaha 25hp installed. All other respondents said they had Yamaha 40hp engines. One respondent indicated that he had two Yamaha 40hp engines. The others did not indicate how many engines they had.
11. One respondent said that their Alia's engine was in the 0–4-year age-range. 23 engines were noted to be more than 10 years old. All others said that they were in the 4-7-year age-range.
12. Regarding costs incurred on servicing the boat engine, the lowest value noted was WST 150, while the highest was WST 20,000 and an average of WST 3,258. Regarding costs for engine oil and lubricants, the lowest value noted was WST 240, while the highest was WST 10,000. The average was WST 3410.83. Results are shown in Figure 5 and Table 1.
13. There were seemingly some inconsistencies, or human errors:
    a. Respondent 1, while saying his engine's servicing cost him WST 20,000, said that the cost of engine oil and lubricants was a mere WST 240.
    b. The opposite was noted for Respondent 30 – while his servicing costs were WST 1,200, his engine oil and lubricants cost WST 10,000.
    c. Two respondents put "10,000" for both.

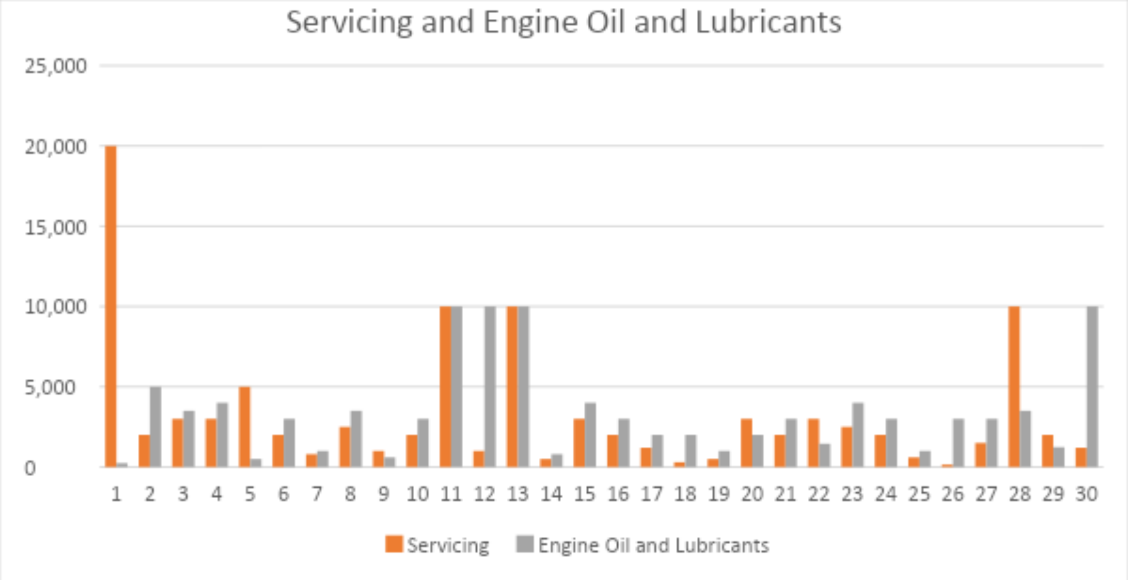

Figure 5. Survey results - Cost of Servicing and Engine Oil and Lubricants in WST from respondents 1 to 30.

Table 1. Survey results - Detailed cost in WST of Servicing and Engine Oil and Lubricants.

Respondent	Servicing Costs (WST)	Costs of Engine Oil and Lubricants (WST)
1	20,000	240
2	2,000	5,000
3	3,000	3,500
4	3,000	4,000
5	5,000	500
6	2,000	3,000
7	800	1000
8	2,500	3,500
9	1000	600
10	2,000	3,000
11	10,000	10,000
12	1,000	10,000
13	10,000	10,000
14	500	800
15	3,000	4,000
16	2,000	3,000
17	1,200	2,000
18	300	2,000
19	500	1,000
20	3,000	2,000
21	2,000	3,000
22	3,000	1,450
23	2,500	4,000
24	2,000	3,000
25	600	1,000

26	150	3,000
27	1,500	3,000
28	10,000	3,500
29	2,000	1,235
30	1,200	10,000

14. More than 95% of respondents referenced an engineer, Poliko Mauu, who would service their boats' engines when needed, and a welder, Auapaau Fetulima, who would weld their Alia if needed. The intervals of servicing their boat engines varied as shown in Figure 6.
15. Fuel consumption proved a little difficult to analyse statistically and is best reflected in data collated into a table, below. For starters, the relationship between daily consumption and monthly consumption can only be gleaned from some responses (See Table 2). Respondent 5, for instance, uses WST 100 of fuel in a day, and when multiplied by 30 days adds up to WST 3000. It is obvious that not all boats[12] work all days.
16. In (7), above, 83% said that they ferried passengers to and from Manono Island, and the number of trips varied from three times a day, at the minimum, to 7 times a day, at the maximum. This could not explain the notable difference in what was reported for fuel usage. All respondents mixed their own fuel.
17. In general comments, requests were made for:
    a. Leading lights on wharves;
    b. Spare batteries;
    c. Ropes;
    d. Boat ramps;
    e. New boat; and,
    f. Captain's Training.

All of these requests are reasonable, but it is unknown which can be accommodated under the project scope. The request for leading lights raises an interesting issue for e-outboard vessels. The survey did not ask the quantity of nighttime vessel use but the vessels will of course be restricted to their battery capacity between shore charges for range at night, the PV system having no effect. At medium speed, a fully charged battery will provide 4-6 hours of engine power but this is rapidly reduced if the vessel is operated at full power. Again, the role of a successful induction and training program will be critical.

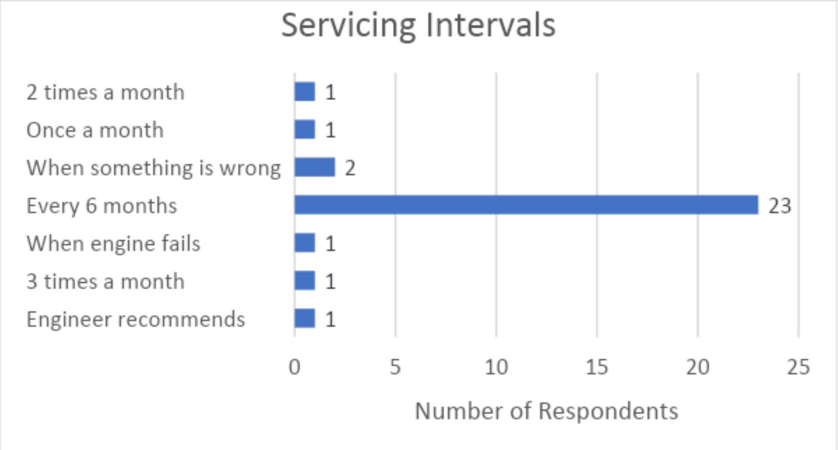

Figure 6. Survey results - Overview of Servicing intervals.

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[12] WST 100 is approximately equivalent to 30 litres of petrol, and WST 150 is to about 50 litres. A Yamaha 40hp 2 stroke uses 13.6 l/h @ 5500 r/min. WST 100 would therefore equate to a little over 2 hours of running time at high speed and about four hours at moderate speed. It can be assumed that most engines would be running between one and six hours per day when they operate.

Table 2. Survey results - Cost of Fuel in a Day and in a Month.

Respondent	Fuel Used in a Day (WST or litres)	Fuel Used in a Month (WST or litres)
1	120	240
2	100	1000
3	172 or 50 litres	5,145 or 1500 litres
4	150	500
5	100	3,000
6	150	600
7	150	2000
8	150	800
9	120	2000
10	250	1,500
11	35 litres	200 litres
12	200	1,800
13	Depended on usage	10,000
14	50-100	1,800
15	150	500
16	150	1,500
17	120	500
18	80-100	1,000
19	120	3,000
20	200	4,000
21	150	600
22	180	5,100
23	150	1,500
24	150	600
25	80	1,500
26	140	2,800
27	150	800
28	150	3000
29	600 or 150 litres	18,000 or 3,600 litres
30	26 litres	840 or 248 litres

Gender Analysis

The results written survey[13] of local Manono-based Alia operators in Samoa above-mentioned shows a huge gender disparity among the small-vessels operators, as from the 30 respondents, 29 were male and one was female (See Table 3). This disparity in the results was expected, considering the ongoing gender role predominancy in the country. It is influenced by various factors deeply rooted in cultural, social, and economic contexts in Samoa. Several possible explanations and potential strategies to address this gender imbalance are outlined below.

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[13] The Survey Form is available at Annex 1 of this report.

Table 3. Survey results - Gender Analysis.

Respondent number	
Male	Female
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30	23

Labour force participation is consistently higher for men than women in the Pacific region[14], for example in Samoa labour force participation for women is 23% as compared to 58% for men. Occupation type varies considerably by gender across the Pacific region. While men tend to dominate the fishing[15], agriculture, and forestry[16] industries, women are more engaged in shore-based harvesting and processing[17] and in manufacturing roles, such as making handcrafts, garments, and cigarettes[18].

This current situation in Samoa is affected by social, cultural, and economic barriers that are embedded in the Pacific patriarchal culture. These barriers include harmful social norms and discriminatory practices against women and diverse gender identities. The underrepresentation of women in small-vessel boat transport might also be due to a lack of visible role models or female pioneers in the industry. Another important aspect to consider is the limited access to education and training opportunities that might cause a barrier for women who want to enter the industry. Moreover, the nature of the environment may be perceived as unsafe or uncomfortable for women, contributing to gender disparity.

Therefore, taking into consideration all these issues, one of the aims of this projects is to contribute to decrease this gender disparity, by applying a Gender Equality focus, which would promote women's leadership, meet the practical and strategic needs of women and open opportunities for investments in women-led business. In this line, this project would consider the active participation of women in the induction and training program for the operators, mentioned below. Additionally, collaboration among different stakeholders is essential to create an inclusive ecosystem, as it can lead to initiatives that address the gender disparity issue collectively. Finally, by encouraging women to take on entrepreneurial roles within small vessels can empower them and make them be more active in an area initially dominated by men.

Transport Vessels Currently Used

The current vessels servicing routes 1 and 2 are aluminium-hulled Alia's. The two Namua Island vessels are older 9-metre Alia in poor condition. While the plating and hulls still appear strong, if well used, exposed leading edges and fittings are all in poor condition (See Figure 7).

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[14] Fiji Bureau of Statistics, 2021, p.56; Tuvalu Statistics Division, 2017, p.4; Tokelau National Statistics Office and Stats NZ, 2017, p.51.

[15] Graham and D'Andrea, 2021, p.27.

[16] Graham and D'Andrea, 2021, p.27; Samoa Bureau of Statistics and United Nations Population Fund, 2020, p.76; United Nations Conference for Trade and Development, 2020, p.16.

[17] Graham and D'Andrea, 2021, p.27.

[18] United Nations Conference for Trade and Development, 2020, p.16; Republic of the Marshall Islands, 2012, p.42; Samoa Bureau of Statistics and United Nations Population Fund, 2020, p.76; Government of Tonga, 2019, p.22.

Figure 7. Field visit to Namua Island. Photo © Nikhil Lal & Peter Nuttall.

The Alia servicing Manono and Apolima are a mixture of Alia types and vintages ranging from 9m to 11m versions, some with ply wheelhouses and decks and some aluminium, in a variety of conditions and ages though most vessels appear well worn (See Figure 8). There are no new vessels, and most are over 10 years old. Wear and patching on leading edges and poorly maintained or broken fittings are common. It is not possible to ascertain the current integrity of the aluminium plates and welding by just visual inspection. The vast majority are powered by 40hp Yamaha 2-strokes ICEs of varying vintage and condition.

Figure 8. Field visit to Manono Wharf. Photo © Nikhil Lal & Peter Nuttall.

C. Available e-upgrade Package

A replacement e-mobility package for the current transport fleet involves upgrading to new, more efficient vessel platforms with more sophisticated steering systems and introduction of relatively sophisticated new technologies – e-outboard motors, lithium-ion batteries, chargers, controllers and PV arrays. No previous literacy or experience in this new technology exists within this community and introduction of an electric transport maritime solution at this scale and speed has no precedence in Samoa or neighbouring Pacific Island countries (PICs). The project must therefore be considered relatively high risk and experimental in nature rather than a project implementing a previously proven solution.

The project requires more than just a swap out from ICE to e-outboard motors. In addition to vessel design modifications and the introduction of new electrical componentry, there are operational changes needed in shifting from one propulsive technology to another – both in terms of operational use of the vessel and management of the vessel's energy supply – and these must be fully understood by the operator. Again, the induction and training for both assembling the new package and introducing it to the operators is critical to the success of this project.

It is highly unlikely that any one supplier will be able to supply a full package and that the vessels will need to be built up from a consortium of suppliers. Current boat fabricators in Samoa (and the Pacific generally) have no or limited experience in constructing vessels with electric componentry on the scale envisaged for this project, with most Samoan village vessels currently operating without any onboard battery or charging capacity. The electrical componentry will need to be assembled and installation overseen by an appropriately qualified technician. Consideration will then need to be made as to who is to be contracted to assemble the final package and deliver the induction programme, commissioning and monitoring of the vessel technology operations over time. The vessel package componentry can be separated out into four main sets of equipment:

1. Vessels, including:
    a. Bare hulls;
    b. Safety equipment;
    c. Ancillary equipment, themselves including but not limited to:
        i. steering
        ii. remote throttle controls
        iii. other items such as anchors, mooring warps, and so forth.
2. Motors;
3. Charging, including:
    a. onboard;
    b. shoreside;
4. Ancillary electrical equipment, including:
    a. controllers;
    b. chargers; and
    c. connectors and wiring.

The options available for each of these components of the overall package are discussed in more detail below.

Cost-benefit Analysis

As discussed with the project team, a normal CBA is not applicable to this project as the current BAU model, and an electronic replacement do not provide for a comparison of like to like.

The current vessel fleet exploits a well-rehearsed formula, using well understood and known technologies, all of which can be considered relatively low-tech to the electronic systems being proposed. As an experimental proof-of-concept project, there are initial research, development and deployment costs for both vessels and the related equipment that would not normally be considered. Samoa, like other PICs, is expected to now undergo a technology revolution away from GHG emitting technologies at a speed and scale unprecedented in Pacific maritime history and in an environment where there has been limited or no previous investment in solutions appropriate to a Pacific operating scenario. The compressed time frames for delivery of this project mean there is no allowance possible for piloting one or two demonstration models first and so a small fleet replacement has to be attempted immediately. All of this implies cost and risk factors that would not normally be part of a conventional CBA.

In terms of an economic model, in essence, the BAU model is a low CapEx, lowest possible technology approach, employing aged vessels and low CapEx propulsion with a low-to-medium level OpEx – minimal technology with minimal maintenance and fossil fuel costs a major ongoing operational expense. Under this model an initial CapEx outlay of less than US$45,000 is needed to establish the vessel with an annual operating budget that includes minimal maintenance and a monthly fuel budget of approximately $400 to $1,200 for the average vessel.

The e-transport model being introduced assumes a similar or slightly increased CapEx for the bare vessel but a marked increase for the propulsive technology and 'fuel' essentially purchased in advance through battery storage and charging capacity resulting in high initial CapEx but very low operating costs. How well this plays out in real time will be largely determined by the quality of the initial componentry and its assembly and the success of the induction and training program for the operators in managing the new energy budgets of the vessels and their charging.

In financial terms, a higher initial CapEx (approx. $45,000 for the BAU vessel versus upward of $70,000 to $100,000 for a newbuild e-option) provides for a low motor maintenance cost and much reduced charging costs. If appropriate battery management can ensure full life expectancy and see a 10-year+ life rotation, then average monthly fuel costs of $800+ currently are replaced by much lower electricity costs and an annual battery cost of approximately $1,000 p.a., with costs of batteries and related components generally predicted to fall over time.

In simple book value, the BAU option continues to prevail over the cost of replacement with a low carbon or e-option. In the case of this project, the higher CapEx cost is justified by virtue of its role as a 'proof of concept' trial of an emergent new technology essential for Samoa to maintain its ambition of reducing its energy use to full decarbonisation and not on its initial cost effectiveness. In theory, the long-life expectancy of the batteries and PV panels and the extremely low maintenance attributes of the e-solution over time result in much reduced OpEx costs and greater profit. Only monitoring over time will determine the real savings in cost and emissions from this experiment.

It is also worth noting that small-scale domestic maritime vessel operations are at best a marginal business case in this scenario, with likely extremely slim operating margins. From the evidence available, replacements for vessels and motors over the past two decades have largely come from aid interventions by donor and bi-lateral partners following major natural disaster events that have seen attrition to the fleet and replacement hulls and motors gifted to operators to replace lost or damaged equipment. It is unlikely this sector would act unilaterally to transition to new technologies without an intervention such as offered by this project as an incentive.

Whether the project results in a longer-term saving in practice will be largely dependent on the effectiveness of the support given to in-country manufacturers and then to boat operators, both who will be required to make a significant transition to both the technology but also their current business models. Three key elements can be considered essential: the oversight of the competent assembly of the vessels and its components, the induction given to boatbuilders, operators and passengers and the monitoring and ongoing project support. These are discussed in greater detail in Section K below.

D. Vessel Upgrade Options

Context

The current fleet of vessels all derives from an initial design by FAO naval architect Ovin Gulbrandsen for a 9-meter (m) catamaran fishing vessel, originally built in plywood sheathed in glass cloth in the 1970s and universally converted to welded aluminium hulls in the 1980s. The fleet has fluctuated in size and with various adaptations to hulls, cabins and ancillary equipment through the rise and fall of the longline tuna export sector and following natural disasters, with both cyclones and tsunamis which occurred intermittently. Reports of 40% of the domestic small-vessel fleet being affected by such natural disasters have been noted following major storm events in the early 2000's and during the 2009 tsunami, with replacement of both hulls and motors occurring via various bilateral and agency disaster response programming and artisanal fisheries projects.

There does not appear to be any recruitment of new vessels into the fleet in recent years and the remaining stock varies in condition from well-worn but well-maintained to abandoned worn-out and beached vessels[19]. Three options are identified for replacement of the vessel component – the existing vessels could be refitted, the existing vessels could be replaced with newbuilds of an improved Alia design (the recommended option), or there could be replacement with new builds of a new design.

Refit Existing Vessels (not recommended)

The original Alia was built from welded high-quality 2.5-millimeter (mm) plate aluminium with reasonable skill and several hundred such vessels have been locally made and even exported to neighbouring countries since the 1980s. However, many are now aged. Leading edges at bows and sterns are usually well worn and often patched as can be expected after a working life exposed to coral reefs and concrete jetties. Older vessels were built with ply wheelhouses and decking. A variety of shade and roofing additions have been made. These vessels, collectively, are clearly at end-of-life stage and new-build replacements are strongly recommended as refits will only give a marginal extension to

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[19] A comprehensive history of the successful introduction of both ICE outboards and aluminium catamarans is found in the literature review undertaken at the commencement of this contract.

the useful commercial lifespan of the vessel in any regard, resulting in new propulsive and charging equipment being fitted to end-of-life vessel platforms.

Additionally, as discussed in the motors option section, the preferred replacement motors see the single existing 2-stroke ICE, which is mounted in the centre of the vessel, replaced by two smaller capacity e-outboards mounted at the back of each hull. This, combined with a wider hull spacing, provides for greatly increased propulsive efficiency over the current design. In the current model the single propeller is works in the centre of the turbulence created by the two hulls. In the improved design the two propellers are operating in much cleaner water flows and providing improved efficiency of thrust whilst the increased spacing between the hulls limits the disturbance one hull creates for the other and increases stability and load carrying capacity. Accommodating this in the existing hulls would mean modifications of the existing engine mounting arrangements and fabricating new engine mounts at the rear of each existing hull and retrofitting of steering and throttle controls. This would be eliminated in a new build scenario where these aspects can be built in during construction.

Unfortunately, even if these changes were made to the existing vessels, it does not resolve the issue that the existing design positions the hulls too closely together to maximize their efficiency. So a retrofitted vessel is always going to be less efficient than a newbuild unless the retrofit includes widening the spacing between the hulls. Addressing that issue with the existing fleet would require major rebuilding of the vessels, at which point it is obviously economically preferable to build new vessels.

Given the above points, it is difficult to see a business case for this option. If pursued, a refit option would entail:

1. A vessel-by-vessel inspection to agree which vessels were of sufficient quality to refit and which should be retired from commercial service. Retired vessels could be scrapped, generating 1500-2000 kg of recyclable materials[20].
2. Contracting in a boat maintenance firm to undertake:
    a. A wide range of basic repair and maintenance work to hulls, decks, superstructure, fittings, etc. Rebuild of current superstructure and canopy awnings to accommodate PV charging.
    b. Construction of new motor mounts and related stern modifications at the rear of each hull.
    c. Retrofitted steering and engine controls.
    d. Retrofit of plug and play deck-box to accommodate all batteries and electronics.
    e. Fit out to Samoa domestic survey standards.
    f. Monitoring and reporting.

Build New Alia (recommended)

In this option, newbuild Alia hulls are supplied ready to be fitted with survey and safety equipment, e-outboard motors, batteries, PV array and charging componentry. A number of adaptations can be made to the existing Alia design to produce a new version that builds on the strengths of the existing model that both fabricators and operators in Samoa are already well familiarised with while increasing the efficiency and operation aspects of the design. This would include:

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[20] This could be incorporated into the Secretariat of the Pacific Regional Environment Programme (SPREP)/ Swire Shipping's *Moana Taka* waste shipping project.

1. Refine existing lines to improve vessel efficiency; primarily by increasing the hull spacing and relocating the propulsion units to directly aft of each hull. Additional protection of the motors in this new location will be required. A steering system and engine controllers would be required to operate the two motors in sync.
2. Reconfigure existing design to include superstructure and canopy framework to accommodate PV and Shore recharging[21].
3. Built-in 'plug-n-play' deck-box to accommodate all batteries and electronics to Samoan domestic electrical standards.
4. Fit out to Samoa domestic survey standards.
5. Monitoring and reporting.

Figure 9. A new 9.5m Alia built in 2022 in Apia, Samoa. Photo © Frank and Sons Boatcraft.

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[21] Note, full build plans and associated stability and load calculations will be required to be procured.

At least one boat building shop, Frank and Sons Boatcraft, is operational in-country capable of building new Alia from New Zealand (NZ)-sourced aluminium to high standard with a new 9.5m bare-hull being completed in 14 working days in 2022 as shown in Figure 9, delivered at a cost of WST 85,000 (~US$31,000).

A suggested modified design concept can be found in Figure 10, adapted to carry two smaller e-motors at the rear of each hull, widened spacing between hulls, improved canopy to carry a PV array and with inbuilt plug and play deck box to house batteries and electrical complementary is shown below. Final design drawings, stability and load calculations will be required once the final specification of motors and other componentry has been determined.

Figure 10. Proposed modified design concept for the Alia. Photo © Nikhil Lal & Peter Nuttall.

Introduce a New Design (not recommended)

Consideration was given to developing a new vessel design, building off recent design work in Fiji and the Netherlands with a high-speed e-outboard powered parametric fast hull (PFH) platform (See Figure 11). The efficiencies from this design arise primarily from its operation in high-speed planning mode. The platform requires about double the hp of the Alia used in Samoa with the platform designed to carry the weight of batteries needed. However, the transport routes in Samoa are not always deep-water and, especially at low tide, motors must be tilted and operated at lower throttle in shallow water amongst coral.

Figure 11. Alia in Fiji. Photo © Nikhil Lal & Peter Nuttall.

Given these operating constraints, the initial assessment is that the efficiency gains from a new hull design relative to a modified Alia is likely to be marginal and insufficient to outweigh factors such as the existing familiarity with building, handling and maintaining the Alia against the increased likely cost of a full new design of this nature. Following discussion with the team this option has not been considered further at this time.

E. Indicative New Alia Build Cost

No direct quotes for delivery of the modified bare hull Alia have been sourced. A new purpose-built bareboat Alia was commissioned from Frank and Sons in 2022 for an American Samoa client at the cost of WST 85,000.

Bare Hull

For the purposes of this study, it is assumed the new Alia built to a modified design (including modified engine mountings, PV array canopy, wider hull spacings and built in electrical deck box) can be locally sourced and delivered in batches of five vessels at a unit cost of around WST 100,000 –120,000 (approx. US$37,000 to $42,000) per hull.

Replacing the single ICE centrally mounted motor with two e-outboards at the back of each hull will require additional equipment for steerage and engine controls. The vessels will also require ancillary equipment such as mooring warps and associated lines. This additional equipment is estimated to add approx. US$3000 to $6000 to the cost.

It is assumed that an in-country supplier is highly preferred. Only one potential supplier has been identified in-country. At least three commercial aluminium boat fabrication companies exist in neighbouring Fiji that could potentially deliver the hulls to an acceptable standard and there are numerous such yards in Australia and NZ that could be potential suppliers. The costs of fabrication in out-of-country yards and the additional transport costs involved have not been estimated but are assumed to be substantially higher than a local build cost.

Survey and Safety Equipment

The vessels will need to be fitted out to local survey requirements. The Principal Surveyor of the Maritime Division, MWTI, advised that this will comprise the following minimum equipment list. Most of this equipment will need to be sourced off-island and in all cases is readily available from a wide range of on-line marine chandeliers. Indicative item prices from reputable chandeliers in the United States (US) and NZ are shown in Table 4. A bulk purchase would likely reduce individual item costs and bode well for shipping and freight. Given the importance of maintaining safe operating best practice, the purchase of known brand equipment from reputable sources is strongly recommended. This gives a cost range of this package of components of approx. US$1000 to $4000.

Table 4. Overview of Survey and Safety Equipment required in the Alia.

Safety Equipment	West Marine[22] (Price Range)	Burnsco[23] (Price Range)	Australian Boating[24] (Price Range)	Lower Range (US$)	Upper Range (US$)
Navigation Lights	US$130 - $190	$70 - $90	$30 - $130	$30	$90
Radio (Very High Frequency – VHF)	$100 - $230	$55 - $155	$160 - $180	$55	$230
Mobile Phone	Average Expected Cost: $200	Average Expected Cost: $200	Average Expected Cost: $200	$200	$200
Compass	$99 - $285	$60 - $105	$270 - $285	$60	$285
Bail Hand Pump (2 needed)	$100 - $320 each	$35 - $125 each	$35 - $150 each	$35	$320
Fire Extinguisher (Dry Powder)	$40 - $115	$20 - $80	$65 - $100	$20	$115
Anchor	$230 - $1,200	$500 - $550	$90 - $201	$90	$1200
Parachute Rockets	$90 - $100	$60 - $120	Not available.	$60	$120

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[22] https://www.westmarine.com/.
[23] https://www.burnsco.co.nz/.
[24] https://austboating.com.au/.

Hand Flares	$40 - $135	$70 - $100	$50 - $60	$40	$135
Smoke Signal	$40 - $90	$50 - $60	Not available.	$40	$90
Lifejackets	$30 - $230	$30 - $130	$80 - $100	$30	$230
First Aid Kit	$20 - $70	$50 - $165	$25 - $105	$20	$165
Engine Spare Parts and Tools	Average Expected Cost: $200	Average Expected Cost: $200	Average Expected Cost: $200	$200	$200
Signal Horn	$20 - $145	$20 - $130	$55 - $155	$20	$155
Search Light (Torch)	$125 - $280	$60 - $100	$105- $225	$60	$280
TOTALS:				$960 (approx. $1,000)	$3915 (approx. $4,000)

F. Propulsion Options

Context

The only currently available propulsion option available to operators in-country is the Yamaha Enduro 40hp 2-stroke series[25] with Asco Motors having a monopoly franchise for sales and service. A reliable service chain is well-established in Samoa.

The traditional 2-stroke ICE outboards that have dominated island small vessel propulsion for the past half-century are highly energy inefficient. Internationally 2-strokes are increasingly being phased out in favour of higher cost and technology but superior efficiency/lower fuel use 4-stroke models. 40hp 2-stroke motors are no longer available in NZ and Australia for example. However, the simplicity, low cost and robustness of the 2-stroke combined with easily sourced spare parts makes them the preferred current option for island deployment. The motors can be serviced locally and are well understood by operators whereas a 4-stroke operation requires a much stricter and more expensive servicing regime and higher technology componentry.

The marked increase in global investment research, development and deployment (RD&D) of alternative fuels and technologies for large-scale shipping as the sector prepares for the International Maritime Organisation's (IMO) new targets of total decarbonisation by 2050 is not yet reflected at the micro-scale of Pacific village outboard propelled vessels. E-outboard motors, which have been produced commercially since the 1930s, have developed primarily for the small-scale recreational boating market in Europe and the US. More recently large-scale e-motors and high voltage battery plants have been

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[25] Costed at WST 9,600 in-country purchase as of August 2023.

developed for the top end of the luxury fast vessel/sports fishing boat class. There are therefore a limited number of e-outboard options available as plug and play units on the market.

The dimensions of a potential solar-electric propulsion system have been estimated by a series of computer simulations. Following the results of the Manono operators survey, the simulations were carried out with passenger transport between Manono and the mainland in mind (distance 2.4 nautical miles (nm), round trip 4.8 nm, sheltered by reef). The simulation model itself is based on the average monthly radiation data for Apia of the past decade. Three configurations were investigated as shown in Table 5.

Table 5. Three configurations considered for the simulation model for propulsions options.

	Configuration 1	**Configuration 2**	**Configuration 3**
Battery [kWh]	17	25	30
Battery type	$LiFePO_4$	$LiFePO_4$	$LiFePO_4$
Number of panels	16	16	12
Solar power [kWp]	6.4	6.4	4.8
Weight of PV system [kg]*	630	750	760
Cost*	low	mid	high

**Excluding engine and wiring*

During the simulation the energy flow for roundtrips to Manono was calculated, assuming an average speed of 6 knots (See Table 6). An exemplary simulation result for one week can be found in the appendix. According to the survey 3-5 round trips per day are typical.

Table 6. Overview of estimated roundtrips per day with different configurations.

	Configuration 1	**Configuration 2**	**Configuration 3**
Number of roundtrips per day without shore charging	2	2.5	2
Number of roundtrips per day with shore charging overnight	3	4	4
Number of roundtrips per day with shore charging overnight and in between round trips	5	6	6

The results clearly show the positive impact of a large solar array on the battery size, weight and cost. While configuration cannot keep up with the high-cost configuration 3 due to a smaller battery, it still offers acceptable service for a considerably lower price. The mid-priced configuration 2 is even slightly superior compared to configuration 3 when it comes to self-sufficient operation without charging.

Two basic approaches of e-motor technology are potentially available; the lower cost one using existing 2-stroke propellor housings with the ICE replaced by a marinized version of commercially available e-motors and agnostic as to battery partnering. This approach assumes water cooling. Of these options Aquawatt (Austria) and Elco (US) can supply 48-volt options, though neither can currently offer after sales service in Samoa. 96-volt systems based on existing 2-stroke casings are also available from recent startups in Australia, US and Asia that offer a lower initial cost option. These were not considered further given the voltage, the greater battery capacity and weight needed and that lack of after sales service capacity.

The higher cost but more simplified technology option is dedicated custom e-outboard designs with Combi (Holland) and Torqeedo (German) offering potential solutions. The Combi motors are somewhat less expensive units and battery agnostic while the Torqeedo is the highest priced option and must be paired to its own specified batteries, controllers and chargers. These models are not required to be water-cooled, have very few moving parts and, as long as the integrity of the watertight seal to the motor is not compromised, require no servicing and maintenance in the first 2000 hours of operation and marginal maintenance past this point. A high CapEx but nil or very low OpEx scenario for the motor component is potentially offered.

Option 1 – Transition to 4-Stroke ICE:

Replacing the existing 2-strokes with 4-stroke Suzuki Leanburn 40 hp could increase efficiency by more than 50% over BAU[26]. 4-stroke outboard motors are more efficient than 2-strokes. They are also more technically complex with a greater reliance on state-of-the-art electronics, generally electric start and a much higher initial purchase cost (50-70% more expensive) and require much stricter standards of maintenance and servicing. Given the almost complete reliance on 2-stroke Yamaha Enduro's, a 4-stroke transition would require comprehensive upskilling and literacy for both outboard owners, operators and service agents and incentivization to maintain servicing schedules and investment to achieve full fuel savings (and associated reduced emissions and noise benefits).

A 2-stroke to 4-stroke transition is an available option, especially for the fishing fleet where the range of electric options is insufficient to meet the operating profile with current battery technology and cost. Both Yamaha and Suzuki produce 4-stroke motors with Suzuki claiming a 23% efficiency on its competitors with its most recent models. Whichever brand was introduced, a secure service and supply chain would need to be established either in partnership with Asco Motors or by introducing a competitor. Given the micro-market size (potential range of 1-200 units) both options present significant challenges.

Other challenges also present. A maritime 2 to 4-stroke transition reduces but does not eliminate dependency on fossil fuels and so must be viewed as an intermediate step to full decarbonization. The 4-stroke option is significantly technologically more complex, with the dependency on electronics meaning batteries and wiring circuits need to be carried and maintained in any regard, as opposed to the pull-start, and no-battery option currently employed. This also raises obvious safety flags as it is unlikely that any major mechanical work could be contemplated onboard by the operator in the event of an engine failure at sea.

Option 2 – Transition to E-outboard:

A transition pathway from 2-stroke to electric outboard propulsion is more than simply replacing one motor with another. A whole new technology is being introduced and a full literacy and local induction and training program is needed if maximum uptake and successful operation is to be achieved. Electric drives operate differently in terms of the torque delivered to the propellor and the drain on the batteries with high-speed use. Operators will need to adjust and adapt their usual operating practices accordingly. An e-outboard approach is a long-term investment in a low operational cost low emissions

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[26] Suzuki is currently undertaking research to substantiate their claims that their Leanburn model is 23% more efficient than its competitors.

model. There is very little maintenance required (no oil changes, filters, sparkplugs, etc) as long as systems are protected and sealed and results in much lower overall energy costs if solar is maximized[27]. Time will need to be invested in ensuring the operators understand fully the new system, its benefits and operational limits.

If an electric replacement is desired, then the best solution is to replace the single existing 40hp with two 10-15kw e-motors using a maximum of a 48-volt system (for safety reasons). Twin motors provide redundancy in regard to the failure of a single unit. Options for 48-volt motors available from Aquawatt, Elco, Torqeedo, Combi have been investigated.

An alternative option is a single 25-30kw e-motor in a 96-volt system[28]. This option has not been considered further given the safety aspects of a higher voltage system following discussions with the Samoan authorities.

The motor then needs to be paired with an appropriate battery array and associated wiring and charging options. We assume charging will be by plug-in at a shoreside charging station to support permanently mounted solar arrays. The larger the solar array, the smaller the battery capacity needed and the reduced reliance on shore supply. For vessels only working from Manono to the mainland, the PV should supply most power needs on sunny days. Fast charging options are also available, but at additional cost.

This leaves a small short-list of available options as compiled in Table 7. All would require a reliable full-service chain to be established in Samoa to be deployable at any more than a pilot scale. Thus far, only Torqeedo and Combi have indicated that they can provide direct after sales support to Samoa (although Elco claim they provide worldwide service cover).

Table 7. Overview of commercial electric outboard motor options.

Brand	Model(S)	Outboard Price/Weight	Notes
Aquawatt[29]	48V/13kW/20hp Green Power	EUR 9,820 (approx. US$10,550) 52 kilograms (kg)	Water-cooled alternating current (AC) induction.
Elco[30] (USA)	EP-20 Electric Outboard 48V/8.4kw/20hp	US$5,450 38.56kg	Dimensions Sheet Water cooled, brushless AC motor. two-year warranty.
Torqeedo[31] (Germany)	10Kw/20hp/48v	US$13,500 61.8kg	Range at low throttle = 6 hours Range at full throttle = 1 hour
	12kw/25hp/48v	US$14,850 61.3kg	Range low throttle=10hrs Range ½ throttle=1.25hr Range full throttle=50min

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[27] When the system is charging from solar, a full 100% emissions savings can be claimed. When charging from grid supply, that portion of the grid that is renewable supply can be claimed as clean energy supply. It is assumed that shoreside charging is primarily a nighttime activity when the vessels are at rest and short-day time 'top-up' charges.

[28] While 96-volt systems are technically inside Australian 'safe-to-hold' limits, we do not recommend them due to potential safety risks in maritime deployment at this scale of vessel and use. With a 96-volt system there is the potential for a 120-volt current at peak loadings. Suppliers of 96-volt systems present a case that their systems do not present such a risk and that the 96-volsystem delivers much greater efficiencies.

29 https://www.aquawatt.at/en/electric-boat-propulsion/electric-outboards.

30 https://www.elcomotoryachts.com/.

31 https://www.torqeedo.com/en/products/outboards.

Combi E-thruster[32] (Netherlands)	Largest system is 15 HP equivalent 48 Volt DC	NZ$21,341 (approx. US$12,800)	2000 hours running with zero maintenance. Two-year warranty.
Eclass[33] (Australia)	96V/20kW/40hp	AU$12,550 (approx. US$8,100) 80kg	Three-year manufacturer's warranty. Uses a 2-stroke outboard without the power head, supplied by a Yamaha competitor. All the components with the exception of the all-electric power head, can be replaced with parts from a local Yamaha Marine dealer.

The e-outboard options can be grouped as:

High-end, high-tech, high-cost option with matched outboard to batteries – Torqeedo:
Torqeedo offers a full system of dedicated motors, batteries and chargers. With 2 x 12kW motors, the cost of motors and batteries is around US$60,000, plus chargers, wiring etc. A single 25kW system is likely US$70,000 and needs to be fitted by a qualified Torqeedo technician. One of the advantages of the Torqeedo system is that it is entirely plug and play and the weight of the batteries is about 30% less than any other competitor. A dedicated Torqeedo sales representative covering Samoa is found in NZ. Although the manufacturer recommends pairing its motors with the design batteries, Torqeedo motors can be effectively paired with non-Torqeedo batteries to give a more cost-effective option.

Custom designed – Combi, Aquawatt, Elco – all battery agnostic:
Both models have been available for several years and have a strong reputation for reliability and rugged construction. Combi is only available in 12kW, is slightly cheaper than the Torqeedo motors at US$12,000 per unit. The motor is fully contained in the propeller pod meaning a completely sealed unit with no cooling required. A dedicated Combi sales representative covering Samoa is found in NZ.
Elco have maintained a traditional outboard design and have been producing e-outboards since 1939. At US$5,500 for their 20hp equivalent per unit they have the lowest motor cost. No dedicated sales representative has been identified for the Pacific.

Retrofitted existing ICE outboard casings, E-class and Stealth – all battery agnostic:
This option uses Yamaha enduro copy casings and retrofits these with marinized e-motors, retaining the existing drive and water-cooling system. They are 96-volt systems so at the upper limit for safety considerations and requiring larger battery capacity. Their advantage is their much cheaper CapEx. They only require one unit and all parts of the outboard apart from the electrical components can be sourced from Yamaha (and the existing second-hand motors). This approach would be a lower tech and cost one but come with higher risks.

G. Battery Storage Options

Batteries are the equivalent of the fuel tank in an ICE system. The performance of electric and ICE motors is not directly comparable. An electric motor provides full torque from start-up and at all revolutions, unlike an ICE motor which requires accelerated revolutions to achieve the most effective

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[32] https://combi-outboards.com/en/products/outboard.
[33] https://eclassoutboards.com.au/.

operating powerband. With electric motors, the power drain increases significantly with full load. The range is therefore dependent on the size of the battery, the amount of load and the rate of charge. At lower speeds and with an operational onboard PV charging system, the range is greatly increased and the need for large onboard battery storage is thereby reduced. However, it must be emphasized that the operational changes will need to be fully explained and absorbed by the vessel operators. Prolonged operation at full throttle will quickly drain the battery reserves, especially in dull or nighttime conditions.

The choice of battery and its operational characteristics will depend to a large degree on the type of battery (e.g. lead-acid (LA), lead-carbon, Gel-acid, Lithium-ion). There are pros and cons to all. LA is the BAU option and there is limited literacy on other types. There are a number of types of Lithium ion (LI) batteries. Only Lithium Iron Phosphate ($LifePO_4$ – LFP) type batteries combined with a battery management system (BMS) are considered in this study, as they are currently the most secure Lithium-Ion technology on the market. LI is likely to be two to three times the purchase cost of LA but with lower weight and many times the cycling and storage capacity of LA argues as a long-term saving over LA. Carbon offers a possible compromise solution but comes with the same prohibitive weight issues as LA. A whole-of-life approach needs to underpin battery selection and the introduction of new technology. It is assumed that other aspects of the broader project will address lifecycle issues of batteries.

Regardless of choice of battery type, it must still be matched to the energy needs of the vessel. The characteristics of an e-motor, as opposed to an ICE motor, means it has full torque from startup but will drain power quickly at full load. The solutions to this are to operate at lower speeds, increase the battery storage capacity or increase the charging capacity or frequency. As greater battery capacity will increase both cost and weight, changes in operational behaviour and charging become important.

Given the light and irregular workload of many vessels, a built-in canopy solar array with monocrystalline panels and Maximum Power Point Tracking (MPPT) controllers as the primary charger is recommended[34]. Any shortfalls in charging capacity due to increased workload or low sunlight days can be compensated by shoreside charging[35] with a simple cable to a charger built into the battery box. Some LI battery options, including the EZ[36] outboard batteries, come with inbuilt 230-volt charging and BMS available. In the event that batteries are drained below their operating level on passage, as long as there is some sunlight, the motor will be available at reduced speed, an important safety factor.

A choice (or trade-off) between battery type, weight, storage capacity and charging capacity, both onboard and onshore, needs to be made. The higher CapEx price of LI batteries is theoretically offset by their longer service life and lower weight over LA. The high weight of LA means insufficient storage capacity can be carried for these vessel designs. Amp hour storage can be reduced by increasing charging capacity onboard or shoreside. Onboard PV charging will always be lower cost than larger batteries or onshore charging so as rule of thumb more panels is lowest cost.

Following discussion of these options with the UNDP ITM and programme team, a decision to proceed with Lithium Iron Phosphate ($LifePO_4$ – LFP) type batteries has been made. Therefore, the options analysis is restricted to the choice of this type of battery.

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[34] A range of options are available for this depending on the number of panels and size and quality of the controller with 200W 24-volt panels starting at less than $100.

[35] Shore side charging and locations are being developed by separate expertise and are not considered further in this analysis except to note that it will be 203 volt, 3-phase grid supplied and correctly earthed to insure it is fully isolated from the aluminum vessel hulls.

[36] https://electricboat.co.nz/index.php/product/ez-outboards-48v-lithium-ion-modular-battery-pack/.

Battery Pricing Options

It is important to note that the prices shown are for reputable brand marine grade batteries and can be expected to give 10+ years of service life if correctly used. Marine grade batteries are generally modifications of existing high quality automotive batteries. A range of commercial grade 48-volt batteries are commonly advertised online as available for lower prices (20-50%) but their quality cannot be assured or their longevity if deployed in a marine environment. We have recommended only considering marine grade componentry.

If a Torqeedo motor option is selected, then the highest quality outcome is to pair it with a Torqeedo battery system allowing a full plug & play system with fully matched componentry. The Torqeedo batteries are about 30% lighter than other options and promoted as having greater efficiency. They also come at a much higher price than any other option. The EZ outboard battery option sourced from NZ will provide similar performance at less than half the price albeit a 30% weight penalty which can be considered acceptable.

The prices shown are for individual retail units at the time this report was prepared. Discounts for bulk purchases are available across this range of batteries but will need to be negotiated with the supplier.

48V $LiFePO_4$ (Lithium Ion) – 25 kW storage capacity (for 30kW add 20% to price):
Torqeedo – 5 x 48-volt-5000 batteries are required for 25kWh.

NZ price = NZ$11,725/US$6,950 x 5 + Standard 750w/230v charger US$1400 = Total **US$36,150**
(https://electricboat.co.nz/index.php/product/torqeedo-power-48-5000-battery/)

US Price = US$5,199 per unit x 5 = US$25,995 + charger US$1,400 = **US$27,395**
(https://www.torqeedo.com/en/products/batteries/power-48-5000/2104-00.html)

EZ Outboards – 48v lithium-ion modular battery pack:
NZ prices – 10 x 50ah (25kwh) includes charger and BMS, stainless steel casing – NZ$25,950 = approx. **US$15,250** (https://electricboat.co.nz/index.php/product/ez-outboards-48v-lithium-ion-modular-battery-pack/)

ELCO supplied lithium-ion modular battery pack – 48V – 100AH:
US price US$2,950 x 5 x 100ah = US$14,750 + US$625.00 NOCO GX4820 Charger = **US$15,375**

(https://www.elcomotoryachts.com/product-category/batteries-accessories/batteries/ and https://www.elcomotoryachts.com/shop/batteries-accessories/battery-chargers/noco-gx4820/)
If VICTRON BMV-700H charger @ US$728 then a total of **US$15,478**
(https://www.elcomotoryachts.com/shop/batteries-accessories/battery-chargers/noco-gx4820/)

H. Charging Options

It is recommended that onboard battery charging be supplied via a PV canopy mounted arrays in parallel regulated via reputable brand MTTP controllers. The greater the capacity of the PV array, the smaller the size of the house battery bank needed to be carried onboard. As the cost of such charging is always less than the cost of the battery, it follows that the greater the PV array, the lower the overall vessel cost.

A PV simulation based on global radiation in Apia throughout the year was carried out to estimate the energy that can be harvested from the PV energy system considering the efficiency of the charging system. The results from this simulation can be found in Annex 5 – Solar Simulation. Simulations were run for different configurations (PV size-battery size) and considering different use case scenarios.

Given the estimated maximum size of the canopy (7m length and 4.6m with) and the results from the simulation, a 12 x 400-watt, ie 4.8 kWp panel array supplying a 25 kWh 48-volt battery bank is recommended as a standard option. Alternatively, a 16-panel array, ie 6.4 kWh, and 30 kWh battery would give maximum range and efficiency, albeit at a 20% increase in CapEx for the package.

Onboard 48-volt Charging

A PV array is recommended made up of at least 12 x 400-watt rigid monocrystalline panels wired in parallel strings with a collective nominal capacity of 4.8 kW is recommended.

A 16-panel array would provide a nominal capacity of 6.4 kW. The final design needs to be optimized for the selected number of panels. The centre of gravity needs to be taken into account for the stability of the complete system (hull, construction for the canopy). Figure 12 presents the proposed design of the canopy to accommodate the PV array.

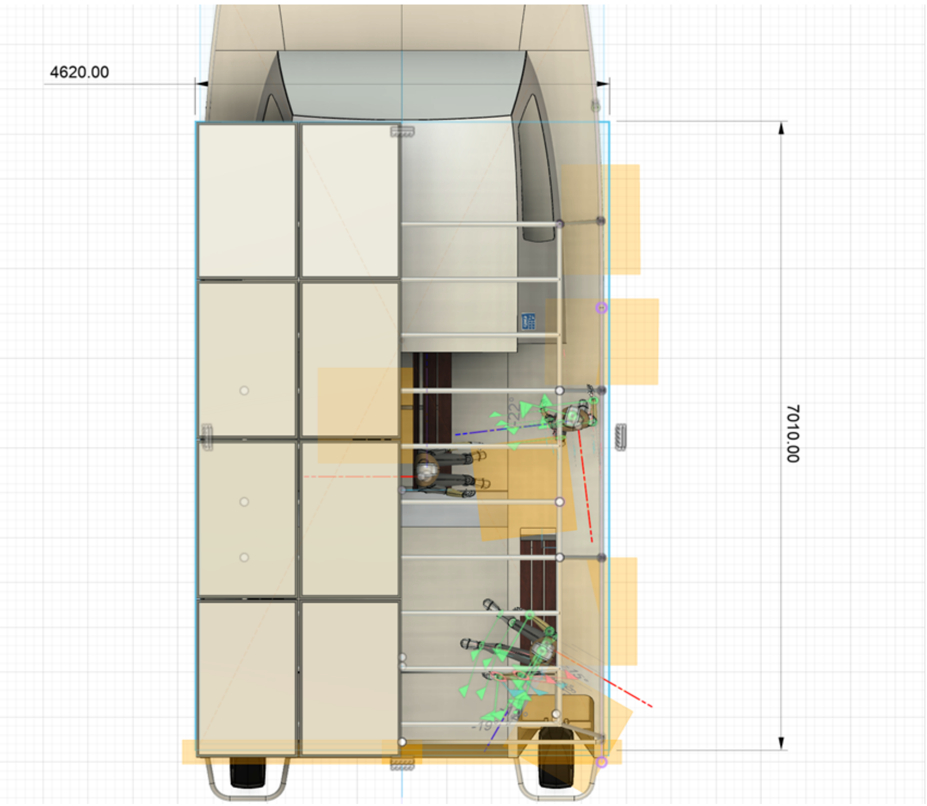

Figure 12. Proposed design for the PV canopy mounted arrays.

Another recommended criteria for the solar canopy is the frame height of the panels. The latest generations of domestic panels tend to have smaller frames (heigt 25mm -35mm) than then older versions (50mm - 65mm). Going for the newer versions PV panels may save some weight without any negative side effects.

The following prices for such panels are commercially available from US, Australia, NZ and Indian suppliers at the following prices:

400 watt monocrystalline Aluminium framed rigid panels

These panels are available from numerous sources. More reputable brands offer up to 30-year warranty and most brands offer discounts for bulk purchases – generally orders of more than 100 units attract around 15-20% reductions. Prices range from US$150 per unit to $480 per unit. A reputable brand with up to 30-year warranty should be able to be sourced for US$200-250 per unit. The following prices for such panels are commercially available from US, Australia, NZ and Indian suppliers at the time of report writing:

- https://www.zunpulse.com/products/electric-power-and-solar/ZV222078/zunsolar-400-watt-24-volt-mono-perc-solar-panel in India at **US$180** per unit.
- https://a1solarstore.com/solar-panels/400-watt-solar-panels.html in US offers a range of products from **US$151** per unit.
- https://a1solarstore.com/aptos-400w-solar-panel-108-cell-dna-108-mf10-1.html and https://a1solarstore.com/panasonic-400w-solar-panel-132-cell-evp132gl.html offers up to **US$480** per unit for hi-end Panasonic brand.
- https://www.12volt.com.au/trina-vertex-s-24v-400w-solar-panel in Australia at **US$290** per unit.
- https://poweronsolar.co.nz/product/400-watt-monocrystaline-solar-panel/ in New Zealand at **US$180** per unit.

Controllers

The onboard charging is managed through a MPPT controller to regulate the charge to the battery in the most efficient manner without exceeding charging limits. If 4.8kW watts of PV array is used, then a 100 amp controller will be needed. A 6.4kW array will require a minimum of a 150-amp controller. Price options for the 100 Amp setup (See Figure 8).

Table 8. Cost overview of different Controllers.

Supplier	Renogy Australia	FazCorp Solar, NZ	Sunyee/Kogan Australia	Renogy USA
Item	Rover Li 100A 12/24/36/48V MPPT Solar Charge Controller[37]	MPPT Solar Charge Controller 100A 12V/24V/48V MC-Series[38]	DC MONT 100A MPPT Solar Charge Controller 12/24/36/48V	Rover 100 Amp MPPT Solar Charge Controller[40]

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[37] https://au.renogy.com/renogy-rover-100-amp-mppt-solar-charge-controller/.
[38] https://fazcorp.co.nz/products/mppt-solar-charge-controller-100a-12v24v48v-mc-series.
[40] https://www.renogy.com/rover-100-amp-mppt-solar-charge-controller/.

			Battery Regulator Bluetooth[39]	
Cost	AU$800.00 (US$515.00)	NZ$749.00 (US$440.00)	AU$400.00 (US$260.00)	US$700.00

Wiring and Connectors

A number of appropriately sized wiring looms and connectors will be required along with fuses, shunts, etc. These can be ordered as individual units but if a bulk order is required then wiring looms would be better made on site assuming an appropriately qualified technician is engaged at greatly reduced cost. All the electronic components (MPPT's, shunts, BMS, display, controller, fuses, charger, etc) must fit together so getting these components from one source (e.g. Victron) makes it much easier because everything is plug and play and data transfer and visualization works out of the box.

Shoreside 230-volt Charging

The PV charging is complemented by access to shoreside 230-volt grid supplied charging via an onboard built-in charger. Most e-motors can be partnered with either standard or fast chargers. As a rule of thumb, a fast charger delivers about three-times the charging speed at approximately twice the cost of the charger. Shore side charging stations must be adequately grounded in order to ensure there is no stray charging occurring to the aluminium vessel hull. It is assumed the shoreside charging stations will be installed by an appropriately qualified technician and complaint with all relevant Samoan domestic regulations.

I. e-Replacement Vessel Package Indicative Cost Summary

In the simulation modelling undertaken, a bare minimum capacity of 17kWh battery capacity paired with a 16-panel array and supported by some onshore charging is needed for maintaining the work reported by most operators surveyed. While this is the lowest cost option, this leaves little safety margin to cover periods of extended work or harder working vessels. For this reason, overall cost estimates are provided for high and low component costs for two options, a standard version with 25kWh of battery storage (Table 9) and a 12-panel array and an extended range option with a 30kWh battery and 16 panel array configurations (Table 10).

The final selection of motors, batteries and chargers is a trade-off between capacity, range, cost and weight. A larger battery capacity reduces the amount of onboard charging required, so a 30kWh battery could be paired with a 12-panel system or a smaller 20 or 25 kWh battery paired with a larger array.

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[39] https://www.kogan.com/au/buy/vor-dc-mont-100a-mppt-solar-charge-controller-12243648v-battery-regulator-bluetooth-dc-mppt-mpk2-100a-sun/.

The price variance in batteries is the greatest extreme, with Torqeedo batteries increasing the overall vessel cost considerably. The cost variance in motors is the second greatest price factor with Elco motors less than half the price of Combi motors and around a third the cost of Torqeedo options based on prices quoted at time of report writing.

Table 9. Option 1 – Extended Range – Array of 16 Panels and a 30kw Battery.

Category	Item	Unit	Estimated Cost Range (US$)	Total Low (US$)	Total High (US$)
Vessel					
	Bare Hull	1	$35,000 – $42,000	$35,000	$42,000
	Safety Equipment	Refer Annex 3	$1,000 – $4,000	$1,000	$4,000
	Ancillary Equipment	Various	$3,000 – $6,000	$3,000	$6,000
E- Motors					
	10-15kWh	2	$5,450 – $14,850	$10,900	$29,700
Charging					
	PV Panels	16	$150 – $480 per unit	$2400	$7680
	Controllers	1 x MPPT 150 Amp	$260 – $700	$260	$700
	Battery	30kWh	$18,300 – $43,380	$18,300	$43,380
TOTAL				$70,860	$133,460

Table 10. Option 2 – Standard Version – Array of 12 Panels and a 25kw Battery.

Category	Item	Unit	Estimated Cost Range (US$)	Total Low (US$)	Total High (US$)
Vessel					
	Bare Hull	1	$35,000 – $42,000	$35,000	$42,000
	Safety Equipment	Refer to Annex 4	$1,000 – $4,000	$1,000	$4,000
	Ancillary Equipment	Various	$3,000 – $6,000	$3,000	$6,000
E-Motors					
	10-15kWh	2	$5,450 - $14,850	$10,900	$29,700
Charging					
	PV Panels	12	$150 – $480 per unit	$1,800	$5,760

	Controllers	1 x MPPT x 100 Amp	$260 – $700	$260	$700
	Battery	25kWh	$15,250 – $36,150	$15,250	$36,150
TOTAL				$67,210	$124,210

J. Oversight, Induction & Monitoring, Evaluation & Learning (MEL)

As discussed previously, the success of this trial project will be largely dependent on the effectiveness of the support given to in-country manufacturers and then to boat operators, both who will be required to make a significant transition to both the technology but also their current business models. Three key tasks need to be given particular attention are:

1. The quality of oversight in ensuring the new vessels and technology components are of reputable quality and are assembled to commercial standard. It is highly unlikely that one vendor will be able to provide a complete package of vessels, motors, storage, charging and safety equipment and therefore the project will need to provide adequate supervision of this. All parts of the package and their assembly – vessel fabrication, survey equipment and electrical installation – will need to comply with the relevant Samoan standards. In the case of the small vessel project in the Marshall Islands[41] this support has been achieved through a University partnership with senior graduate engineering student interns which proved very successful. In the case of Samoa this could include an arrangement with the relevant technical teaching institute or the contracting of an appropriate external technical expertise.

2. The induction and training program for the operators is adequate to bridge the technology transfer from one energy source to another. The new technology reviewed here is reputed to be ruggedly constructed to high standards with very low maintenance requirements. It is, of course, totally new to the boatbuilders, the operators and the passengers and will require an appropriate induction program and training program so that the characteristics of the charging and storage of energy and the operational characteristics of electric as opposed to petrol propulsion are fully understood. In the current model, none of the boats are fitted with electronic componentry. It is assumed that the motor supplier will be able to contribute to this task, but the induction program needs to go further than just the operation of the motors and cover the management, maintenance and operation of all the new vessels systems. For example, the new designs have twin motors and steerage. The induction program needs to also include the passengers. For example, even if robustly designed, the PV canopy will not support passengers riding on it or cargo being stowed. it is important that the passengers understand the safety and operational requirements of the new vessels. It is also recommended that all courses include material translated in Samoan wherever possible and encourage full participation of women operators and passengers. There was a common request in many of the survey responses for boat master qualification courses. It would seem

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[41] https://www.canoesmarshallislands.com/2020/01/inside-lagoon-transport-tlcseat-project-phase-1/

sensible to work with the maritime safety authorities to consider holding such courses in tandem with the induction program.

3. The MEL from this project. As the first trials of any scale with this technology in the Pacific, it is critically important that they are appropriately monitored and evaluated and the lessons learnt reported, absorbed and addressed.

Consideration needs to be given as to how the participants in this experimental trial are supported throughout the lifecycle of the trial and beyond the finite project timeframes. As a first step the initial survey undertaken could be repeated in more detail and over time to establish a true cost and emissions profile baseline and then be repeated annually to record the transition. This could be possibly achieved as a graduate student research project in an arrangement with the University of Samoa or similar institution.

K. Whole of Life-cycle Considerations

With the introduction of new technology, especially one being brokered as a response to environmental issues, it is important to consider the whole of life cycle considerations. In the case of this initiative this refers primarily to the motors, batteries and electrical componentry where full recovery and recycling of end-of-life components should be insisted on. The quantity of these materials over the life cycle of the project is likely low, with the batteries expected to give 10 years of service life. In some ways this makes the problem harder to address as there is insufficient bulk material to provide any economy of scale when it comes to storage of waste or ultimate disposal.

It is assumed that this is a common issue for the whole e-mobility project and the maritime waste cycle will be incorporated into the broader programme in due course. It is certainly a matter that needs to be addressed in the induction programme.

The hulls are aluminium and can be recycled as standard scrap metal potentially shipped via the SPREP/Moana Taka project.

L. Recommended Option and next steps

This study recommends that a newly built prototype vessel, based on the concept design developed, be built on site and tested before moving to produce a small production line of vessels. The prototype is to be used as the basis of an induction and training program to transition the existing operators to a high level of familiarity with the new technology.

The new design (Figure 13) calls for a modified version of the existing Alia vessels where hull efficiency, stability and load carrying capacity is increased through an improved hull shape, increased spacing between the hulls and more efficient engine mountings. The design incorporates an overhead canopy frame carrying an array of 12 x 400-watt 24v monocrystalline rigid PV panels to charge a 25kWh lithium-ion Phosphate (LifePO$_4$ – LFP) type battery bank connected via MTPP controllers. Shore charging to a 230volt grid supply is also required. This design requires development of a 'plug & play' compartment to be built into the vessel to accommodate the electrical componentry. The full electrical layout needs to be first designed and tested to fit within a dedicated 'plug & play' compartment to be built into the vessel with a customised wiring loom. It is recommended this step is done initially off-site in a laboratory to ensure the electronics componentry can be seamlessly matched with the new hull to make the entire system is as safe, fool-proof and easily maintained as possible.

Figure 13. Concept design of Alia. Photo © Nikhil Lal & Peter Nuttall.

The current single, centre-mounted, ICE 40hp outboard is replaced with two 12-15kwh 48volt e-outboards mounted on the transom of each hull. The shift from one centrally-mounted to two transom-mounted engines requires the design and installation of a steering system and engine control station. Various modifications are required to the existing deck layout, superstructure, and hulls. This concept design now needs to be fully developed by a competent naval architect into a full build plan with accompanying hydrostatic and stability calculations to international standards (ISO) small vessel standards and to the satisfaction of the Samoan maritime survey authorities.

Existing capacity exists in Samoa for constructing the vessels, with a small but experienced yard identified as having built ICE-powered alia to a commercial standard. However, no capacity or experience exists in-country in building or operating electric versions of conventional vessels, particularly in the use of LI batteries and related componentry. External expert supervision, mentoring and support is required to prepare the build plans, develop the prototype and assemble the various componentry into a single package, and undertake the necessary induction and training program.

A prototype vessel needs to be then constructed on site and successfully sea-trialled and surveyed before moving to produce a small production line of vessels. The prototype is also to be used as the basis of an induction and training program to transition the existing operators to a high level of familiarity with the new technology. No current literacy within Samoa exists in terms of operation or maintenance of these new technologies and external expert support and supervision will be required to fulfil this function.

M. Potential Future Low Carbon Technology Applications

Facing a deepening climate emergency, Samoa has committed via its Nationally Determined Contributions under the Paris Agreement, to highly ambitious emissions reduction targets. Whilst Samoa's emissions are completely negligeable on a global scale, Samoa has clearly signalled its intent to match step with global progress in this regard. As fossil fuel prices can be projected to increase with the introduction of carbon pricing in the future, not transitioning away from fossils fuels is likely to lead to ever increasing costs to Samoa.

Decarbonization solutions in the maritime sector globally are now developing at significant speed. Innovation includes technology advances in the use of next generation fuels – ammonia, methanol and hydrogen – now being commercially trialled in several first world locations, a variety of wind hybrid technologies including Flettner Rotors, kites, fixed wing and soft sail applications now available at all scales of shipping and new engines, propeller and hull efficiencies. Electric propulsion is being proven in commercial deployment in various harbour and near shore applications including tugboats, coastal passenger ferries and small cruise liners.

To date, most of these advances are occurring either in large scale shipping serving major economies and trade routes or in developed world scenarios with secure and low carbon electricity generation support. Developments in decarbonized shipping at Samoan scale is still embryonic and restricted to a small number of demonstration and proof of concept trials. This situation is predicted to improve significantly in the near and medium future.

Due to project delivery parameters, this feasibility study has resulted in recommendations for an e-mobility solution in one sector of the Samoan transport scenario. Looking more broadly, a range of technology solutions currently exist that could be applied to other sectors of Samoa's maritime fleet. Listed below are some existing projects that could be considered by Samoa in the future.

For Samoa's small maritime fleet, a range of options present for decreasing fuel dependency varying on the type of vessel, from small outboard powered craft through to its inter-island ferries and the ships employed on its international trade with American Samoa, Tokelau and chartered for services in the Cook Islands. Mature technologies now available with potential direct application to a Samoan maritime scenario include much improved vessel hull design and new engine and marine electronic technology, wind hybrid designs of varying designs, electric drives as being trialled in this project and larger vessels such as the electric tugboats and passenger ferries now in service in NZ.

Looking a little further ahead, the biggest challenge facing Samoa and other Pacific small island fleets is the question of which of the emerging alternative fuels will become available and at what cost. Island economies face major economies of scale issues, as much with the storage, distribution and bunkering infrastructure that will be needed to deploy such fuels as with the availability of the fuel itself. The most likely candidates are: stored electricity, biofuels, electro-fuels (ammonia, methanol and hydrogen – so called because an ample supply of clean electricity is needed to convert these to usable fuel onboard the vessel) and wind. Wind aside, each of the fuel options present challenges that must be overcome before they can be seriously considered in Samoa.

The issues with electricity as fuel are two-fold. While battery and PV charging have matured at high speed globally, modern batteries are still not small and cheap enough to provide the range needed for more than short trips or payloads before the cost becomes prohibitive. When used based on regular charging from grid supplied shore power (known as 'cold-ironing') as is the case with the electric tug and ferry vessels in NZ for instance, the assumption is made that sufficient grid-supply exists for all uses in Samoa. The fuel is only as green as the means of producing it. In Samoa this would mean that only around 30% of the electric used would come from renewable sources if they are reliant on current grid supply.

Biofuels, where the fuel is made from biological fuel stocks, have been irregularly suggested now over several decades. In theory, Samoa's fertile soils, good water and tropical growing conditions could provide an ample feedstock. The reality is it is difficult to find a feedstock or processing method that is cost effective or isn't in competition with other uses for the same products. Coconut oil, for example, which can be processed to a near match with diesel oil requiring only minor modifications to motors and fuels storage appears an ideal candidate. However, when processed to the consistent standards required to operate safely in a maritime environment, the costs of production versus the cost of fossil fuel does not make this competitive with other uses of coconut n foodstuff, health and beauty product markets. For any sort of effective uptake, a market needs to be created that generates a sufficient production of fuels to become economically viable, a considerable challenge at island scale. Insufficient research has been done as yet to overcome these challenges.

Electro fuels bring their own peculiar traits and barriers. Of those under consideration globally, only methanol offers an alternative that comes close to being a drop-in replacement for current fuel storage and bunkering infrastructure. Even with this, major modifications to all aspects of the fuels supply chain will also be needed training and induction for all workers in the logistic supply network. Ammonia and hydrogen will both require highly specialized bunkering on shore and then on ship, which in turn will require new engines and associated machinery. The price differential between these new fuels and fossil fuels is still considerable, although carbon pricing and other measures are currently being debated at IMO to address this. New fuels are expected to increasingly come onstream commercially at ever greater scale by the end of this decade. The issue of future fuel choices of course affects more than the maritime industry but all aspects of the island energy sector and represents one of the greatest and far-reaching economic decisions to be made by this generation of Pacific leaders.

Wind energy, as it has for several thousand years, is the Pacific's greatest friend here. Wind energy remains available, free and untaxed. The irregularities in supply – the wind blows at various strengths and from various directions – means this energy source needs to be paired with a secondary propulsion, be this conventional fossil fuel drive or electric motors, to create a hybrid. Efficiencies range from retrofit rigs or rotors targeting 10-40% fuel saving on existing vessels to custom new build designs capable of up to 80% fuel savings. Greatest efficiencies will be achieved when combined with operational measures including hull coating and propellor technologies and weather routing.

Two low carbon applications in a Samoan operating environment present as obvious choices, both using wind hybrid approaches, the small vessel fishing fleet and the interisland ferry vessels. Recent projects in the Marshall Islands illustrate this potential at both scales.

Waan Aelõñ in Majel (WAM, or Canoes of the Marshall Islands) has been active for three decades spearheading a revitalisation in Marshallese sailing heritage where these islanders excelled at fast, efficient and revolutionary naval architecture incorporating asymmetrical hulls, a proa design coupled with the incredibly efficient ocean lateen sail and shunting rig. More recently, WAM has been developing modern variations designed to be built in-country with island appropriate materials and construction methods. Such vessels are now in increasing demand by outer-atoll communities where they provide an effective and low-cost option to conventional outboard powered fibreglass punts. WAM is now trialling small e-outboards as auxiliaries (Figure 14 and Figure 15).

Figure 14. Canoes of the Marshall Islands. Photo © Waan Aelõñ in Majel (WAM). [Waan Aelõñ in Majel (Canoes of the Marshall Islands) | Majuro | Facebook]

Figure 15. Example of vessel in the Marshall Islands. Photo © Waan Aelõñ in Majel (WAM). [Waan Aelõñ in Majel (Canoes of the Marshall Islands) | Majuro | Facebook]

The WAM vessel designs are specific to their Marshallese atoll operating environment and as such do not represent a drop-in option for Samoa. However, a similar design approach could be used to develop an appropriate wind hybrid design for the Samoan small vessel fishing fleet, combining a simple sail rig on a multi-hull platform with either ICE or e-motor auxiliary propulsion. Depending on the technology level, these could be further developed to include parametric fast hull (PFH) concepts and a range of wind technologies, including micro-rotors and fixed wing aero foils. This prototype design combines PFH hulls with electric outboards (Figure 16).

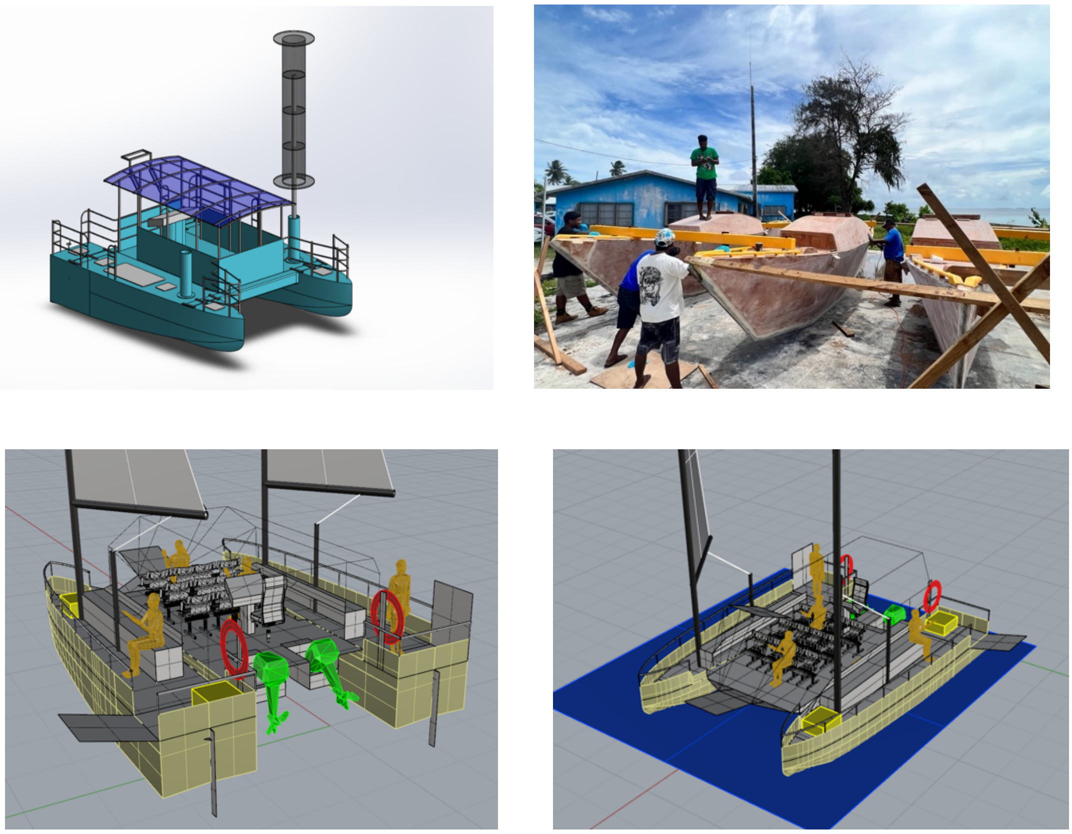

Figure 16. WAM vessel Concept Designs prepared for Marshall Islands. Photo © Waan Aelõñ in Majel (WAM).

This design concept could be further developed to combine PFH platforms with a combination of renewable energy technologies to produce a small-scale fishing vessel capable of operating in Samoa's offshore coastal fishery with a very low to zero carbon operating footprint.

Turning to Samoa's larger vessel fleet of inter-island general purpose vessels ranging up to 1,200gt. Without an affordable alternative fuel option available, wind hybrid options present as the most rational choice. The Marshall Islands provides the only current proof of concept vessels in this vessel type, with a 400gt, 48m wind hybrid general purpose vessel being launched in late 2023 (Figure 17).

Figure 17. Example of hybrid vessel for Marshall Islands build in South Korea with wind-powered solution. Photo from [Marshall Islands to get wind-powered solution to help decouple from international bunker prices | TradeWinds (tradewindsnews.com)]() and Concept Design example from [Designing Wind Assisted Commercial Cargo Vessels › CAESES]().

This vessel is smaller than the current Samoan ships. However, the design concept is modular and can therefore be scaled as necessary as shown in this concept design for a 60m island supply vessel for the Government Shipping Service in Fiji (Figure 18).

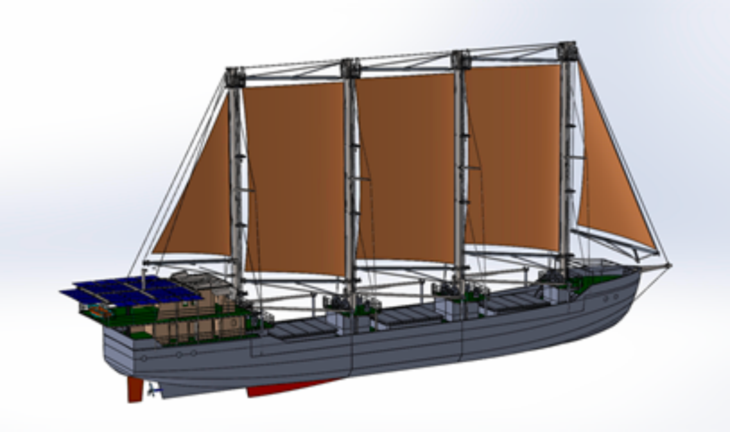

Figure 18. Concept Design for a 60m island supply vessel for the Government Shipping Service in Fiji.

This design concept would lack the roll-on, roll-off capacity of the current Samoan inter-island fleet. This design from French market leader Neoline is under construction currently for work on the Atlantic trade and could easily be adapted and scaled to meet a Samoan operating profile (Figure 19). The current design is for a wind hybrid combining soft sails with a conventional ICE propulsion plant but is designed to be upgraded to an alternative fuel engine as a future retrofit as the technology matures.

Figure 19. Example of vessel from Neoline. Photos from [The NEOLINE solution - NEOLINE](#).

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Annex 1 – Manono Island Alia Operator Survey (in Samoan)

SAILIILIGA MO LE ‘AU FAIVA’A MO MANONO

(Tasi(1) le pepa mo le vaa e faatumu mai faamolemole)

Vaega 1 – Faamatalaga faalaua’itele:

1. Suafa o lē e ana le va’a:
____

2. Alii pe tamaita’i lē e anaina: ____________________________________

3. Igoa o le Alia (va’a): _____________________________________

4. Itumalo/Nu’u: ____

5. Ua leva le Alia?

☐ 0 – 4 tausaga ☐ 4 – 7 tausaga ☐ 7 – 10 tausaga ☐ silia i le 10

E tusa e fia se tau na e faatauaina ai le Alia? ___________________________

Vaega 2 – Faaaogaina o lau Alia:

6. E fa’aaoga mo le ā lau Alia:

a. Faa va’a la’u pasese i Manono? Afai o lea, e fia malaga i le aso a o fea foi nuu e alu iai?

____

b. E fia pasese o le vaa e mafai ona ave?

☐ 1 – 7 ☐ 8 – 15 ☐ 16 – 20 ☐ sili atu ile 20

c. E tusa e fia alii ae fia foi tamaitai?

☐ Mafuli i tamaitai ☐ Mafuli i alii ☐ Fefiloi lava

d. E fia le totogi o pasese? _____________________________________

e. E fai ma fesuisuia’i le totogi? O a taimi e sui ai totogi o pasese a o le a foi le mafuaaga?

____

f. E fa’aaoga lau Alia mo fagotaga?

☐ Ioe ☐ Leai ☐ Isi taimi – faailoa mai lalo faamolemole:

____

g. E faafia ile masina ona alu lau/le Alia i Apolima? O fea nu'u o Apolima e malaga iai?

____

h. E faafia ile masina ona alu lau/le Alia i Savai'i? O fea nu'u o Savai'i e malaga iai?

____

Vaega 3 – Afi ma le faaleleinas:

7. O le a le afi /poo afi o loo faaaogaina i le taimi nei e lau Alia?

____

8. O le a le leva o ia afi?

☐ 0 – 4 tausaga ☐ 4 – 7 taus. ☐ 7 – 10 taus. ☐ Silia ile 10

9. E faafia ona siaki ma faaleleia lau afi?

☐ Ta'i 6 masina ☐ faatasi ile tausaga ☐ Vagana ua iai se faaletonu

Isi: ____

10. E tusa e fia sau tupe na fa'aalu mo le siakiina/faaleleia o lau afiva'a i le tausaga talu ai?

____

11. E tusa e fia na e fa'aalu i suau'u-afi ma isi mea e faaga'o ai le Alia i le tausaga talu ai?

____

12. O fea e ave iai lau afi-va'a mo galuega toe faaleleia?

____

13. O fea e ave iai lau Alia mo galuega toe faaleleia?

____

14. O le ā se penisi aupito tele e mafai ona e faaaogaina i le aso? Faailoa mai faamolemole le aofa'i ma le tau.

____

15. O le a se penisini aupito tele e mafai ona e faaaogaina i le masina? Faailoa mai faamolemole le aofa'i ma le tau.

____

16. E te faatauina penisini ua mae'a ona sui pe sui lava e oe lau penisini?

____

Faaaoga mai le avanoa lea mo nisi faamatalaga e te fia faailoaina mai faamolemole:

____

____

Mae'a le Sailiiliga

Annex 2 – Manono Island Alia Operator Survey (in English)

SURVEY FOR MANONO BOAT OPERATORS

(Please complete one (1) sheet per boat)

Section 1 – General Information:

1. Owners Name: ____
2. Gender of owner: ____
3. Alia's Name: ____
4. District/Village: ____
5. How old is your Alia?

☐ 0 – 4 years ☐ 4 – 7 years ☐ 7 – 10 years ☐ More than 10

5. For approximately how much did you purchase your Alia? ________________________

Section 2 – How You Use Your Alia:

6. What do you use your Alia for:

a. Do you ferry passengers to/from Manono? If yes, how many times in a day and to which villages?

____

b. How many passengers do you carry?

☐ 1 – 7 ☐ 8 – 15 ☐ 16 – 20 ☐ More than 20

c. How is the gender distribution of the passengers?

☐ Mostly women ☐ Mostly men ☐ Mixed

d. How much do you charge passengers? ____

e. Do your charges change? When and why do they change?

____

f. Do you use your Alia for fishing?

☐ Yes ☐ No ☐ Sometimes – please explain below:

____

g. How often in a month do you take your Alia to Apolima? Which villages in Apolima do you visit?

____

h. How often in a month do you take your Alia to Savai'i? Which villages in Savai'i do you visit?

____

Section 3 – Engines and Repairs:

7. What engine/s is/are currently on your Alia?

____

8. How old are the engines?

☐ 0 – 4 years ☐ 4 – 7 years ☐ 7 – 10 years ☐ More than 10

9. How often do you get the engine serviced?

☐ Every 6 months ☐ Once a year ☐ When there is something wrong

Other: ____

10. Approximately how much did you spend on servicing the boat's engine in the last year?

____

11. Approximately how much did you spend on engine oil and other lubricants in the last year?

____

12. Where do you take your engine for repairs?

____

13. Where do you take your Alia for repairs?

____

14. What is the most fuel you would use in a day? Please indicate quantity and cost.

____

15. What is the most fuel you would use in a month? Please indicate quantity and cost.

____

16. Do you buy premix, or do you mix your own fuel?

____

Please use this space to note any additional comments and/or information and/or data:

____

____

____

Survey Ends

Annex 3 – Alia History (Extracted from Literature Review)

Commercial fishing and sea safety in Samoa is closely linked with the "Alia" catamaran fishing craft. Notable aspects of the fleet are given in Gillett (2002). The original plywood Alia catamarans were designed by FAO in conjunction with a Danish-funded fisheries development project in the mid-1970s. The first 120 craft were constructed in plywood and then several hundred more were built from welded aluminium. In the early to mid-1980s the Alia fleet numbered some 200 craft. Initially much of the fleet engaged in bottom fishing along the shelf area and reef slopes, landing high-value deep-water snappers for air-export to Hawaii. However, as the deep-bottom resource became more heavily exploited, fishing effort began to be re-directed offshore, with fishers targeting skipjack and small yellowfin tuna by trolling around fish aggregation devices (FADs). The fleet was reduced still further, to only 40 vessels, as a result of the destruction caused by two severe cyclones which struck Samoa in 1991.

The introduction of effective small-scale longline fishing techniques and gear in the early 1990s saw the number of Alia grow rapidly during the decade. The development in the mid-1990s of an export market for albacore and other tuna resulted in further expansion in the fishery. The status of the tuna fleet in 2000 was:

- Conventional nine to ten metres Alia: about 119 vessels operating; 63% based in the Apia urban area.
- 10 to 12.5 metres catamarans and monohull longliners: about 20 operating; 89% based in Apia.
- 12 to 15 metres catamarans and monohull longliners: nine operating; 100 % based in Apia.
- Monohull longliners greater than 15 metres: six operating; 100% based in the Apia.

Watt and Imo (2002) state that a total of 149 vessels participated in the Samoa longline tuna fishery in 2001: 116 vessels less than ten metres in length, 14 vessels over ten metres and up to 12.5 metres, eight vessels over 12.5 metres and up to 15 metres, and 11 vessels over 15 metres. Because of the poor tuna fishing in early 2003, the active Alia fleet (vessels in the category of "less than less than ten metres") has contracted considerably. In February 2003, only 17 Alia were active in the Apia area and about 20 to 25 in rural areas. The size of the Alia longline fleet has actually contracted more than these numbers suggest as many of the active boats participated in fisheries other than tuna longlining (bottom fishing, trolling).

A typical safety incident at sea in Samoa involves an Alia, or modified Alia, fishing more than 25 nautical miles offshore which has either (a) suffered a engine problem, or (b) been so heavily loaded that it has swamped, or (c) lost sight of the island and has travelled in the wrong direction until the fuel has been expended. Over the years, Samoan fishers have drifted to American Samoa, Niue, Tonga, Wallis, Fiji, Solomon Islands, Papua New Guinea and Vanuatu.

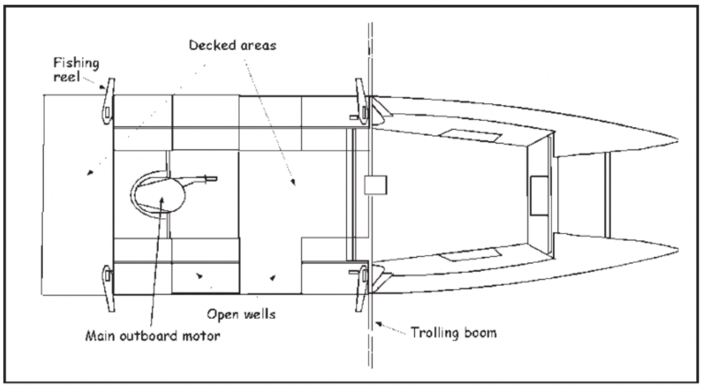

Figure 2: The original aluminium alia *catamaran rigged with handreels and trolling booms*

The boat building industry of the 1980s, which had shrunk to almost nothing in the early to mid 1990s, was expanded suddenly to meet the demands of the fishing industry. In the space of a couple of years, the alia fleet expanded to over 200 vessels with just about all of them involved in tuna longlining. (Chapman 1998)

1976-78 - the first Alia

DANIDA (Danish Aid) through FAO. A total of US$408, 000 was approved for financing starting January 1976. During the last two years this project has:

- established a boatyard with 17 workers;
- built more than 100 boats of 28 ft;
- trained 400 fishermen;
- improved repair facilities for outboards
- established a Fish Market in Apia and a Fish Marketing scheme for Upolu, where 70% of the population lives.

The "FAO/DANIDA Village Fisheries Development Project" will terminate in June 1978 but with the boatyard turning out 50-60 boats per year and the finance secured through the Revolving Fund there is not yet any sign of lack of interest from the fishermen.

Watt and Imo (2002) state that a total of 149 vessels participated in the Samoa longline tuna fishery in 2001: 116 vessels less than ten metres in length, 14 vessels over ten metres and up to 12.5 metres, eight vessels over 12.5 metres and up to 15 metres, and 11 vessels over 15 metres. Because of the poor tuna fishing in early 2003, the active alia fleet (vessels in the category of "less than less than ten metres") has contracted considerably. In February 2003, only 17 alia were active in the Apia area and about 20 to 25 in rural areas.

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Annex 4 – List of Safety Equipment

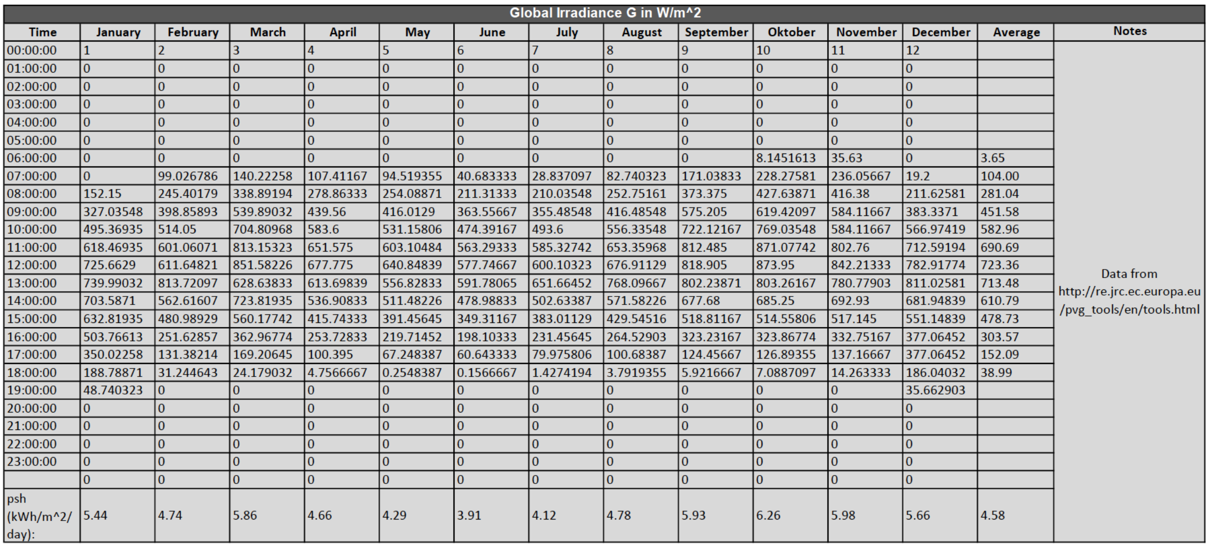
Safety Equipment	West Marine ($US)	Burnsco	Australian Boating
Navigation Lights	1. Attwood 3 Mile LED US$137.99 2. Deck Mount Navigation Lights $182.99	1. Railblaza IPS LED Light $70.00 2. Hella Bi-Colour Navigation Lights $90.00	1. Lalizas Navigation Lights $100.00 2. Navigation Lights Bi-Colour Horiz $30.00
Radio (VHF)	1. Standard Horizon Fixed Mount VHF/GPS Radio $199.99 2. Uniden FRS/GMRS Two-Way Radios $99.99 3. ICOM M73 Submersible Handheld VHF Radio $229.99	1. GME UHF Radio Twin Pack TX677 $150.00 2. Uniden Atlantis 270 VHF $135.00 3. Uniden UHF Radios UH45-2 $55.00	1. ICOM VHF Handheld Waterproof Radio M25 $160.00 2. GME GX700 VHF Marine Radio $170.00
Mobile Phone	$200.00	$200.00	$200.00
Compass	1. Ritchie Flush-Mount Explorer Compass $99.99 2. Offshore 115 Compass $284.99	1. Ritchie Explorer S-53 Compass $105.00 2. Ritchie Sport X-10 Compass $60.00	1. Sailboat Compass Olympic 115 $275.00 2. Contest 101 Sailboat Compass $285.00
Bail Hand Pump (2 needed - one for each hull).	1. Gusher Urchin Thru-Hull Manual Bilge Pump with Removable Handle $124.99 2. Gusher 10 Manual Bilge Pump $319.99 3. Gusher Urchin On-Deck Manual Bilge Pump with Fixed Handle $102.99	1. Manual Bilge Pump 720GPH $35.00 2. Whale Titan Standard Manual Bilge Pump 1665GPH $120.00	1. Pump -Manual Bilge 35LPM $35.00 2. Amazon Thru-Deck Manual Pump 25mm $150.00
Fire Extinguisher (Dry Powder)	1. Kidde Mariner 110 Fire Extinguisher $39.99 2. Kidde PRO 5MP Fire Extinguisher $107.99 3. Kidde Mariner 10 Fire Extinguisher $38.99	1. ABE Fire Extinguisher 1KG $20.00 2. ABE Fire Extinguisher 2.5KG $60.00 3. ABE Fire Extinguisher 4.5KG $80.00	1. ABE Fire Extinguisher 4.5KG $100.00 2. Fire Ext Box 2 Kg $65.00

Anchor	1. 22lb. Galvanized Delta Fast-Set Anchor $237.99 2. Stainless Steel Delta Fast-Set Anchors $1,239.99	1. Manson Supreme Anchors (45lb (boats 12m to 14m) $500.00	1. Standfast Sand Anchor 12kg $90.00 2. Manson Anchor 12kg $210.00
Parachute Rockets	Orion Red Parachute SOLAS Signal Rocket $89.99	1. Flare Comet Red Parachute Rocket $60.00 2. Comet Cruising Flare Pack $120.00	Not available.
Hand Flares	1. Red Handheld Locate Flares, 3-Pack $38.99 2. Coastal Alerter Flare Kit with Accessories $134.99 3. Orion 12-Gauge High-Performance Alerter Basic 4-Flare Kit $99.99	1. Comet Inshore Flare Pack $100.00 2. Comet Powerboat Flare Pack $70.00	1. Flare Kit - 2 x Red 2 x Orange $56.00
Smoke Signal	1. Orion Handheld Orange Smoke Flare, Single Flare $43.99 2. Handheld Orange Smoke Flares, 3-Pack $89.99 3. Orange SOLAS Floating Smoke Signal $87.99	1. Flare Comet Orange Smoke $60.00	Not available.
Lifejackets	1. All Clear Offshore Inflatable Life Jacket with Harness $229.99 2. Runabout Life Jacket 3-Pack $54.99 3. Universal Type II Life Jackets, 3-Pack $35.99	1. Burnsco Starguard Lifejacket $30.00 2. Ultra Raider Adult Lifejacket $70.00 3. Hutchwilco Wee Wilco XS Lifejacket $95.00	1. Lifejacket Adult Large $90 2. Crewsaver Manual Inflate Life Jacket $85.00 3. Life Jacket Automatic with Harness $100.00
First Aid Kit	1. Coastal First Aid Kit $19.99 2. Orion Offshore Emergency Medical Kit $69.99 3. Blue Water Emergency Medical Kit $67.99	1. Platinum Coastal First Aid Kit. $50.00 2. Offshore First Aid Kit $165.00	1. First Aid Kit $25.00 2. First Aid Kit - Deluxe Green Box $105.00
Engine Spare Parts, Engine Tools	$200.00	$200.00	$200.00
Signal Horn	1. Super Blast Marine Signal Horn, 8 oz. $21.99	1. Pump Air Horn $20.00	1. Ecoblast PRO Rechargeable Air Horn

	2. TaylorMade EcoBlast Rechargeable Signal Air Horn $62.99 3. Marinco International Shorty Horn $144.99	2. Air Horn With Canister $20.00	$150.00 2. Horn Dual Tone Stainless 12v $155.00 3. Horn - Air ECOBLAST & Pump $55
Search Light (Torch)	1. Waterproof 3000-Lumen Rechargeable LED Spotlight $124.99 2. Golight Halogen Permanent Mount Searchlight with Hardwired Dash Mount Remote $279.99	1. Hella 100W Spotlight $90.00 2. LED Floating Spotlight 1000 Lumen $60.00 3. Burnsco Waterproof 1500 Lumen LED Spotlight $85.00	1. Deck Lamp LED Oval Flood Beam $105.00 2. AAA Remote Control LED Spotlight 12-24 Volt $225.00

Annex 5 – Solar Simulation

This sample simulation has a 17kWh battery array paired with a 6.4kW PV array (16 panels):



Global Irradiance G in W/m^2														
Time	January	February	March	April	May	June	July	August	September	Oktober	November	December	Average	Notes
00:00:00	1	2	3	4	5	6	7	8	9	10	11	12		Data from http://re.jrc.ec.europa.eu /pvg_tools/en/tools.html
01:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
02:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
03:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
04:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
05:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
06:00:00	0	0	0	0	0	0	0	0	0	8.1451613	35.63	0	3.65	
07:00:00	0	99.026786	140.22258	107.41167	94.519355	40.683333	28.837097	82.740323	171.03833	228.27581	236.05667	19.2	104.00	
08:00:00	152.15	245.40179	338.89194	278.86333	254.08871	211.31333	210.03548	252.75161	373.375	427.63871	416.38	211.62581	281.04	
09:00:00	327.03548	398.85893	539.89032	439.56	416.0129	363.55667	355.48548	416.48548	575.205	619.42097	584.11667	383.3371	451.58	
10:00:00	495.36935	514.05	704.80968	583.6	531.15806	474.39167	493.6	556.33548	722.12167	769.03548	584.11667	566.97419	582.96	
11:00:00	618.46935	601.06071	813.15323	651.575	603.10484	563.29333	585.32742	653.35968	812.485	871.07742	802.76	712.59194	690.69	
12:00:00	725.6629	611.64821	851.58226	677.775	640.84839	577.74667	600.10323	676.91129	818.905	873.95	842.21333	782.91774	723.36	
13:00:00	739.99032	813.72097	628.63833	613.69839	556.82833	591.78065	651.66452	768.09667	802.23871	803.26167	780.77903	811.02581	713.48	
14:00:00	703.5871	562.61607	723.81935	536.90833	511.48226	478.98833	502.63387	571.58226	677.68	685.25	692.93	681.94839	610.79	
15:00:00	632.81935	480.98929	560.17742	415.74333	391.45645	349.31167	383.01129	429.54516	518.81167	514.55806	517.145	551.14839	478.73	
16:00:00	503.76613	251.62857	362.96774	253.72833	219.71452	198.10333	231.45645	264.52903	323.23167	323.86774	332.75167	377.06452	303.57	
17:00:00	350.02258	131.38214	169.20645	100.395	67.248387	60.643333	79.975806	100.68387	124.45667	126.89355	137.16667	377.06452	152.09	
18:00:00	188.78871	31.244643	24.179032	4.7566667	0.2548387	0.1566667	1.4274194	3.7919355	5.9216667	7.0887097	14.263333	186.04032	38.99	
19:00:00	48.740323	0	0	0	0	0	0	0	0	0	0	35.662903		
20:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
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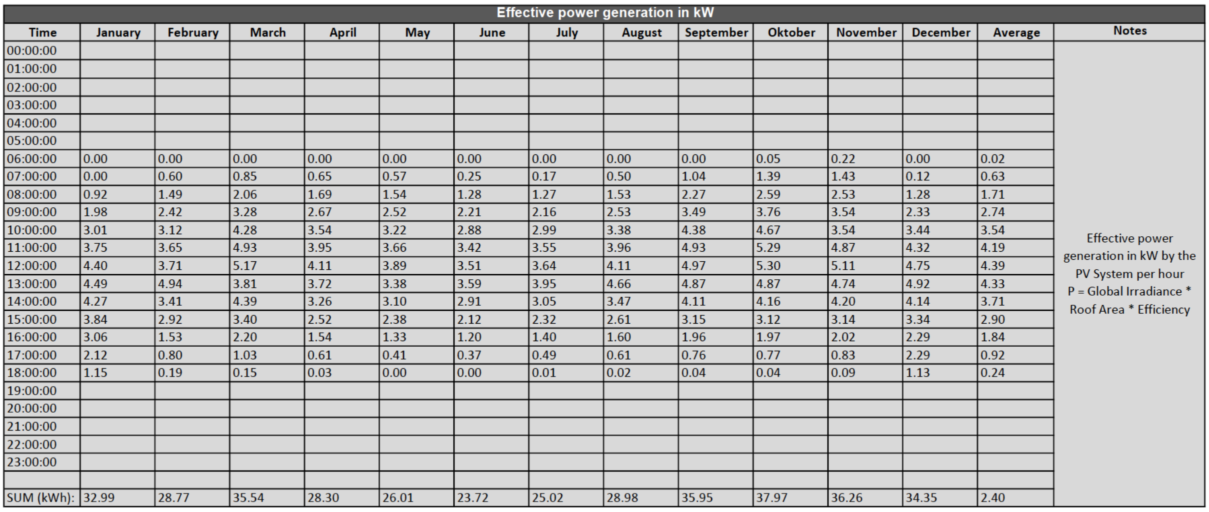
22:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
23:00:00	0	0	0	0	0	0	0	0	0	0	0	0		
	0	0	0	0	0	0	0	0	0	0	0	0		
psh (kWh/m^2/ day):	5.44	4.74	5.86	4.66	4.29	3.91	4.12	4.78	5.93	6.26	5.98	5.66	4.58	

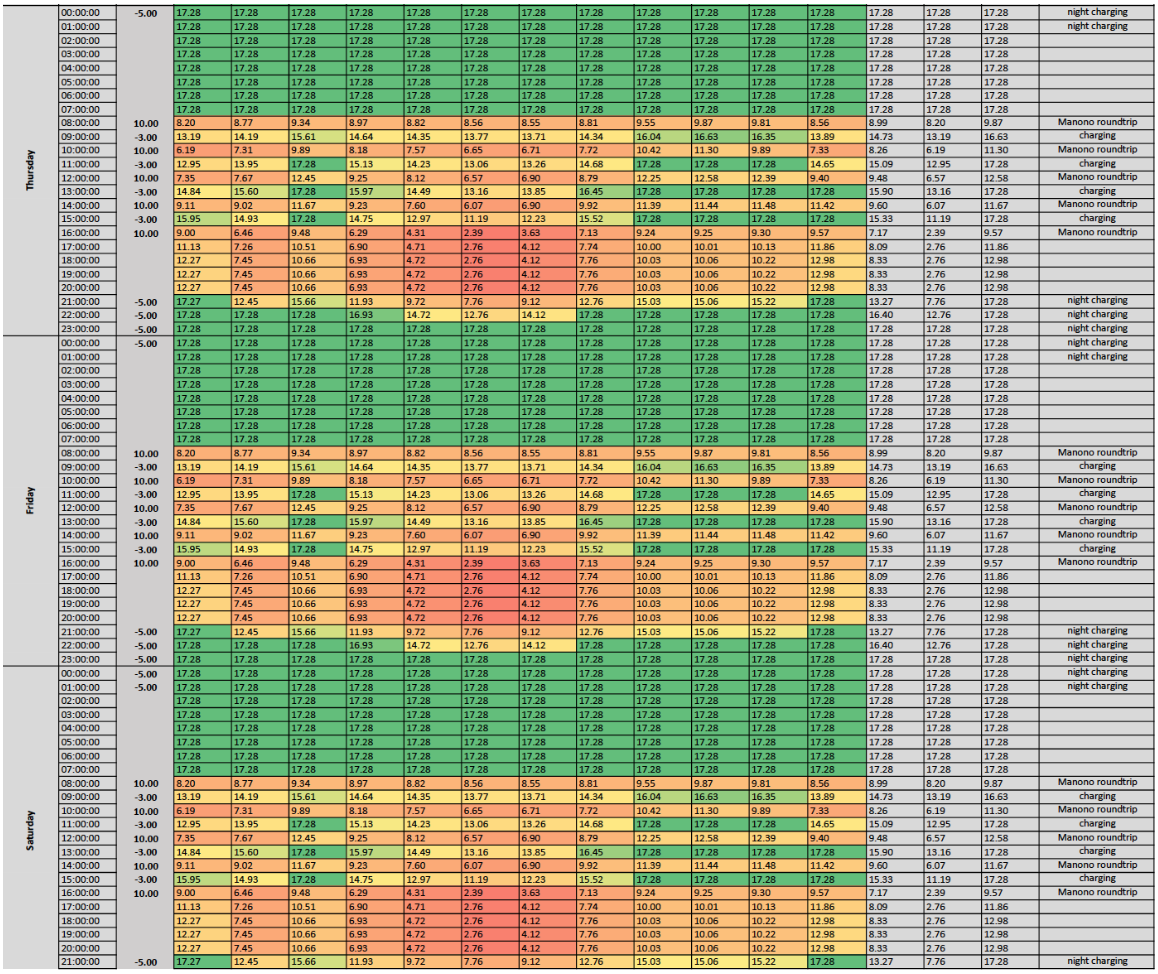


Effective power generation in kW														
Time	January	February	March	April	May	June	July	August	September	Oktober	November	December	Average	Notes
00:00:00														Effective power generation in kW by the PV System per hour P = Global Irradiance * Roof Area * Efficiency
01:00:00														
02:00:00														
03:00:00														
04:00:00														
05:00:00														
06:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22	0.00	0.02	
07:00:00	0.00	0.60	0.85	0.65	0.57	0.25	0.17	0.50	1.04	1.39	1.43	0.12	0.63	
08:00:00	0.92	1.49	2.06	1.69	1.54	1.28	1.27	1.53	2.27	2.59	2.53	1.28	1.71	
09:00:00	1.98	2.42	3.28	2.67	2.52	2.21	2.16	2.53	3.49	3.76	3.54	2.33	2.74	
10:00:00	3.01	3.12	4.28	3.54	3.22	2.88	2.99	3.38	4.38	4.67	3.54	3.44	3.54	
11:00:00	3.75	3.65	4.93	3.95	3.66	3.42	3.55	3.96	4.93	5.29	4.87	4.32	4.19	
12:00:00	4.40	3.71	5.17	4.11	3.89	3.51	3.64	4.11	4.97	5.30	5.11	4.75	4.39	
13:00:00	4.49	4.94	3.81	3.72	3.38	3.59	3.95	4.66	4.87	4.87	4.74	4.92	4.33	
14:00:00	4.27	3.41	4.39	3.26	3.10	2.91	3.05	3.47	4.11	4.16	4.20	4.14	3.71	
15:00:00	3.84	2.92	3.40	2.52	2.38	2.12	2.32	2.61	3.15	3.12	3.14	3.34	2.90	
16:00:00	3.06	1.53	2.20	1.54	1.33	1.20	1.40	1.60	1.96	1.97	2.02	2.29	1.84	
17:00:00	2.12	0.80	1.03	0.61	0.41	0.37	0.49	0.61	0.76	0.77	0.83	2.29	0.92	
18:00:00	1.15	0.19	0.15	0.03	0.00	0.00	0.01	0.02	0.04	0.04	0.09	1.13	0.24	
19:00:00														
20:00:00														
21:00:00														
22:00:00														
23:00:00														
SUM (kWh):	32.99	28.77	35.54	28.30	26.01	23.72	25.02	28.98	35.95	37.97	36.26	34.35	2.40	

	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Tuesday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Wednesday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging

Battery Charge in kWh

Date	Time	Power in kW	January	February	March	April	May	June	July	August	September	Oktober	November	December	Average	Minimum	Maximum	Notes
Saturday	00:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	01:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	02:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	03:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	04:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	05:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	06:00:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22	0.00	0.02	0.00	0.22	
	07:00:00		0.00	0.60	0.85	0.65	0.57	0.25	0.17	0.50	1.04	1.43	1.65	0.12	0.65	0.00	1.65	
	08:00:00		0.92	2.09	2.91	2.34	2.12	1.53	1.45	2.04	3.30	4.03	4.17	1.40	2.36	0.92	4.17	
	09:00:00		2.91	4.51	6.18	5.01	4.64	3.73	3.61	4.56	6.79	7.79	7.72	3.73	5.10	2.91	7.79	
	10:00:00		5.91	7.63	10.46	8.55	7.86	6.61	6.60	7.94	11.17	12.45	11.26	7.17	8.64	5.91	12.45	
	11:00:00		9.67	11.28	15.39	12.50	11.52	10.03	10.15	11.90	16.10	17.28	16.13	11.49	12.79	9.67	17.28	
	12:00:00		14.07	14.99	17.28	16.62	15.41	13.54	13.79	16.01	17.28	17.28	17.28	16.24	15.82	13.54	17.28	
	13:00:00		17.28	17.28	17.28	17.28	17.28	17.13	17.28	17.28	17.28	17.28	17.28	17.28	17.27	17.13	17.28	
	14:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	15:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	16:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	17:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	18:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	19:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	20:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	21:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	22:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	23:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
Sunday	00:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Monday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip



Thursday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Friday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
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	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
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	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Saturday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
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	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
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	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
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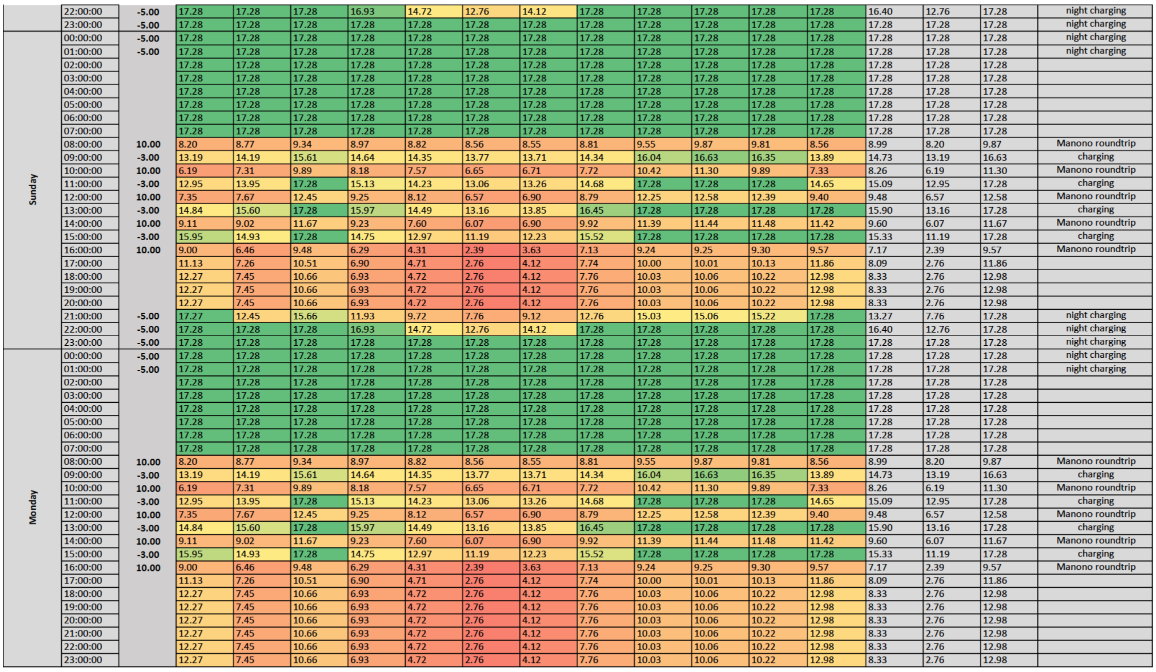
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging



	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Sunday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
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	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00	-5.00	17.27	12.45	15.66	11.93	9.72	7.76	9.12	12.76	15.03	15.06	15.22	17.28	13.27	7.76	17.28	night charging
	22:00:00	-5.00	17.28	17.28	17.28	16.93	14.72	12.76	14.12	17.28	17.28	17.28	17.28	17.28	16.40	12.76	17.28	night charging
	23:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
Monday	00:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	01:00:00	-5.00	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	night charging
	02:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	03:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	04:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	05:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	06:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	07:00:00		17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	17.28	
	08:00:00	10.00	8.20	8.77	9.34	8.97	8.82	8.56	8.55	8.81	9.55	9.87	9.81	8.56	8.99	8.20	9.87	Manono roundtrip
	09:00:00	-3.00	13.19	14.19	15.61	14.64	14.35	13.77	13.71	14.34	16.04	16.63	16.35	13.89	14.73	13.19	16.63	charging
	10:00:00	10.00	6.19	7.31	9.89	8.18	7.57	6.65	6.71	7.72	10.42	11.30	9.89	7.33	8.26	6.19	11.30	Manono roundtrip
	11:00:00	-3.00	12.95	13.95	17.28	15.13	14.23	13.06	13.26	14.68	17.28	17.28	17.28	14.65	15.09	12.95	17.28	charging
	12:00:00	10.00	7.35	7.67	12.45	9.25	8.12	6.57	6.90	8.79	12.25	12.58	12.39	9.40	9.48	6.57	12.58	Manono roundtrip
	13:00:00	-3.00	14.84	15.60	17.28	15.97	14.49	13.16	13.85	16.45	17.28	17.28	17.28	17.28	15.90	13.16	17.28	charging
	14:00:00	10.00	9.11	9.02	11.67	9.23	7.60	6.07	6.90	9.92	11.39	11.44	11.48	11.42	9.60	6.07	11.67	Manono roundtrip
	15:00:00	-3.00	15.95	14.93	17.28	14.75	12.97	11.19	12.23	15.52	17.28	17.28	17.28	17.28	15.33	11.19	17.28	charging
	16:00:00	10.00	9.00	6.46	9.48	6.29	4.31	2.39	3.63	7.13	9.24	9.25	9.30	9.57	7.17	2.39	9.57	Manono roundtrip
	17:00:00		11.13	7.26	10.51	6.90	4.71	2.76	4.12	7.74	10.00	10.01	10.13	11.86	8.09	2.76	11.86	
	18:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	19:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	20:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	21:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	22:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	
	23:00:00		12.27	7.45	10.66	6.93	4.72	2.76	4.12	7.76	10.03	10.06	10.22	12.98	8.33	2.76	12.98	

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