Technical Background Paper:

Options for Integrated Electric Mobility and Renewable Power Markets in the Pacific Island Countries and Territories (PICT)

Prepared as follow-up to the decisions of the Fourth Pacific Regional Energy and Transport Ministers' Meeting, held from 18 to 20 September 2019, in Apia, Samoa

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PCREEE Pacific Centre for Renewable Energy and Energy Efficiency

Pacific Community Communauté du Pacifique

UNIDO UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

GN-SEC Global Network Regional Sustainable Energy Centres

Consulting Team:

Andrew Campbell (Fuel Technology Limited, Team Lead and Lead Author)
Elizabeth Yeaman (Retyna Limited), Simon Troman (Atratus Pty Ltd) and John McCrystal.

PCREEE Project Team:
Solomone Fifita, Jesse Benjaman
PCREEE Secretariat, Nuku'alofa, Kingdom of Tonga

UNIDO Project Team:
Martin Lugmayr, Weijun Shen,
Climate Policy and Partnerships Division,
Vienna International Centre (VIC)

With financial support of:

NORWEGIAN MINISTRY OF FOREIGN AFFAIRS

AUSTRIAN DEVELOPMENT COOPERATION

Contact:
Please do not hesitate to contact the project team:
E-Mail: emobility@pcreee.org or emobility@gn-sec.net

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Abbreviations and Acronyms

A*x*	Policy Activity *x*
BAU	Business as Usual
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
e-	Electric (e.g., e-bus)
EV	Electric vehicle
FAESP	Framework for Action on Energy Security in the Pacific
FATS	Framework for Action on Transport Services
FRDP	Framework for Resilient Development in the Pacific
GGGI	Global Green Growth Institute
GHG	Greenhouse gas or greenhouse gases
ICE	Internal Combustion Engine vehicles
kW	Kilowatt
kWh	Kilowatt-hour
NDC	Nationally Determined Contribution
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PICT	Pacific Island Countries and Territories
PV	Photovoltaic
RE	Renewable Energy
RMI	Republic of the Marshal Islands
SOC	State of charge (with reference to batteries)
SPC	Pacific Community
TOR	Terms of Reference
TOU	Time of use (metering)
UNIDO	United Nation Industrial Development Organization
UNDP	United Nations Development Programme
V2H	Vehicle-to-home
V2G	Vehicle-to-grid

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1. Introduction

1.1. Extending Climate Leadership

The Fourth Pacific Regional Energy and Transport Ministers' Meeting, held from 18 to 20 September 2019, in Apia, Samoa, requested the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE)[1] and the United Nations Industrial Development Organization (UNIDO) to assist Pacific Island Countries and Territories (PICTs) in the development of a regional electric mobility (e-mobility) policy and program.

Since e-mobility markets in most PICT are at infant stages and all face similar deployment barriers, a harmonized regional approach has the potential to enable efficient and equal progress through joint learning and testing. The regional policy will outline the short-term and long-term vision of PICTs with regard to integrated e-mobility and renewable power markets. It will propose regional e-mobility targets for 2030 and 2050, and include a regional implementation and monitoring framework.

The e-mobility efforts contribute to the 100% renewable energy vision of the region, extending this PICT "climate leadership" to the transport sector, and developed e-mobility policy aims to integrate with important regional policies already in place, such as the 2020-2030 Framework for Action on Energy Security in the Pacific (FAESP), the Framework of Action on Transport Services (FATS) and Framework for Resilient Development in the Pacific (FRDP).

The proposed e-mobility program aims to connect to global EV initiatives, including those operating under the Paris Declaration on Electro-Mobility and Climate Change (e.g. Clean Energy Ministerial, UNEP/IEA EV programs). SIDS-SIDS cooperation and joint learning on EV related island issues will also be promoted by UNIDO and PCREEE through the the Global Network of Regional Sustainable Energy Centres (GN-SEC[2]) some members of whom are also working on similar initiatives.[3]

1.2. Purpose and Added Value of the Report

This technical report was developed to inform PICT decision-makers on the technical options for integrated e-mobility and renewable power markets, and aimed at providing a "realistic view" on opportunities and barriers, as well as potential risks and benefits.

Advances in electric vehicle (EV) technology have seen all forms of electric vehicles become noticeable in the transport systems of many countries, ranging from electric push-scooters to electric buses and trucks. The EV sector has seen large changes over the last 10 years and more are expected to happen, and quickly, such is the rapid pace at which the related technologies are developing.

Advanced EV countries (e.g. China, Norway, US, individual EU countries) have introduced targets, enabling policies, monetary and non-monetary incentives to promote the market introduction of EVs and the expansion of charging infrastructure (e.g. tax and duty reductions/increases, public procurement, stricter environmental standards, permit the use of carpool or bus lanes, public charging or concessional finance for charging infrastructure).

In 2017, the global stock of electric cars surpassed 3 million vehicles. Around 40% of the global electric car fleet is in China, while the European Union and the United States each accounted for about a quarter of the global total. Electric cars accounted for 39% of new car sales in Norway in 2017. Electrification of other transport modes is also developing quickly, especially for 2-wheelers and buses. In 2017, sales of electric buses were about 100.000 and sales of two-wheelers were estimated at 30 million (both mostly in China).

This growth in e-mobility uptake is expected to accelerate, brought about by decreasing EV costs (primarily due to decreasing lithium battery prices – experts expect the standard electric car to reach cost parity within the next few years in Europe and China, and some project that by 2040, 35% of new car sales globally and 25% of the world's car fleet will be electric cars).

[1] www.pcreee.org
[2] www.gn-sec.net
[3] For example, the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) is working on the Caribbean Community (CARICOM) Electric Vehicle Strategy Framework.

E-mobility offers an opportunity to decrease fossil fuel imports and spending (contributing to energy security), to enhance transport affordability (due to lower operating costs and also lower capital costs, when this point is reached), to provide people with more mobility, with beneficial social and other effects, to localize parts of the transport value chain, and to reduce air, noise and GHG emissions. And on the latter, the use of EVs can reduce net greenhouse emissions even when the vehicles are charged from grids that are mostly supplied by petroleum-derived generation (which in turn will help meet Nationally Determined Contributions). And far from being an extra burden upon electricity supply arrangements, EV batteries may even be used to compliment the supply of electricity, particularly where generation is intermittent (as is the case for wind and solar).

Theoretically, e-mobility can represent a paradigm shift if the technical characteristics and regulatory frameworks of the transport and power sectors are smartly integrated. This requires strong cooperation between and capacities of the key stakeholders in the power and transport sectors. Combined with the latest digital innovations (e.g. internet of things devices) and the shift of vehicle ownership to shared modalities, e-mobility concepts open up opportunities for new business models, such as vehicle-to-grid (V2G) and grid-to-vehicle (G2V) services.

As mentioned in the leading paragraph to this section, this technical report looks to provide a realistic view of what this potential might mean for PICTs.

1.3. How to Use This Report

The main body provides short introductions to electric vehicles (EVs) and their related technologies including how they are charged, and how the batteries of in-service EVs might be used to support the supply of electricity in different scenarios. This main body is concluded with consideration of which EV-electricity supply combination might best suit the types of electricity supply scenarios found in PICTs. This is divided thus:

- Section 2 provides technical background on electric mobility technologies;
- Section 3 provides technical background on electric vehicles and energy (electricity) grids;
- Section 4 provides context for electric vehicles and electricity supply systems in PICTs, then, in light of these, seeks to consider various EV-and-electricity supply combinations where benefit might be realised through their combination;
- Section 5 assesses the fit and potential value of the identified EV-electricity supply combinations; and
- Section 6 sets out the conclusions to this work.

In order to make this report as readable as possible, much of the technical detail has been relegated to the appendices: directions in the main text will point the interested reader to the relevant Appendix. This detail has been divided into the following:

- Appendix A provides a more detailed technical backgrounder on mainstream electric vehicles;
- Appendix B considers charging of EVs in more detail;
- Appendix C provides detail on other EV types;
- Appendix D provides a comparison of the emissions performance and various payback periods for EVs compared with their petroleum counterparts;
- Appendix E provides a backgrounder on the EV market in PICTs;
- Appendix F provides a backgrounder on the electricity supply markets in PICTs; and
- Appendix G provides PICT profiles through the provision of various PICT statistics.

2. Electric Mobility Technologies

2.1. Introduction

While electric modes of transport have been around for well over a century, and some (notably trains) have been in mainstream use for a good proportion of that time, the last decade has seen considerable change: new technology provided the market with batteries that were lighter, could hold more energy in a given space, and were far cheaper. This changed the electric vehicle (EV) scene from one comprising research and the use of EVs by an exclusive club, to one where the use of light passenger car EVs are normal in many countries today. Meanwhile, other technological developments have seen electric buses enter service in many cities in China, and new forms of e-mobility, such as "push e-scooters" and e-bikes, emerging at a commercial level. These also stand to become reasonably significant features in future global mobility.

2.2. Types of Electric Vehicles

The focus of this report is on those types of electric vehicle that are propelled by an electric motor that draws current from a battery that can be recharged from an energy source that is off the vehicle. The two most common forms of such "plug-in" EVs are **battery electric vehicles** (BEVs, which comprise a battery, an electric motor, and power electronics to make these operate) and **plug-in hybrid electric vehicles** (PHEVs, which in addition to the same motor and battery system on a BEV, have an on-board petroleum-fuelled engine that can be used as well as, or instead of, the electric motor and battery to provide additional power and/or additional range).

There are also so-called "hybrid" vehicles (sometime also referred to as **hybrid electric vehicles**, or HEVs) which also use an electric motor and battery plus a petroleum-fuelled engine, but they do not have the capability to charge their batteries from an external source. Instead, their batteries are largely charged using energy captured by "regenerative braking", which is then used to propel the vehicle, with the effect that the fuel economy of a HEV can be over 30% better than comparable non-hybrid vehicles. However, while HEVs are playing their part in reducing greenhouse gases and are referred to as a point of comparison in one section of this report, they are best regarded as simply more efficient conventionally fuelled vehicles. For the most part, this report focuses on "true" electric vehicles, i.e. those vehicles that can be plugged in – BEVs and PHEVs.

The first mainstream production BEV was the Nissan Leaf, first released in 2010[4] with a useful range of around 110 km on one charge. Whilst this might be an admirable range in an island situation and covers general commuting in most other parts of the globe, reasonable attention still needs to be paid to when and where charging is carried out. The term "range anxiety" came about to describe the fear that drivers of early model electric vehicles experienced when they were unsure if they would reach their destination or a charging point on the remaining charge of their battery. Driven by market demand and enabled by newer technology — most notably cheaper, more energy-dense batteries — mainstream BEV models (including the latest generation of Nissan Leafs) now have a range of 300 km or more. The greater useful range and the positive experience of anyone who has sat behind the wheel of an electric vehicles has gone a long way to mainstreaming these types of vehicle around the world (despite the cost premium of EVs over their petroleum-fuelled counterparts: this still presents a significant barrier in some markets, which is discussed below).

PHEVs were developed in recognition of the fact that for the main part, the majority of private vehicle owners drive their vehicles a short distance, yet have the occasional need to make longer range journeys. PHEVs tend to have a smaller battery capacity —commonly with an all-electric range of only 40-50km — but supplemented with a petroleum-fuelled engine that can take the vehicle significantly further (whether by propelling the car as a conventional, petroleum-fuelled vehicle, or by generating electricity to boost the electric range).

Electric vehicles (EVs, referring here to both BEVs and PHEVs) come in all shapes and sizes besides passenger cars, including buses, trucks, boats, motorised 2- and 3- wheelers,[5] and, as has been mentioned, e-bikes and e-scooters. Whereas the larger vehicles and vessels tend to

[4] There were other models released in small numbers before this, but it cannot be said that they ran into mainstream production.

[5] Here a 2-wheeler refers to a motorbike or motor-scooter-sized bike, and a 3-wheeler refers to a powered tricycle, referred to as an e-trike in some countries, for the electric version, some of which are designed to carry six or more passengers. For this report, an "e-bike" refers to an electrically-assisted bicycle that can also be pedalled. An e-bike is not a type of electric 2-wheeler, for this report.

be based on the use of high-voltage electrical systems, some of the latter are “low-voltage” mobility options that have seen very rapid growth globally over the last year.

Further detail regarding electric vehicle types and their operation is provided in Appendix A.

2.3. Ride Hailing and Mobility Sharing

Whilst not strictly an electric vehicle technology, the rise of the use of the mobile phone has unlocked many new mobility options, including ride-hailing (where a phone-based application conveniently introduces vehicle operators and customers wishing to travel, then manages the customer’s chosen trip), and car, e-scooter and bike sharing (where people wishing to self-drive a vehicle can gain access to a range of vehicles for short-term use via a phone-based application). For the user, these provide alternatives to personal vehicle ownership that can boost the utilisation of the vehicles (it is often said that private vehicles spend less than 1% of their time operating). This is an advantage in the case of larger-sized EVs, for which high utilisation is normally required in order to offset the high purchase cost premium. For smaller-sized vehicles, it is their simplicity and good service expectations that make them attractive for these applications.

3. Electric Vehicles and Energy Grids

3.1. Electric Vehicle Charging

The rate at which an EV can be charged depends on the weakest/slowest component anywhere in the chain between the supply of electricity to the premises through to the ability of the vehicle’s battery to accept charge. In most parts of the world — and the PICTs are no exception — electricity supply arrangements were designed before the demands of electric vehicle charging were envisaged (and this has required chargers to be relatively limited in their charging rate when using existing domestic circuits[6]).

In most common applications, the propulsion battery of an EV is electrically a Direct Current (DC) device that requires to be charged with DC current. Mains electricity is normally Alternating Current (AC), and thus an AC-to-DC converter is required to charge an electric vehicle from mains electricity. Most EVs have an on-board AC-to-DC charger, and connection to the mains is by so-called Electric Vehicle Supply Equipment (EVSE), the purpose of which is to regulate the supply of AC electricity to suit the limitations both of the mains supply and the on-board charger. For passenger car EVs, “slow” charge rates can range from 1.7kW (about that for a powerful electric kettle) in the case of a portable EVSE device intended to be plugged into a conventional domestic power outlet, through to 3.3kW, 6.6kW or even higher for EVSE devices that are hard-wired into the switchboard and supported by appropriate supply circuits.

Note that the rate at which a charger can deliver electricity during charging is normally specified in terms of kilowatts (kW). Charging at a rate of 1.7kW (using the example of a portable charger above) for 1 hour results in the transfer of 1.7kW x 1h = 1.7kWh of energy. The first model Leaf had a battery capacity of 24kWh which if fully depleted would take 24kWh/1.7kW = 14 hours of charging. However, it is neither normal nor good practice to discharge these batteries below around a 20% State of Charge (SOC), so in practice a “full charge” would take less time. Further, it is normal in a home-charging situation to keep topping up the battery, when a vehicle is used on a regular basis, which also means that individual periods of charging are kept lower.

Some older model and most newer model electric vehicles also have a charging connector that enables direct DC charging. This avoids the weight and size restrictions on the AC-to-DC convertor by siting this component offboard. Until recently, DC charging at 50kW has been the common charging rate for such “fast” charging[7]. At present, you will only see these in

6 And most early model EVs also had low charge rates for AC mains electricity charging, in line with this.

7 Note that peak kW is used when specifying the charging rate of EVSE, but in order to avoid faster degradation of the batteries, the charging rate is normally controlled so that it reduces as the battery nears full charge. For fast charging our first model Nissan Leaf example fitted with a 24kWh battery, charging from a low state of charge (i.e., 20% SOC, as it is not normal to discharge below this) to a high state of charge (i.e., 80% SOC, by which point the rate of charging becomes reasonably depressed), at 50kW, requires the transfer of (80%-20%)x24kWh = 14.4kWh

commercial setups as they are comparatively very expensive and the draw is far beyond the current that domestic (and many light commercial) electricity supply circuits can support. Vehicle battery sizes and technology now support faster charging still and some countries are already installing "ultra-rapid" 350kW charging. In the case of heavy vehicles, charging may be at even faster rates than this.

Meanwhile, at the other end of the scale, low-voltage e-mobility options (such as e-bikes and e-scooters) tend to be charged at relatively low rates (drawing as little as 2A from a supply of 230V AC – a fraction of the draw from an electric kettle (for comparison, a normal domestic socket outlet is rated at 10A, five times this)). This means that their demands can easily be met in the kinds of low-current electrical supply arrangements common in remote areas, or where generation is small-scale (e.g., where small gensets or small-scale renewable energy generators such as wind or solar photovoltaic cells are used. Solar generation also produces a DC current and can be very easily used to charge low-voltage battery systems).

Further information on charging electric vehicles is provided in Appendix B.

3.2. Managing Electric Vehicle Charging

Providing electricity supply infrastructure is expensive and electricity suppliers are often balancing the provision of peak capacity with the cost to do so. Erring on the side of careful financial management, the electricity supply infrastructure can be stressed at times of peak load, and the looming prospect of new demand on top of this from charging a new fleet of EVs poses a significant concern to those tasked with supplying electricity. Where "smart" meters or "Time of Use" metering is available (where the electricity supplier can recognise the times when electricity is consumed, as well as how much), electricity retailers can offer advantageous prices for charging at times that suit the electricity generation/supply profile. This encourages migration of some demand away from the peaks that are difficult to provide for. This is a good match with the charging management tools that are now available on most modern passenger car EVs and some EVSE – timers can be set that allow the operator to choose when charging begins. Similarly, technology is emerging whereby a third party (such as an electricity supplier) will be able to actively schedule or otherwise manage charging events (as in "managed charging") and perhaps even draw electricity from connected vehicles (as in "vehicle-to-grid", sometimes referred to as V2G, which allows electricity to flow in both directions): not only will some of these tools protect electricity supply security, but they also have the potential to yield significant benefits to the management of electricity generation, including the integration of energy from renewable sources and reducing reliance upon more carbon-intensive modes of generation.

More information about the management of electric vehicle charging is provided in Appendix F.7

3.3. Exporting Electricity from an Electric Vehicle

The propulsion battery in electric vehicles is, in practical terms, very similar to the battery types that are increasingly being used to store electricity generated from renewable energy sources: indeed, when an EV battery's capacity has been depleted beyond the point at which it can offer useful range, it will commonly be re-purposed as an electricity supply storage battery and enjoy a "second life" in this role[8].

The batteries on some in-service passenger car EVs can also be used in a similar way. The fast charging port not only permits supply to the vehicle battery, but it can also be used to draw from it, and devices exists that can be used to power up an isolated, local electricity supply circuit that can run, for example, a power-tool. Globally, such devices are available from several third-party (that is, not supported or approved by EV manufacturers) suppliers. Some EV manufacturers also offer early market versions under controlled release. (Note that this is quite different to the mains power socket available in the back of some Japanese "domestic-

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of electrical energy, which will take 14.4kWh/50kW = 0.29 hours, which is about 20 minutes – the source of one of the global EV industry's early slogans of fast charging an EV in only 20 minutes.

8 But also noting that an EV battery tends to have high performance compared to batteries purpose-built for stationary energy storage, and EV-type batteries are normally more expensive for this reason.

market" specification electric vehicles. These sockets are powered from the electric vehicle's 12V lead-acid auxiliary battery, and can provide only very limited power compared with the propulsion battery).

So-called Vehicle-to-Home (V2H) devices, which operate in much the same way, are also now available to the market from third-party suppliers. In a V2H configuration, the vehicle is connected via the fast charger port either to a circuit that is completely isolated from the grid, or to a domestic (or similar) switchboard. Note that where the switchboard in question is connected to a grid, the V2H device will supply power alongside or instead of the grid, but it won't allow power to be exported to the grid. Several vehicle manufacturers are also working in this area and manufacturer-supported V2H devices are expected to become available by the end of 2020. Both types of device thus appear to be on the cusp of moving from market-demonstration level to commercial availability.

In what could arguably be considered the ultimate in the integration of electric vehicles with the electricity supply system, it is envisaged that electric vehicle batteries could be used to absorb and store electricity from the grid when supply exceeds demand, and then feed it back again when demand rises to exceed supply. This would make the most of what generation and demand was available at any given time. The technical difficulties in accomplishing such Vehicle-to-Grid (V2G) capability are significant, and the technology is at an early stage of development. It is not expected to feature outside small-scale demonstrations for many years.

At the low-voltage end of the scale, many e-bike battery packs are already fitted with power output plugs, including a standard 5V USB port. A small number of e-bike manufacturers have also adopted a standard battery format, allowing the use of conforming third-party batteries and battery swapping. In Japan, for example, there are two main 24V battery and connector configurations in use for e-bikes. In other countries, there appear to be many different voltages and battery pack configurations making battery swapping far less practical (which is a similar situation for power hand-tools, where a battery pack from one make cannot be coupled with a toll of another make).

Aiming at the 2-wheeler market, Gogoro of Taiwan have established a battery swapping business based on their proprietary 48V battery. It appears that Yamaha and others have adopted this battery for at least some of their electric 2-wheelers,[9] although reportedly Honda, Yamaha, Kawasaki and Suzuki are collaborating to develop a common swappable battery for other markets[10] and, on the back of this, Honda has launched a prototype battery and electric 2-wheeler scooter.[11] Two-wheelers far outnumber any other vehicle type in some countries and are considered "the people's car"; given cost-parity with some petroleum-fuelled 2-wheelers has already been achieved and that some governments and aid agencies are providing incentives to move to cleaner mobility options, this market is expected to develop very quickly over the next few years. As batteries are far and away the most expensive component in any electric vehicle, the setup of battery swapping stations could play a vital role in the expansion of the 2-wheeler market. Where users rent rather than own a battery (and charging and "specialist" battery-related services are provided by a relatively few, knowledgeable providers), the cost of electric 2-wheeler transport options can be significantly more affordable to users.[12]

Using such batteries to meet the demand of low energy-intensive dwellings seems a logical extension. This is already a model that is used in some remote locations in the PICTs, although mostly based on lead-acid batteries. Should such systems become popular using modern batteries, there is the risk that problems may arise from inappropriate disposal. It is to be hoped that the relatively high value that even depleted batteries retain will mitigate this risk.

Further detail on exporting electricity from an electric vehicle is provided in Appendix F.7

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[9] https://techcrunch.com/2019/08/06/gogoro-announces-yamaha-aeon-and-pgo-are-the-first-manufacturers-that-will-use-its-swappable-batteries-in-their-own-scooters/
[10] https://electrek.co/2019/04/03/honda-yamaha-kawasaki-electric-motorcycles/
[11] https://www.rideapart.com/articles/378084/honda-swappable-battery-scooter-tech/
[12] But noting that this affordability is dependent upon investment made by a third party that then provides access to the batteries. Such business models are only now starting to become financially acceptable, mainly due to recent significant cost reductions in the batteries.

3.4. EV Batteries and Renewable Energy Generation

Replacing petroleum-fuelled vehicles with EVs stands to bring about a significant reduction in GHG emissions, simply through the higher efficiency of electric propulsion technology compared to petrol or diesel engines (electric motors can be more than 90% energy efficient, compared with combustion engines, which range from 10% to 30% energy efficient in typical automotive use). Similarly, operating at 40% efficiency and above, the engines used to generate electricity from diesel are more efficient than vehicular diesel motors, so the effect of transferring the load from a diesel-powered vehicle fleet to an electric fleet drawing power from diesel-generated supply is to increase overall energy efficiency, even when electricity line losses and inefficiencies of battery charging are taken into consideration. Modelling of this, provided in Appendix D, indicates a small net reduction in GHG emissions for the operation of an electric bus charged from diesel-generated electricity compared with the operation of a diesel bus, and moderate reductions in GHG emissions where an EV is replacing a gasoline-fuelled vehicle. Naturally, the reduction in GHG emissions becomes greater as the proportion of renewables in the electricity mix increases.

But the uptake of electric vehicles can also be seen as the deployment and distribution of (mobile) storage batteries that might be used to overcome one of the limitations of electricity generation from renewables such as solar or wind: namely, the tendency for many of the renewables to be intermittent. Wind generators will only produce electricity when the wind blows. The performance of solar photovoltaic (PV) cells falls away on cloudy days, and solar PV does not produce power at all at night. Demand cannot be switched off and on to suit any one method to match the fickle output of renewable generation: this limitation is traditionally overcome by storing electricity when production is high and drawing upon this store when generation ceases or falls away. The type of Vehicle-to-Home (V2H) connections discussed above can provide for this, and supply local electricity supply circuits: this technology is already available. A further — perhaps the ultimate — advance is where the battery could be used to export electricity to the grid electricity supply networks. However, the technology involved is sufficiently far off that it is not expected to feature in PICT power supply for many years.

At the same time, the charging requirements of the kinds of low-voltage batteries used in new e-mobility modes are relatively easily met through the simple regulation of voltage provided by small solar PV generation systems. Such batteries could therefore be used to provide power to homes with low power requirements — a low-voltage, solar e-mobility and "e-home" combination — an arrangement that would appear to be a good match with remote island scenarios, especially considering such simple systems are also more likely to survive, or at least be more easily reinstated after, extreme weather events or disasters (noting also that many modern appliances such as lights, home entertainment and communication systems actually use low-voltage DC[13], which might mean the need for high voltage AC circuits is altogether eliminated in remote locations: live-aboard yachts have been operating in this manner for decades).

It so happens that the price of solar PV and the associated control electronics has fallen steeply in the last five years, which is why this technology has lately flourished. Its integration with low-voltage e-mobility has yet to develop.

4. Electricity and Electric Vehicles in PICTs

The 14 countries and territories designated as PICTs are highly diverse in ways that are relevant to considering how EVs may feature in their respective futures. There are large differences in:

- **Urbanisation** (ranging from below 20% of the population living in urban environments for PNG and Samoa, to above 90% of the population living in urban environments for American Samoa, Guam and Northern Mariana Islands).

[13] Through use of an internal AC-to-DC power converter.

- **Relative wealth** (which bears upon the affordability of new technology). Relative wealth is indicated by the GDP per capita, which ranges from just over US$1500 for Kiribati to above $30,000 for Guam and Nouvelle-Calédonie).
- **Roading infrastructure**, including:
    - The length of paved and unpaved roads (ranging from Tuvalu at less than 0.1 kilometre of road per square kilometre of land to the Marshall Islands with over 11 kilometres of formed roads per square kilometre);[14]
    - And the level of roading (from high-quality roading to single-path tracks).
- **Vehicle fleet**-related factors, including:
    - Vehicle source (which can be determined by such factors as which side of the road people drive on, which in turn determines where appropriately configured vehicles may be sourced);
    - Vehicle type makeup (including that related to ease of access to cheaper, used vehicles);
    - Vehicle ownership rates (related both to per capita GDP and access to cheaper vehicles – statistics suggest that vehicle ownership rates range from around 10 vehicles per 1000 people in PNG to more than 600 vehicles per 1000 people for Guam and the Cook Islands, although this data could be unreliable);
    - Vehicle annual distances travelled (estimations from fuel consumption and vehicle registration data indicate that vehicle distances travelled range from 15,000 km per year for gasoline cars in the Marshall Islands to 1,000-2,000 km per year in the Solomon Islands);
    - Rates of private vs public ownership; and
    - Dependency on public transport (with very high dependency on public transport provided by buses in PNG).
- **The electricity market**, including:
    - Per capita consumption (ranging from less than 200 kWh per capita per year for the Solomon Islands to more than 10,000 kWh per capita per year for Nouvelle-Calédonie — no less than a 50-fold difference);
    - Access to electricity (ranging from less than 60% with access to electricity in PNG to over 99% with access to electricity for the majority of PICTs, although with mixed dependability of continuous supply and variable quality of electricity within this);
    - Electricity generation mix (which can comprise different proportions of diesel, dammed and run-of-river hydro, wind and solar PV);
    - Proportion of renewable energy (RE) in that electricity mix (for grid electricity ranging from less than 1% for some PICTs to over 50% for Fiji, and with the proportion of RE increasing rapidly for many PICTs);
    - The makeup of the diesel electricity generation fleet (ranging from near-continuous operation of >2 MW engines through to occasional use of small diesel (and gasoline) gensets).
- **The fuel market**, including:
    - Supply ranging from direct tanker supply from international refineries to major PICT ports to transport of “tank-tainers”, drums and even smaller containers to lesser ports and more remote locations;
    - Fuel quality and fuel quality-related practices, from those set by international markets to unsuitable field practices that result in poor fuel quality at the point of use (resulting in unreliable equipment operation and added operational costs).
- **Access to main island markets**:
    - Some remote islands have very limited access to inter-island transport services, let alone access to skilled labour.

[14] See background statistics, in Appendix G.

Such diversity not only makes it difficult to generalise across PICT contexts, but also near-impossible to prescribe a one-size-fits-all EV solution. As a result, some technologies show greater promise in the PICT context than others.

4.1. PICT Electricity Markets – a Backgrounder

On some remote islands, or in isolated reaches of larger territories, electricity demand is basic and has traditionally been supplied by small, petroleum-fuelled generators. The majority of electricity users in PICTs, however, have access to grid-supplied electricity and with this they have access to modern conveniences such as refrigerators, entertainment systems and air conditioning. The demands from these and other devices powered by grid electricity tend to produce a relatively repetitive demand profile. An example is provided in Figure 1 below to illustrate this, which is for Upolu (Samoa). This indicates a consistently high demand during office hours (8:00 am to 5:00 pm, weekdays, likely the product of business day activities and business air conditioning load), and an evening peak in demand from household activity.[15]

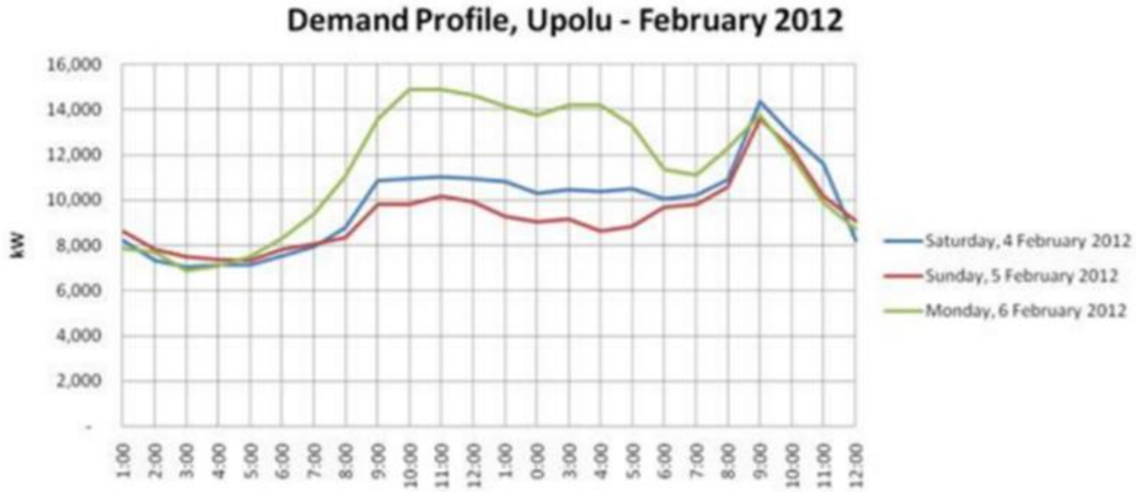

Figure 1: Upolu Electricity Demand Profile (from IRENA 2013[16]).

Factors that bear upon how the electricity supplier can cater to this demand include the electricity generation mix (i.e., the proportion generated from diesel-, hydro-, solar PV-, etc.) that is at their disposal and when; the cost to operate and maintain the various generation assets; their reliability; the supplier's ability to regulate electricity supply to the required quality; what storage is available (in the case of hydro, for example) and what stresses there are on the distribution systems (and in particular, for example, due time of peak demand). The electricity supplier, along with other service providers in this supply chain, balance these often-conflicting parameters as best they can to provide target electricity quality and reliability at least cost.

Further information on demand profiles and meeting them is provided in Appendix F.

4.2. PICTs and Renewable Energy

An obvious way in which PICTs might decarbonise (in order to meet their Nationally Determined Contributions Targets) is to increase their use of renewable energy (RE). The RE options already in use in PICTs include dammed and run-of-river hydro, solar thermal (e.g., for domestic hot water), solar photovoltaics (PV), wind and biodiesel (the use of raw coconut oil is included in this definition of biodiesel). For those islands and territories that have the necessary resources, hydro (apart from in dry years) and biodiesel provide dispatchable

[15] Noting that the demand here is provided in kilowatts (kW) which is also a common unit to use when considering the charging rate of EV chargers.

[16] International Renewable Energy Agency, 2013b. Pacific Lighthouses Renewable Energy Opportunities and Challenges in the Pacific Islands Region. Samoa. https://www.irena.org/DocumentDownloads/Publications/Samoa.pdf

generation – supply that can dependably be called upon when required. Solar thermal reliably provides hot water and already has an easy storage mechanism – a hot water cylinder – that provides a delay between the capture of energy and its use. Wind is less reliable in the PICTs, and it is uncertain how the wind resource will be affected by climate change. Increasingly, because of its cost competitiveness and other advantages, solar photovoltaic (PV) electricity is fast becoming a mainstream RE option. For this reason, and because its adoption promises both to facilitate and accompany the uptake of EVs, PV is the RE option considered most by this report.

Solar PV can be deployed at a scale ranging from the panel, smaller than a fingernail, that powers a wristwatch to vast arrays covering several hectares. It is a relatively flexible means of generation but, as its very name suggests, it is crucially reliant upon the intensity of incident solar radiation. Shaded panels only generate a small fraction of their full-sun capacity, and solar PV is inoperative at night. For this reason, when used as a standalone generator, solar PV is normally coupled with an electricity storage device such as a battery. In the case of grid-scale devices with complex management systems, the battery system is sometimes referred to as a **battery energy storage system**, or BESS. Without a BESS, the intermittent nature of generation from solar PV requires offsetting by other generation to fill the RE troughs in supply. For many PICTs, this balancing is often provided by the diesel generation fleet.

Increasing solar PV penetration introduces more and more complexity to the regulation provided by the supplementary diesel generators, to the point where stability may be difficult to maintain. This is the situation faced by many PICTs contemplating an increase in their RE component – while the first solar PV (or other RE supply, given that most RE generation is similarly intermittent) may be relatively cheap to include in the electricity mix, future additions may be far more expensive due to the more complex systems and devices required, including the use of batteries. As touched upon earlier in the report, one potential solution is to use the storage capacity of electric vehicles as a kind of BESS.

4.3. Integrating the Batteries of Electric Vehicles with PICT Grid Supply

This section considers how electric vehicles and renewable energy/electricity supply might work together. It starts with a futuristic scenario where electric vehicles are in close communication and coordinated with the supply of grid electricity and retreats from this scenario through a series of simplifications, each step removing a component that is not currently available in the open marketplace or might be difficult to provide in a PICT environment. The result is the identification of a number of integrated EV-RE (and electricity supply) solutions that range from expected high-benefit but futuristic to simple but able to be implemented in current PICT electricity markets. This technology slide begins with vehicle-to-grid (V2G). Note that “grid controller” can also refer to a third party acting in support of the grid controller.

Technology 1: V2G

At some point in the near future, we are assured that it will be possible to fully integrate an EV fleet into a mains electricity supply in such a way that it functions as a kind of BESS. The technology required to accomplish this will make it possible for the electricity supplier to detect, communicate with and control charging and electricity drawing events from vehicles. This arrangement has the potential to maximise the benefits of integrating EV batteries with power supply. It is, however, some years away from commercial availability and the difficulty in predicting developments that may occur before it is commercialised make it difficult to prepare for such a future. It is also (and will remain) a far more complex option than the use of a dedicated BESS and would currently be far more expensive[17].

It is therefore recommended that PICTs only maintain a watching brief on global V2G developments.

Technology simplification: removing the electricity-supplier communication that allows control of charging, and prevents export of the battery energy to the grid brings us to

Technology 2: V2H

The technology for EV owners to power their house (or similar premises) from the propulsion battery of their vehicle already exists, in the form of third-party equipment and with the availability of OEM-supported equipment in prospect. V2H arrangements would allow charging from RE generation to then be turned around to cater to electricity demand on local supply circuits (which may, in turn, promote adoption of domestic-scale RE generation or make it possible to supply electricity in off-grid situations where it was previously impractical – although strong competition would be expected from the use of a dedicated battery for this). In order for it to be advantageous for the grid-connected consumer, some kind of management (at the very least, a time-of-use pricing regime) of charging would need to be implemented in order to encourage V2H use at periods of peak demand.

It is recommended that managed charging is supported through the development and provision of quality information.

Removing the ability to export electricity from the battery to the local electricity supply network but reinstating (electricity supplier) managed charging gives us:

Technology 3: V1G (control of when charging occurs)

This configuration relies upon the ability of the electricity supplier to manage charging events on a grid scale. Charging could then be directed away from peak demand periods, or allowed opportunistically when RE generation is underway. (The difference between V1G and V2H arrangements is that V1G does not anticipate the use of energy stored in EV batteries to be used to power homes etc). V1G technology is emerging, and commercial solutions are expected to be available in the next few years.

It is recommended that a strong signal is provided to the market to encourage uptake of managed charging technology as it becomes practical and affordable.

Removing the communications link that enables control of charging by the electricity supplier results in:

continued next page

[17] Using a (low) installed cost of US$5,000 per V2G station and 200 stations equals US$10M for non-assured access to around 3MWh of (relatively slow response, when considering frequency regulation) battery storage. Upgrade by the electricity grid controller to enable use of these stations would be on top of this. In comparison, a fully installed and grid-connected and controlled BESS of similar storage capacity would be to the order of a quarter of the cost and also better provide for faster frequency regulation.

Technology 4: On-site managed charging

Managing charging on-site means charging can occur in concert with other, on-site demand for electricity and/or on-site RE generation (which can in turn enable "smoothing" of RE electricity exports to the grid if EVs are connected and charging from the on-site system, potentially increasing grid-wide, intermittent RE capacity). On-site managed charging is possible with currently available technologies.

It is suggested that these techniques are supported through development and promotion of industry guidelines and quality demonstrations.

Removing the sophistication of intelligent chargers leaves:

Technology 5: TOU Electricity Pricing

Time of Use electricity pricing (which uses price signals to consumers that are intended to encourage them to charge their EVs when demand on the grid is low and electricity priced accordingly) is possible with "smart meters" (which enables the electricity supplier to know the amount of electricity consumed by a customer at any given time). It is expected that smart meters will be rolled out by the main PICT electricity suppliers over the next 5-10 years.

Where demand profiles and generation are stable and predictable, TOU charging can operate quite effectively on a relatively fixed schedule for various weekday and weekend time periods. In situations with a higher RE generation component, additional benefit could be expected if dynamic pricing was used and the price set according to hour-to-hour variations in RE generation. This would require a higher level of communication between the supplier and the customer, and a higher level of customer awareness.

It is recommended that the introduction and use of TOU be supported.

Simplification to low-voltage systems

Technology 6: Low-Voltage

Low-voltage charging and battery systems are commercially available and in common use. In recent years, systems that provide simple "plug-and-play" options for powering off-grid houses, boats and motorhomes and low voltage e-mobility have become available. The dramatically reduced costs and improvement in quality of such systems due to the scale-up of their manufacture in China and in other countries means that they have increasingly unseated petroleum-fuelled generation in remote areas, and seen the electrification of areas where even the use of small gensets was impractical.

There are several standards and guidelines available for low-voltage systems.[18] However, there appears to be little standardisation with respect to the connectors that are used between a charger and a low-voltage battery system. It would be useful to bring together available electrical standards and guidelines into a set of guidelines for use in PICTs and add standardisation of the connectors. The adoption of one set of connector types stands to provide many benefits.

It is recommended that guidelines for low-voltage PICT systems are developed.

5. What EV and Electricity Supply Combination is Right and Where?

As previously mentioned, there is a wide variation in the makeup of electricity supply systems across and even within the PICTs. Looking across these, there are four quite distinct electricity supply scenarios, namely:

1. A grid system with "dispatchable" RE (e.g., hydro generation, which can be dispatched immediately in response to demand).
2. A grid system with a majority of diesel generation and increasing input from intermittent RE.
3. A "future technology" arrangement that has very high RE generation supported by BESS.
4. Small-scale, local grids and off-grid supply with irregular electricity supply.

[18] For example, those guidelines made available by the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI) at http://www.seiapi.com/guidelines/.

Table 1 considers how the six identified ways in which EVs and electricity supply could be combined (V2G, V2H, grid managed charging (V1G), on-site managed charging, TOU pricing and low voltage systems) and which best match with these four PICT power supply scenarios. The suitability of the EV-electricity supply combination is very much dependent upon the nature of the electricity supply systems with which they are to integrate. Accordingly, the table is colour-coded. Green cells indicate a good fit for the combined solution-and-supply scenario: red signifies a poor fit, and amber is somewhere in between.

Table 2 further filters the integrated electric vehicle solutions according to perceived near-term value that might be realised if the solution is supported, in a rough value-for-effort assessment. This time, green indicates value in supporting, red indicates no value in supporting, and amber indicates something in between these two.

Integrated EV Solution	Dispatchable RE	Intermittent RE	Future Grid with BESS	Local and Off-Grids
V2G	Possible future goal if technology becomes both available and affordable, but advantages are far less where dispatchable RE is available.	Has the potential to increase RE penetration and utilise any excess RE. However, BESS provides easier and lower cost option for same outcome without including EV cost.	Potential to increase RE penetration with smaller BESS but does not offer any cost advantage in short term.	Not applicable, as requires high numbers of EVs to share high set up costs.
V2H	Little advantage with dispatchable RE apart from for customer personal backup/disaster relief or on-site reliability.	Only useful from GHG point of view if excess RE exists and it is used with managed charging to capture this RE. BESS could provide similar service for lower cost, unless grid supply was also unreliable.	Has potential to add battery storage to the grid at reasonable unit cost compared with BESS, but requires charging to be managed for GHG benefits to be realised.	Has potential to provide useful backup or to support local grid battery storage.
Grid Managed Charging	Potential for significant benefits to be realised by electricity supplier … with potential for sharing cost savings with EV customers.	Potential to make good use of intermittent RE generation and potential to at least marginally increase RE penetration.	Potential to make good use of intermittent RE generation and potential to at least marginally increase RE penetration.	Not applicable.
On-site Managed Charging	Little advantage and therefore little incentive to introduce.	Only of use if RE is distributed, in which case has the potential for customer better utilisation of own RE resource. Has potential to marginally increase RE penetration.	Only of use if RE is distributed, in which case has the potential for customer better utilisation of own RE resource. Has potential to marginally increase RE penetration.	Has potential to significantly increase proportion of RE on local grid and maximise use of any excess RE generated.
TOU Pricing	Potential for good cost benefits to electricity supplier and customer and capability close to deployment in Samoa.	Potential to better manage the diesel generation fleet and RE generation, with greater potential benefit again if dynamic TOU.	Potential to better manage the grid with greater benefit again if dynamic TOU.	Currently not applicable as TOU pricing is more a management tool for large grids.
Low Voltage, Local Grid Supply	Low need for off-grid low-voltage local grid options.	Low need for off-grid low-voltage local grid options.	Low need for off-grid low-voltage local grid options.	Could provide a very useful and significant option for increasing mobility and access to electricity, particularly in remote areas.

Table 1: Assessment of the Value and Fit of the Identified EV-Electricity Supply Combinations with Various PICT Electricity Supply Types (with cells coloured green to indicate a perceived good fit, red a perceived poor fit, and amber somewhere between the two).

Integrated EV Solution	Dispatchable RE	Intermittent RE	Future Grid with BESS	Local and Off-Grids
V2G	Not cost-effective and little benefit.	BESS currently provides a more cost-effective solution.	BESS currently provides a more cost-effective solution.	Not applicable
V2H	Little advantage at reasonable cost to individual EV owners.	Individuals might consider an option to improve electricity supply reliability, at their own cost.	Individuals might consider an option to improve electricity supply reliability, at their own cost.	Individuals might consider an option to improve electricity supply reliability, at their own cost.
Grid Managed Charging	Potential for significant benefits to be realised by electricity supplier … with potential of sharing cost savings with EV customers.	Potential to make good use of intermittent RE generation and potential to at least marginally increase RE penetration.	Potential to make good use of intermittent RE generation and potential to at least marginally increase RE penetration.	Not applicable.
On-site Managed Charging	Little advantage.	Likely only a small number of applications with little influence and at reasonable personal cost.	Likely only a small number of applications with little influence and at reasonable personal cost.	Has potential to significantly increase proportion of RE on local grid and maximise use of any excess RE generated.
TOU Pricing	Expected to provide significant benefits far more widely than EV charging only.	Expected to provide significant benefits far more widely than EV charging only.	Potential to enable better management of the grid with greater benefit again if dynamic TOU.	Currently not applicable as TOU pricing is more a management tool for large grids.
Low Voltage, Local Grid Supply.	Not required for normal business. Could provide for added resilience.	Not required for normal business. Could provide for added resilience.	Not required for normal business. Could provide for added resilience.	Potential to be very useful for increasing mobility and access to electricity.

Table 2: Assessment of the Value of Supporting the Development of the EV-Electricity Supply Combinations (with green cells indicating high worth, red cells indicating little or no worth, and amber cells indicating something between the two).

This analysis indicates:

- V2G is currently not a good fit for use in PICT electricity supply systems (and it is recommended that only a watching brief be maintained over this area in case the situation changes).
- V2H has marginal, national-scale benefit. However, it may realise useful benefits for a small number of individuals.
- There appears to be value in supporting the development of grid-scale managed charging for main grids in PICTs.
- On-site managed charging has marginal national-scale benefit. However, it may realise benefits for a small number of individuals.
- National-scale benefits are expected for TOU pricing, with or without electric vehicles, and it is recommended that TOU pricing is developed across major grid systems.
- There appear to be many benefits to be gained from developing low-voltage systems and the development of this sector also deserves attention.

6. Conclusions

This first project stage, which considered the suitability, feasibility and economic viability of various types of EVs in the PICT environment, from push e-scooters to heavy trucks, found potential for most forms of EVs.

Consideration was also given to using EVs in a manner that allowed the capacity of their batteries to be used to support the supply of electricity. This work found that the capability for in-service EVs to support the supply of electricity was emerging and this capability was expected to grow, but that there are cheaper and more convenient options to achieve the same effect. However, significant benefit is expected from managing the charging of EVs in coordination with the supply of electricity, rather than EV charging presenting itself as an uncontrolled demand.

At a more detailed level, the main findings of this investigation can be summarised as follows:

- There are large differences across and within PICTs with respect to urbanisation, relative wealth, roading infrastructure, the vehicle fleet, electricity and fuel markets, and accessibility to main island markets. Such diversity not only makes it difficult to generalise across PICT contexts, but also near-impossible to prescribe one-size-fits-all solutions.
- The availability of advanced battery technologies has presented the market with many electric vehicle options, from electric push scooters to large trucks:
  - Larger-sized electric **push-scooters** are featuring in daily personal mobility in large cities around the world. They have also been introduced to PICTs where they are used, for example, by tourists. This provides an example of where new mobility options can appear almost overnight, and illustrates the need for policy to be nimble to keep up with new technology.
  - **E-bikes** may offer a new mobility solution for PICTs. There is already some take-up in the PICT tourism sector. Their low voltage and simplicity might make them suitable for use in remote locations.
  - **e-Two-wheelers** that compete with petrol-fuelled two-wheelers on price and quality have only recently emerged in the global market. There are many ways in which these could provide new, affordable mobility. They could also replace their petrol-fuelled counterparts. In many parts of the world, where two-wheelers are 'the people's car', their electrification has become a major focus by governments.
  - **Motorised tricycles** are the backbone of transport services in many Asian countries and e-trikes have been deployed in several in an attempt to begin the electrification of this market. By contrast, petroleum-fuelled, motorized tricycles hardly feature in the PICTs, which stands to make the uptake of e-trikes difficult.
  - Apart from the e-buses that have recently become common in China, most EV programs around the world have largely concentrated on the uptake of **electric passenger cars**. The technologies involved are now well developed and EV passenger cars are normal in many countries. However, they are still very new to PICTs and lack of awareness is still a major obstacle to their uptake. What's more, private cars travel relatively small distances each year in PICTs, which means that EVs, which cost more to purchase and depend upon savings from use to recompense this, are relatively unattractive. Use for taxi and ride-hail vehicles offers a far better proposition.
  - Globally, the technology of **electric trucks** is still emerging, but the electrification of this sector is worth considering as the technology matures, as although trucks are a small proportion of the fleet, they consume a large amount of fuel. The upfront cost of electric trucks is currently very high, but it is expected to become more manageable as the market sees the expected fall in the price of batteries. However, getting local technical support would also be a significant barrier to their uptake in the PICTs.
  - **Electric bus** technology is more advanced than for trucks due to the impetus provided by the Chinese market. The availability of ultra-fast charging means that individual buses can get away with smaller onboard batteries, which means projects involving multiple buses are less expensive. Projects involving small

numbers of buses are costly on a per-bus basis for several reasons, which means this technology would only be viable for the largest of cities in the PICTs. Even then, any such project would need to be heavily subsidised in its early years.
    - The electrification of **marine vessels** does not appear financially attractive in the short term apart from small, slow-speed vessels operating in close, inshore waters. There is, however, an opportunity to retrofit small fishing vessels with electric propulsion and to charge these using simple, low-voltage solar generation systems. The kind of small vessels used to ferry tourists could also be electrified.
    - The electrification of aircraft is emerging on the globe scene, but it is unlikely to feature in the PICT market in the short- to medium-term.
- While unmanaged charging could add pressure to already stressed and finely balanced electricity supply networks, electric vehicles might actually de-stress or otherwise support the supply of electricity. Six main ways were identified that could do this:
    - **Vehicle-to-Grid (V2G)**, where the electric vehicle is plugged into a device that connects the electric vehicle's propulsion battery with the grid and allows the electricity supplier to control the import and export of electricity to and from the electric vehicle's battery. This could aid balancing of supply and demand on the grid and could bring about a small increase in the proportion of renewable generation incorporated in the grid. However, V2G technology is still a long way from being perfected, and it is too difficult to plan and prepare for V2G integration at this early stage. As far as an action is concerned, it is therefore recommended that only a watching brief is kept on V2G until there is more certainty around the technology.
    - **Vehicle-to-home (V2H)** is a simpler arrangement, where the vehicle is plugged into a device that allows electricity to be exported from the vehicle to an isolated or local electricity circuit (instead of right through to the grid, as in the case of V2G). This technology is available in the global marketplace and could be installed by individuals, providing them with a short-term backup electricity supply when the grid is down. However, standalone battery systems and standby generators may provide more cost-effective and convenient power supply when grid supply is not available. Given only little effort would be required to make V2H options more accessible in PICTs, and given the potential benefit that might be realised to individuals, it is proposed that V2H be supported to some degree.
    - **Grid-scale managed charging**, where the electricity supplier has control over when and/or at what rate charging of an electric vehicle occurs. This has the advantage of shifting demand from electric vehicle charging to times when it is more beneficial to the grid supply — for example, when there is excess renewable energy available, or when there is spare capacity in the distribution network. Some form of grid-scale managed charging will be necessary when there are enough EVs charging to place a significant demand on the grid. However, the technology involved is still evolving and it is far from market-ready. For this reason, it is recommended that a watching brief be maintained on developments in grid-scale managed charging so that PICTs can begin to prepare for the day when its introduction can be considered.
    - **Local-site managed charging**, where charging of a vehicle is managed according to other demands for electricity on the site and/or what local electricity generation is available (e.g. from on-site solar PV or wind generators). This requires far simpler systems than grid-scale managed charging and uses technology that is already available in the global marketplace. Like V2H, it promises to benefit individuals, but offers little on a national scale unless it were part of a national initiative to promote, say, distributed solar photovoltaic (PV) generation. Considering the small effort required to make on-site managed charging more accessible – mainly through awareness and information initiatives – it is proposed that on-site managed charging is supported at some level.
    - **Time of use (TOU) electricity pricing,** which is used to encourage customers to shift demand to periods that suit the electricity supplier by advertising lower cost

electricity for these times (and benefiting EV owners if they choose to charge when electricity is cheapest). TOU pricing doesn't only benefit those charging vehicles, as it can direct customers' choice as to when they use household appliances and other electrical equipment. TOU pricing requires the use of TOU or "smart" meters. The tools to implement TOU pricing are commercially available, and it is within the capability of PICTs both to install and support the technology. The benefits of doing so would be both significant and on a national scale in practically every case. TOU pricing may also be used in a way that results in a net reduction in GHG emissions.

- **Low voltage systems**, which use voltages under 50V (nominal[19]), direct current (DC) battery systems for e-mobility and for low-power circuits such as those providing lighting and basic utilities in remote locations. Combined with solar generation, these can be operated in isolation from the grid supply. Because of the many benefits to be realised from the uptake of low-voltage systems, and the significant improvements that should be realised through providing guidance to the sector, it is recommended that the development of low-voltage e-mobility and electrification sectors is supported.

As pointed out earlier, none of these EV-electricity supply combinations amount to a reason to promote the use EVs to support the supply of electricity: there are cheaper options to achieve the same effect. These EV-electricity supply combinations should be thought of more as opportunities to be considered if electric vehicles are introduced, or as ways of minimising the effect that the charging of EVs might have on electricity supply systems.

[19] Compared to household grid supply, which is normally around 230V and AC, across the PICTs.

Appendix A: Electric Vehicles – a Backgrounder

A.1 Introduction

The International Electrotechnical Commission (IEC) definition of an electric vehicle, and the one that we follow for this report, ***is a vehicle propelled by an electric motor drawing current from a rechargeable storage battery or from other portable energy storage devices (rechargeable, using energy from a source off the vehicle such as a residential or public electric service)****…*[20]*.* Included in this definition are:

- "Simple" battery and electric motor combinations, as in battery-electric vehicles (BEVs) that have no on-board petroleum-fuelled engine (and are sometimes referred to as pure electric vehicles);
- Plug-in hybrid electric vehicles (PHEV) that have a petroleum-fuelled engine that might, at times, fully or partially propel the vehicle, including configurations where the vehicle's on-board engine is only used to recharge the on-board batteries (the latter sometimes referred to as a range-extender configuration);
- Alternative arrangements to plug-in (conductive) charging of BEVs and PHEVs including battery swapping, (inductive) contactless charging, and occasional charging of the onboard batteries on the move through overhead wires (as demonstrated in several European truck projects).

There are also models of (ordinary) hybrid vehicles where the batteries are only charged by regenerative braking or possibly by electricity generated by the on-board petroleum-fuelled engine. These hybrid vehicles do not draw electricity from an external source and are not classified as electric vehicles for this report.

A.2 Battery Electric Vehicles:

The base drivetrain components of a battery electricity vehicle (BEV) are shown in Figure 2 and comprise:

- A rechargeable storage battery;
- A battery management system that manages both the charging of the battery and the current draw from it;
- A motor controller that manages the transfer of battery electrical energy to the electric motors when the vehicle is being propelled, and vice versa when the electrical motors are used in braking mode, according to a wide range of signals it receives, including those from the driver's accelerator;
- An electrical motor or motors connected to the drive wheels;
- A charging connector and related power electronics.

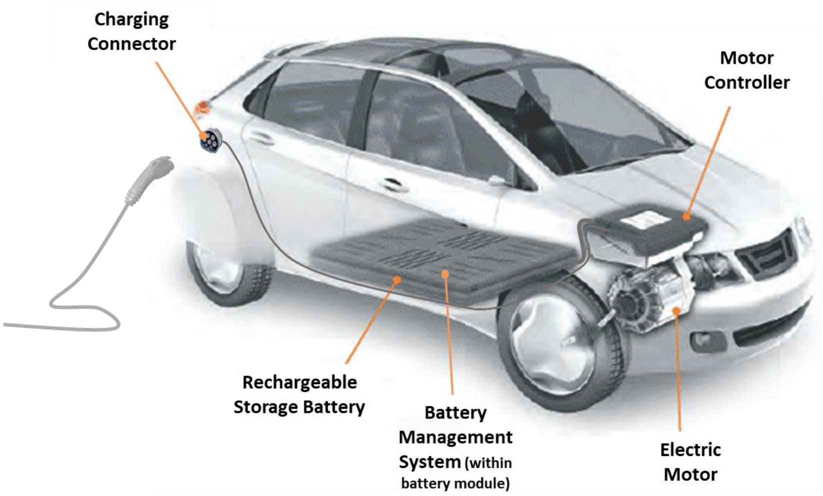

Figure 2: Base Drivetrain Components of a Battery Electric Vehicle

[20] IEC 61851-1

One of the most familiar BEV models is the Nissan Leaf – it was the first EV to be taken to mass production (beginning in 2010) and Nissan reports that 400,000 had been sold as at March 2019[21] (making it also the most popular EV model, globally, closely followed by Tesla models, which are also BEVs). The Nissan Leaf has also become a particularly important market-entry model for BEVs for Pacific countries where people drive on the left-hand side of the road and which readily allow the importation of used vehicles, through the importation of used vehicles from Japan (and, to a lesser extent, from the UK,) at far reduced prices. This is the reason that around half of the electric vehicles in the New Zealand fleet[22] are used Leafs from Japan.

With no backup engine, BEVs are fully reliant upon sufficient pre-trip or during-travel charging of their batteries to provide required range. The first generation Nissan Leaf (manufactured from 2010 until 2017) had a useful range of around 110km in mixed driving for a battery in near-new condition – a range that would easily meet the requirements of the vast majority of commuter-type travel on a single charge in countries such as New Zealand[23] – and would likely provide several days' private commuting in a Pacific Island environment. The global electric vehicle market demands greater range than this and, enabled by falling battery prices, OEMs have responded with many 2019-model BEVs capable of providing more than 300km for a single charge. For example, one of the 2019 models of the Nissan Leaf (fitted with a larger battery pack) can provide a range of over 350km.[24]

This trend of increasing range for mainstream production BEVs is expected to continue. For PICTs, this will likely mean that the battery capacity on new-model electric vehicles is under-utilised, which creates the opportunity for intelligent integration of this battery storage resource with the supply of electric power, without the risk of compromising either the operation of the vehicle or the health of the battery.[25] Such large ranges compared to commuting distances also largely removes "range anxiety" (the fear of running out of electricity and becoming stranded), which is often a significant barrier to EV uptake in market-forming years, especially when there are few public charging stations available.

The relatively high power of the electric motors of this size of electric vehicle is achieved by the use of high voltage (upwards of 400V). Electricity is lethal at these voltages and together with the danger posed, the sophistication of the related power electronics means that specialist technicians must be trained to provide servicing support (although it should be noted that one of the advantages of electric vehicles is their reduced number of moving parts and the general robustness of their drivetrain components and electronics).

A.3 Plug-in Hybrids

A plug-in hybrid comprises the battery, motor controller and motor drive train as for BEVs, plus a petroleum-fuelled engine that provides range extension and sometimes additional motive power. Hybrids tend to have smaller motors than BEVs and smaller petroleum-fuelled engines than for the equivalent conventional internal combustion engine vehicle (ICE), the two drive trains combining (in different configurations, depending upon model) to provide the desired performance. The downsizing of components used for PHEVs, including the battery pack, is to ensure they are price competitive. A consequence of their smaller battery packs is that the all-electric range of a PHEV may be limited to as little as 30-50km.

A plug-in hybrid can be used without plugging it in at all, whereupon it becomes just another conventional hybrid vehicle. PHEVs have, for this reason, posed problems for policy-makers seeking to incentivise the uptake of electric vehicles. At least one jurisdiction noticed that

[21] https://global.nissannews.com/en/releases/nissan-leaf-first-electric-car-to-pass-400k-sales?source=nng&lang=en-US&rss

[22] Vehicle fleet data, downloaded from: https://nzta.govt.nz/resources/new-zealand-motor-vehicle-register-statistics/new-zealand-vehicle-fleet-open-data-sets/

[23] Survey results indicate that 90% of daily vehicle travel in New Zealand was less than 100km: Ministry of Transport. Driver Travel, New Zealand Household Travel Survey 2011 - 2014 March 2015.

[24] Based on the (new) Worldwide Harmonised Light Vehicle Test Procedure, https://www.nissan.co.uk/vehicles/new-vehicles/leaf/prices-specifications.html.

[25] Noting that the ability of a battery to hold charge slowly deteriorates over time and use but frequent, small transfers of electricity to and from a large automotive battery is not expected to bring about a significant change to this degradation rate.

when PHEVs were included in a reduced import tax scheme, there was a sudden influx of luxury PHEV models that were driven without their batteries ever being recharged, which was, of course, purpose-defeating.[26] Policy in many countries now differentiates between BEVs and PHEVs specifically to avoid creating such loopholes).

[26] As judged by the low level of use of public charging facilities in the same jurisdiction.

Appendix B: Electric Vehicle Charging

The battery of an electric vehicle is a direct current (DC) device, and requires a DC current to be charged, whereas mains electricity is alternating current (AC). Charging an EV from a mains electricity supply requires conversion of AC to DC, which is carried out by an AC-to-DC convertor, whether on or off the car. This can be thought of as the same arrangement as required when charging a mobile phone, with the AC-to-DC convertor that is plugged into the wall providing a DC power supply that is transferred to the phone via the (DC) charging cable.

B.1 Mode 2 Charging

Mainstream light passenger electric vehicles have a small, on-board AC-to-DC convertor allowing the EV to be plugged into a mains supply through a flexible charging cable. In what is known as “Mode 2 charging” (as defined by IEC Standard 61851-1), a portable charging cable with an in-cable residual current device (RCD[27]) is used to supply AC mains electricity from a mains electricity socket outlet to the vehicle’s charging socket, and the vehicle’s onboard charger converts the current to DC for charging the batteries. The charging of the battery is managed by the vehicle’s battery management system (BMS) which is connected to the battery and is an integral part of the vehicle’s battery system).

These portable charging cables are typically supplied with the vehicle at the time of purchase. The charging cables are normally rated to a charge rate of 1.7kW-2.3kW, and communicate with the vehicle to limit the current draw to the rated amount. A draw of 1.7kW is similar to or slightly higher than that for a high-speed electric kettle. However, the draw can be sustained over many hours, which can test supply circuits if they are not sufficiently robust. Considering the unknown standard of some household wiring, it is recommended that electricity supply companies provide an inspection service for those wishing to charge EVs.

The on-road energy use for a Nissan Leaf with moderate air conditioning use is expected to be around 18 kWh/100km[28]. At this level of consumption, charging at 1.7kW would be the equivalent of charging at a rate of around 9 km per hour – providing a range of around 80km for an over-night, eight-hour charge.

Figure 3: Example of a Portable Charging Cable Often Supplied with an Electric Vehicle.

Note that normally these portable charging cables have a set or switchable charging rate and if insufficient current is available from the supply, as may be the case for a small, off-grid solar PV system (with the solar PV system’s batteries at low state of charge), charging may be turned off altogether.

[27] Also sometimes referred to as a ground fault circuit interrupter or GFCI, which is a type of circuit breaker that shuts off electric power when it senses an imbalance between the outgoing and incoming current – as would be the case if there is a fault in system. This has the effect of isolating the connected device (the EV, in this case) avoiding the potential for electrocution.

[28] Derived from Flip the Fleet data presented by paper *Analysing real world EV utilisation – what can we learn to speed EV uptake?* Daniel Myall, Henrik Moller & Dima Ivanov, EV World 2019, New Zealand, August 2019.

B.2 Mode 3 Charging

In “Mode 3” charging, a wall- or pedestal-mounted charger containing the RCD/GFCI is hard-wired to the mains supply, and a tethered or non-tethered flexible cable is used to connect the charger to the vehicle to supply AC to the vehicle’s onboard AC-to-DC convertor. Standards provide for charging up to a rate of 43kW for this arrangement, although chargers with charge rates of 3.3kW and 6.6kW are far more common (which also match the common maximum charge rates of many current model light passenger EVs). The charging system is designed to govern itself to charge at the label rating of the charger, the EV, or the charging cable, whichever is the least.

At 3.3 kW, a Nissan Leaf with moderate air conditioning would charge at the equivalent of around 19 km per hour – and around 75km for a four-hour charge period.

Figure 4: Example of a Wall-Mounted AC Charger

Some models of Mode 3 charger allow for the local management of charging across several charging points so that total current draw from charging, or total on-premises demand, remains within pre-set limits (e.g., to keep total electricity demand within the capability of the pole fuse connecting the premises with the grid). These systems have the ability to turn down the charging rate to individual vehicles as the number of vehicles that are charging increases. Some models of Mode 3 charger can also be configured to modulate the charging rate of connected and charging vehicles in concert with the available energy generated from a PV solar array (or other local RE supply), which can be used to maximize the utilisation of RE generated on-site.

A secondary advantage of this setup is that any electricity exports to the grid could be smoothed through modulation with charging, when EVs are connected and charging, providing the opportunity for increased (distributed) RE penetration of the wider grid. However, the dependence on connected and charging EVs would be a risk to this system, which may not be acceptable to a power supplier whose concern is to maintain grid stability.

B.3 Mode 4 Charging

Some electric vehicles have a separate charging connector port that can provide direct access to the onboard propulsion battery, enabling “Mode 4” direct DC-to-DC charging from an off-board AC-to-DC convertor-charger. Being off-board, the AC-to-DC convertor can be much larger (and heavier) and until recently, charge rates of 50kW have been typical for these “fast chargers”. At 50kW, a Nissan Leaf would charge at a rate of almost 5km per minute, with a range of 80km gathered within around 16 minutes.

Advertisements sometimes claim that fast charging will take an electric vehicle from near empty to a 80% state of charge (SOC) in 20 minutes. This was based on earlier Leaf-like specification BEVs. Mention of charging up to 80% SOC reflects the risk to battery health where fast charging continues as the battery nears full charge: charging equipment automatically slows down the charging rate when above 80% SOC for the same reason.

As a corollary of this, it is not good use of a fast charger to continue to use it once charge rates have turned down, if the charger is in demand, which is why some fast-charge service providers levy a fee based on both the amount of electricity delivered and the time connected (the latter incentivising drivers to move on once charging slows).

Figure 5: Example of a Fast Charger, in this Case Providing Customers with a choice of CHAdeMO, CCS and AC Type 2 Charging Connectors through three different charging cables on the same charging unit.

Increased battery capacity and higher voltage configurations enable faster charging rates still. Combined with new battery technologies, some mainstream models of electric vehicle are now capable of charging at nearly 1000V and with charge rates approaching 300kW. And the roll-out of “ultra-rapid” 350kW chargers has begun in several countries, including along the eastern highway of Australia, where the distances between destinations mean EVs must be recharged frequently. 125kW, 150kW and 175kW chargers and charge rates are also in use in some countries. The cost of these chargers and their installation is very high compared to 50kW chargers, not least because the electrical supply required must be very robust.

Such high-speed charging is part of an evolution of how the specifications for EVs have changed and how the use of electric vehicles has extended with this. Up until recently “retail” charging[29] has comprised low charge-rate wall and pedestal chargers installed to attract the business of electric vehicle users, with charging services often provided without additional cost. In a show of how the market is changing, Tritium, a supplier of fast and ultra-rapid chargers, now defines their 50kW fast charge “Veefil-RT” charger as their retail-destination charger, with the traveling EV user now requiring the convenience of faster chargers at roadside charging stations.[30]

B.4 Direct Solar Charging of EVs

Retrofitting a light passenger electric vehicle with roof-area solar PV has the potential to generate an average of around 1.5kWh of electricity per day, or around 500 kWh per year. This could propel a Nissan Leaf (with moderate air conditioning use) around 2,800km per year[31] – which is not a trivial amount for private passenger vehicle use in some PICTs (for example, data from Solomon Islands suggests that the average private vehicle travels 1,000-

[29] Retail charging is where chargers have been installed to attract customers to the area, with land access often provided without cost to a charging provider in return for no charge for the installation.
[30] Les Smith, Tritium Australia, personal communication.
[31] Assuming that the retrofit charges the battery directly, without engaging the battery cooling system, and for an energy consumption of 18 kWh/100km.

2,000 km per year – see Appendix G). The same 1.5m^2 solar panel could provide charging for over 10 e-bikes, indicating how effective the combination of solar and low-voltage e-mobility can be.

This turns the discussion on its head – rather than consider how EVs might benefit the grid, there appears to be the opportunity for off-grid solar PV to benefit e-mobility. This requires further consideration.

For the sake of completeness of the descriptions of the various modes of charging, Mode 1 charging is where a vehicle is connected directly into a mains supply connector using a flexible charging cable permanently wired to the vehicle. Unless the socket outlet is protected by an RCD or equivalent safety device, there is no safety protection device in the system. Mode 1 charging is not allowed in many countries — including New Zealand — due to safety concerns.

B.5 Charging Connectors and Interoperability

The global EV market was initially fragmented with different jurisdictions developing and adopting their own charging connectors. Tesla also developed and used its own charging connector, adding to the variations in the marketplace. Behind each connector and charger is a communications protocol that allows the vehicle to communicate back and forth with the charger that checks that circuits appear to be in good state of health, the charging rate does not exceed the rating of the weakest component in the charging chain, and may check whether access to the charger is permitted, etc. – the many plugs and different protocols risk producing incompatibility and inconvenience – where an EV operator turns up at a public charging station only to find that their vehicle is not compatible, and cannot receive a charge.

This is why most countries that have EV programs have provided strong signals to the industry over which connector to use. However, this was not before a number of connectors and protocols were already established in the marketplace, and as a result you will see some fast chargers (i.e., 50kW) that provide CHAdeMO and Type 2-CCS connectors (with their associated protocols), and sometimes also a fast-charge AC connector on the ends of separate, tethered, flexible cables (as for the configuration shown in Figure 5). In the case of the public supply of AC charging (with simpler protocols and smaller currents and wire sizes) many countries have adopted a guideline of providing a female Type 2 charging socket, with the intention that the EV operator provide a matching flexible cable to connect with their EV. In the case of street-side installations, this also has the advantage of not having loose cabling around when there is no EV connected.

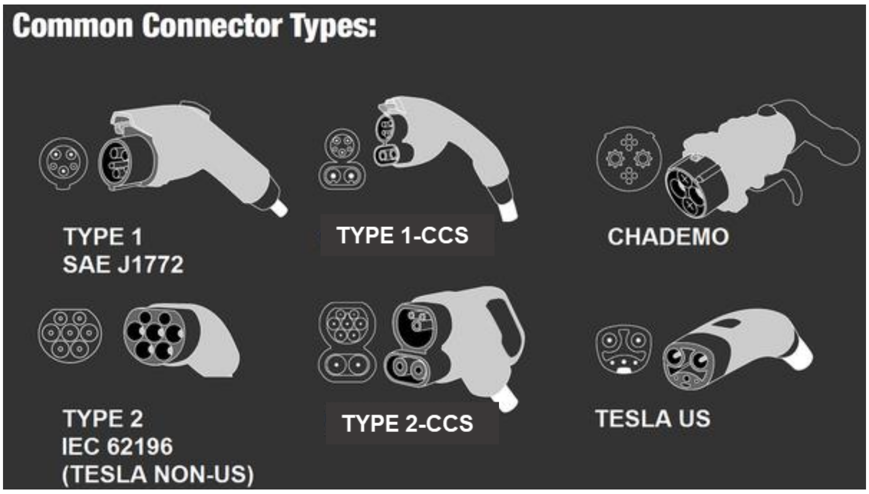

Figure 6: Different Types of Connectors (from Tesla Club Website - modified)

Figure 7: Example of a Street-Side Public Charger with a Type-2 Socket Outlet.

As PICTs import vehicles from a wide range of jurisdictions there is a risk that, without direction, different connector types will become established in different PICTs, causing the already relatively small market to be fragmented further. It is therefore recommended that guidelines are developed to standardise the charging connectors (in at least a voluntary capacity) and also to provide guidelines concerning placement of public chargers, safety and reliability.

Appendix C: Other Electric Vehicle Types

C.1 Low-Voltage Electric Vehicles

Advances in technology have meant that low-voltage (below 50 volts) EV batteries and components can be lightweight, compact and simple, which has driven the development of many new e-mobility markets, including “low-speed” e-scooters and e-bikes, and 2- and 3-wheelers (the latter sometimes called e-trikes). The use of such “non-lethal” low-voltage systems with their comparative lack of sophistication also means that there is a wider range of charging options for these mobility modes and little need for highly trained technicians if service is required.

To give an indication of how rapidly these new modes of transport are expected to grow, the Malaysian government has set a target of 2.1 million e-motorbikes by 2025;[32] the fleet size of low-speed electric vehicles in China is already believed to be above 5 million units[33] (and many PICTs have direct access to the manufacturers of these vehicles); and the uptake of rented e-scooters in the United States has been higher than for the uptake of the ridesharing services of UBER and Lyft.[34] These low-voltage e-mobility markets are new and still developing globally. Many could play a significant role in the mobility sector in PICTs due to their accessibility, affordability, expected local serviceability,[35] the relative ease of recharging (due to the low currents they draw, which are compatible with simple solar PV systems and for low-current service connections), and their convenience for short trips (which many trips are, other than on major islands across PICTs).

Also, unlike passenger car BEVs, where extensive air conditioning use can result in a drastic loss of range – the air conditioning load on a BEV passenger car can potentially reduce useful range by 30% or even more[36] – these e-mobility options do not lose energy to forced air conditioning.

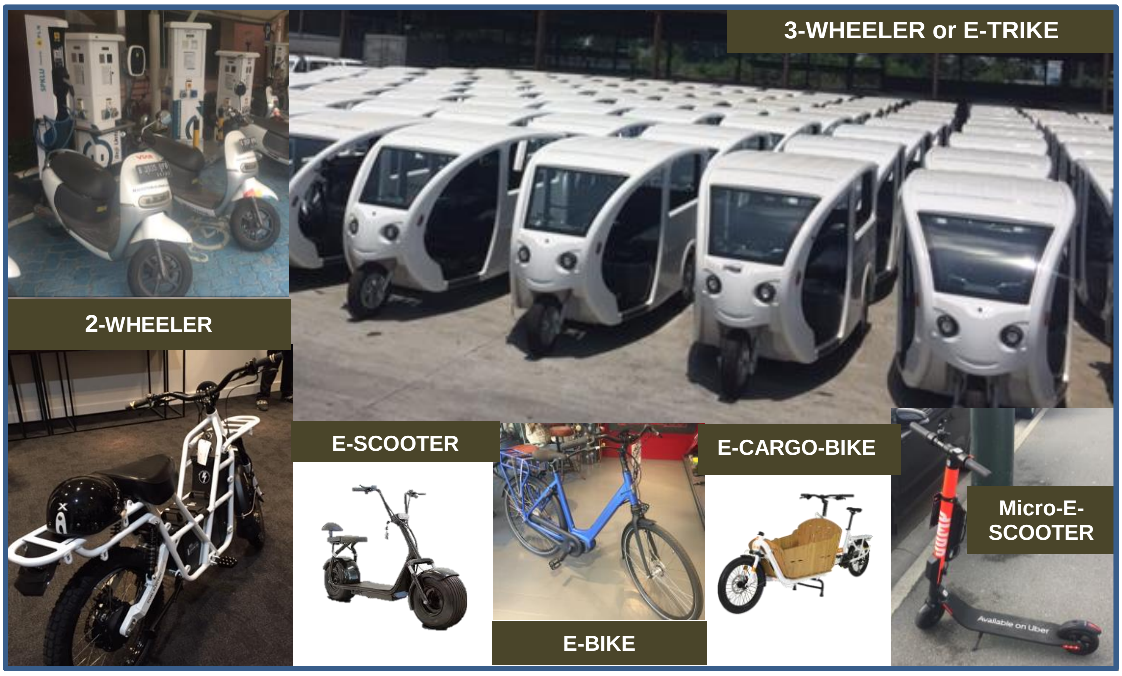

Figure 8: Examples of Low-Voltage E-mobility Options

Currently there appear to be few standards or guidelines for the specification of low-voltage e-mobility options, apart from those imposed by the aviation sector with regard to the

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[32] Presidential Regulation Number 22, 2017.
[33] IEA Global EV Outlook 2019.
[34] “Why You Should Pay Attention to Micromobility”, Oliver Bruce, EV World, New Zealand, August 2019.
[35] Due to the relatively simple componentry and relatively low cost of replacement parts.
[36] Based on the average energy consumption of Nissan Leafs in Flip the Fleet data (Analysing Real World EV Utilisation – Myall et al, EV Work 2019, Auckland, August 2019) relative to the calculated air conditioning load based on air conditioning specifications.

carriage of batteries. This lack of direction has resulted in the use of a wide range of battery voltages (24V, 36V, 48V and 60V), battery chemistries, battery sizes, and connector configurations that result in inconvenience and the very real risk of a mismatch amongst chargers, batteries and devices, which has the potential to damage any of these. Quite apart from the fact that they each require specific chargers, the wide variety of battery types and arrnagements means that there is a lost opportunity to produce a single type with the resulting economies of scale, meaning components are currently more expensive than they need to be.

Low-current charging of low-voltage battery systems is relatively simple and robust where appropriate battery management systems are in place (and relatively easily integrated with simple solar PV generation systems). However, the perceived safety and simplicity of low-voltage systems has also led to tinkering by ill-informed suppliers with predictably poor outcomes. The fires resulting from mismatching chargers and batteries in some of the early models of "hoverboard" (a small, stand-on, two-wheeled micro e-mobility device) is a case in point – mismatching removed the management of the charging of the batteries and overcharging sometimes caused thermal runaway of the batteries, and fires. The carriage of hoverboards on aircraft was banned as a result.[37]

The (light vehicle) automotive industry is currently working through a standardisation process for 48V systems due to the development of 48V "mild hybrid" technology. This standardisation is expected to result in savings in development time and costs. This work includes consideration of a standardised 48V battery pack size.[38] A low-voltage MEPS programme may be able to borrow from these automotive sector initiatives. What's more, if battery types are standardised, the way would be cleared for the kind of battery swapping that is possible with power tools and some e-bike and emerging electric 2-wheeler applications, with many associated benefits.

In the absence of such industry-led initiatives, however, and at the very least, it is recommended that governments provide some form of guidance for low-voltage battery systems. This might take the form of additional MEPS provisions, including taking measures to avoid the import and supply of substandard componentry.

C.2 Electric Buses

The IEA's *EV Outlook 2019* reports that China accounts for 99% of the global electric bus market, which is expected to have now (in mid-2020) surpassed 600,000 electric buses.[39] With this foundation, many Chinese bus manufacturers also offer electric buses globally.

Despite the relatively small numbers of electric buses outside China, the "global industry" feels that electric bus technology is reasonably proven and past the demonstration phase of market development. The main barrier to uptake then becomes the up-front price premium of an electric bus over a conventional diesel bus, which may be higher than 30%, plus the high cost to establish local service support.

This up-front premium is mainly due to the cost of the typically large battery pack required to provide the daily range of a bus (i.e., with the daily bus schedule provided by overnight charging, only). Options around this include use of smaller battery packs with on-route fast and ultra-fast charging, although savings are offset by the generally higher costs of the faster charge-rate charging infrastructure (and possibly the higher cost of electricity, if the fee for electricity includes a demand charge) and the generally higher costs of the higher performance fast-charge batteries required (on a per-kWh stored energy basis). Other advantages of small battery systems include reduced loss of passenger space to batteries and reduced vehicle weight with reduced tyre wear associated with this.

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[37] IATA carriage of Small Vehicle Powered by Lithium Batteries: https://www.iata.org/whatwedo/cargo/dgr/Documents/small-lithium-battery-powered-vehicles.pdf

[38] Dr Peter Pichler, Samsung SDI, personal communication plus http://cii-resource.com/cet/AABE-03-17/Presentations/BATO/Pichler_Peter.pdf

[39] Based on the IEA-reported growth rate and stock of 460,000 electric buses at the end of 2018.

China is also a country of mass production and there can be more than a 20% premium on the cost of electric buses when ordered in lots of fewer than 80-100 buses.[40]

In the case of PICTs, where smaller distances place fewer demands on range and make it possible to specify a smaller capacity battery, there is the opportunity to lower the up-front cost of an electric bus[41]. All things considered, price parity with a diesel-powered bus might be achieved for a "PICT-specification" electric bus by 2030. Lower costs to operate electric vehicles (some operators suggest 40-50% lower for an electric bus – which is a result of fewer moving parts and fewer still that require servicing, and less wear and tear on brakes and running gear, but increases in tyre wear due to heavier weights) mean that the total cost of ownership (TCO) of an electric vehicle will be similar to that for a diesel bus a number of years before this.

There are a number of ways by which others have justified the premium on an electric bus (and for other EVs, for that matter), including:

- Auckland Transport have applied externality costs when considering public transport tenders. These have considered the cost of CO_2e emissions and the cost of health associated with air-quality-related emissions, both of which favour electric buses compared with their petroleum-fuelled counterparts; and
- There is also a strong case not to wait until the price premium disappears before introducing EVs: some form of "EV readiness" transition period — awareness raising, the normalisation of EV technology, and the building-up of industry capability and capacity — is inevitable. Waiting to introduce EVs until it is financially attractive will delay the start of this transition period, and also delay the "EV uptake S-curve", postponing the time at which total economic benefits realised from electrification become significant (i.e., a relatively small early investment should pay good dividends through bringing forward the point where economic returns do become significant[42]).

Looking at neighbouring countries, there are currently small numbers (in the tens) of electric buses operating in New Zealand, Malaysia, Australia, and Singapore. Electric bus operations may also possibly begin in Fiji within the next year. As mentioned, there are reasonable costs in providing local technical support services for such electric bus operations which, when divided between only a small number of buses, can result in very high project start-up costs. Collaboration and clever use of remote diagnostics and servicing support may result in better access to service support and at significantly reduced cost.

[40] Author experience from project work in Asia.
[41] Noting that reducing the battery size may also have other secondary effects such as avoiding the loss of passenger space and making the vehicle lighter and less energy consuming because of this.
[42] For example, from reduced fuel imports, lower air quality-related emissions, and lower carbon emissions.

Figure 9: Example of an Electric Bus Undergoing Ultra-Fast Charging

C.3 Electric Trucks:

The electric truck market is still at an early emerging market stage with numbers outside China in the early hundreds.[43] After-market retrofits provide a significant proportion of this market share.[44] Globally, focus has been on developing trucks for use in urban environments due to their lower battery storage requirements, and their tendency to be quiet in operation and to emit comparatively very little in the way of local air quality emissions. City-based, stop-start truck operations such as curb-side rubbish collection have been found to be a particularly good fit for electric trucks due to the high torque advantage of electric motors at low speed and the significantly reduced operating costs – a function of the lower drivetrain stresses and the efficiencies brought about by the use of regenerative braking.

By contrast, the large energy storage requirements of long-haul, heavy freight trucks introduces significant cost and weight penalties (the latter limiting both the available payload weight and income potential). There is limited opportunity for the use of such heavy trucks in PICTs and these are not considered further in this report (and future reference to electric trucks in this report refers to trucks suited to urban purposes).

Similar to electric buses, there can be significant start-up costs involved in providing local support services for an electric truck model or range, which can result in very high per-vehicle costs when spread across only a small number of trucks. Reducing these costs will require coordination across suppliers and/or clever use of remote diagnostics and servicing support.

PICTs have access to electric truck retrofit technology through at least one Australian supplier and retrofit providers in the US.

[43] Based on data drawn from IEA Global EV Outlook 2019.
[44] IEA Global EV Outlook 2019 and SEA Research (personal communication).

Figure 10: An Example of an Urban Electric Truck: "#001", the First to Enter Service in New Zealand.

C.4 Electric Boats:

Compared to road vehicles, marine vessels are very diverse in size and function and tend to be specified and supplied for their particular task by combining a propulsion unit from one supplier and the hull from another. In a similar fashion, e-boat supply will likely comprise combining an electric propulsion unit from one supplier with a hull from another … with the supply of e-boats likely to follow a similar retrofit direction as developed for the early supply of electric urban trucks.

Similar to land-based e-mobility, e-boat technology can be broadly divided into "simple" low-voltage (but still high-cost compared to their petroleum-fuelled counterparts) systems and more sophisticated, commercially oriented (and very expensive) high-voltage systems.

At the micro-mobility scale, there are several models of small (under-0.5kW), very low-voltage outboards available in the global market, targeting small-boat fishing and small-boat tender markets. These are expected to have minor application in PICTs: at this level, human-powered paddling provides a more dependable, cheaper option. Sails are also used to propel outrigger-type small boats.

In mild weather and sea conditions, a small (up to 5-6 tonne) vessel with a low-drag hull only requires to the order of 5-10kW to be propelled at 5-6 knots in displacement mode.[45] This is well within the capability of smaller, low-voltage (48V) in-board or outboard electric propulsion systems, in combination with relatively unsophisticated motor controllers (i.e., with the potential to relatively easily set up local service support for such in PICTs). There are various off-the-shelf, market-proven systems available for this: for inboard systems, as have been used on tourist boats in the canals in Holland for around 20 years; and more recently for outboards that have been used in numerous small vessel projects all over the world. The demand for these low-voltage systems has drawn out many suppliers. As of February 2020, Plugboats.com[46] lists 13 different manufacturers of outboards under 5kW and 15 different manufactures of outboards above 5kW (although many of the latter require the use of high-voltage systems, which are discussed later).

Hulls tend to have greater life than their petroleum-fuelled propulsion units, offering an opportunity to retrofit a vessel with electric propulsion as part of its normal life. Despite this lower-cost formula, the up-front cost of a small electric propulsion system, including batteries to provide one-hour of operation only, ranges from the region of at least three-fold higher than the cost of a gasoline outboard for providing replacements in the small 10-20hp range, up to above ten-fold more for replacements of larger-sized outboards.[47] One hour of operation is also relatively restrictive and increasing from here adds significant cost due to the additional batteries required. Significant changes in cost will be required before electrification

[45] As an example of many: https://ecoboats.com.au/testimonial/bellmarine-pod-master.
[46] https://plugboats.com/
[47] Results from unpublished studies of marine propulsion systems carried out by Andrew Campbell, Fuel Technology Limited, for numerous clients.

of mainstream marine vessels becomes viable for the types of vessels that are in common use in the PICTs.

It is interesting to note that some Asian countries have small fishing vessels that use small-engined “longtails” (where the gasoline-fuelled engine is connected to a propeller via a long shaft and this shaft and propeller is dipped in the water astern of the vessel for propulsion) and that the electrification of these small vessels appears cost-effective. Early trials of electric “longtails” has been promising.[48]

In other examples, Azura Marine have demonstrated the ability to use vessel-mounted solar generation to power small and large vessels (photo, over).[49] And the need to reduce hull friction to enable the use of greatly reduced battery capacity along with exploiting the flexibility of electric drive system configurations has resulted in new developments in foiled vessels, where vessels rise up and travel on hydrofoils — small wings — in the water. Some have entered into taxi services in Venice, and this is a reminder that new technology could enable new mobility options not yet envisaged.

More locally, there is currently an electric boat in operating in Bora Bora, used to ferry guests to and from a resort. This seems to be a good example of where eco-tourism can afford early adoption of new technology despite the high upfront costs. Early opportunities may also arise where operation is in sensitive waterways, where the use of petroleum fuels and/or noise emissions are to be avoided.

Pushing a hull onto the plane requires an order of magnitude greater motor power than for displacement operation and this tends to demand the use of medium- to high-voltage systems (400V-1000V). Such systems require specialist services for design, installation and commissioning. This market appears to still be at emerging development stage and it is expected that designs will evolve that will reduce the level of specialist involvement required, with a corresponding reduction in cost. Charging infrastructure can be a significant proportion of the over cost of a marine project, particularly if high-speed charging is involved (e.g., as might be the case for a frequent-trip shuttle ferry operation).

An indication of the premium cost of medium- and high-voltage electric propulsion is that the cost of a 100kW electric marine propulsion system could cost to the order of US$200,000 (inclusive of batteries but excluding installation) compared with around US$15,000 for an outboard of similar size,[50] and the cost of a 18.5m commercial electric ferry project in Wellington, New Zealand, is US$2.6million compared with the cost of around US$1.0million for a conventional ferry of similar size,[51] plus around US$600k in ultra-fast charging infrastructure. However, this vessel is expected to cost around US$180k less per year to operate than an equivalent diesel-fuelled one.

The use of an appropriate, marinised battery system is a fundamental requirement for electric boats. Advances and cost reductions in lithium-ion batteries have seen recent preferential use of lithium-ion-based battery systems in marine applications. The specification of these battery systems (i.e., including the safety systems) may be controlled by a governing marine authority if the vessel is used for commercial purposes. The maritime safety requirements for Pacific Countries are currently under development with the support of Maritime New Zealand. The requirements for the use of lithium-ion battery systems in the marine environment in PICTs is currently under review.[52]

The electrification of large ocean-going freight and passenger vessels is also emerging and will deserve attention as the involved technologies become proven and are deemed practical for application in the PICT region. Their high cost stands to be a significant deterrent for many years.

[48]Further results from unpublished studies of marine propulsion systems carried out by Andrew Campbell, Fuel Technology Limited.
[49] https://www.azura-marine.com/
[50] Based on prices provided by various suppliers.
[51] Jeremy Ward, CEO of East-by-West Ferries, Radio New Zealand interview 8 November 2019.
[52] New Zealand Marine Safety Authority, personal communication.

Figure 11: Examples of E-Vessels and Electric Propulsion Systems

C.5 Industry Sector E-Mobility:

Looking to the industrial sector, electric forklifts of around 2 tonnes' capacity command a premium of around 50% compared with an LPG- or duel-fuelled-forklift.[53] Annual savings in the cost of energy would be minor in comparison and the justification for choosing them is more often because their zero-emissions operation allows them to be used in clean and/or enclosed spaces.

[53] Namely around NZD20K for an LPG-fuelled forklift and around NZD30K for an electric forklift, based on quotes from Hurricane Products Limited and EP Equipment New Zealand, for second-tier manufactured product.

C.6 Aviation:

There has been recent, significant progress in the electrification of aircraft, driven mainly by the aviation's desire to reduce global emissions, the potential to decrease operating costs by the order of 40-70%, and the low noise of electric drive systems. Both all-battery and hybrid platforms are under development. Although there are several electric sports class aircraft (which are normally small-sized) available in the global market, it has only been relatively recently that the first test flights of all-electric commercial aircraft have been undertaken. The first commercial flights, still involving smaller aircraft, could begin within the next few years. As for road EVs, PICTs are more likely to be later followers of such technology and the use commercial electric aircraft is unlikely to feature in the short- to medium term for them.

Appendix D: Comparison of Conventional Vehicles with Electric Vehicles – GHG Emissions and Simple Financial Payback

D.1 Will Electric Vehicles Reduce GHG Emissions?

Figure 12 provides the results of analysis comparing the in-service emissions of an electric vehicle with a near-equivalent internal combustion engine (ICE) vehicle for "typical" PICT main island use. The modeling involved has drawn from published data for the average specific fuel consumption of the PICT diesel generation fleet, average losses in electricity distribution, typical electric vehicle charging losses, and the expected fuel and electricity consumption of different, typical vehicle types in the PICT environment.

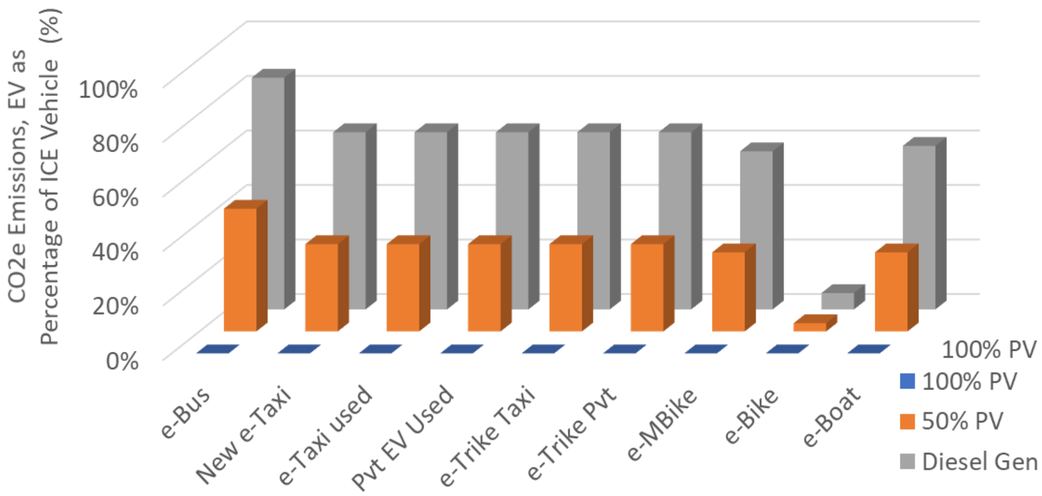

Figure 12: Estimation of In-Service CO_2e Emissions for Different EV Types and Operations compared with a Petroleum-Fuelled Vehicle Equivalent for Charging with Different Proportions of Solar PV Generated Electricity.

With reference to Figure 12:

- The in-service CO_2e emissions of an e-bus are expected to be to the order of 5%-15% lower than a diesel bus (depending upon the level of air conditioning used), even when charging the e-bus using diesel-derived electricity (a function of the net improvement in energy efficiency – an e-bus with the energy efficiency of its charging and electric propulsion system in combination with the reasonable energy efficiency of diesel generation less distribution losses is more efficient than the generally poor efficiency of a diesel engine when used on a road vehicle).
- The in-service emissions are expected to be lower by around a third for the operation of electric passenger cars and 3-wheelers, compared with their gasoline equivalents, even where charging these electric vehicles with diesel-derived electricity.
- The reductions in CO_2e emissions are expected to be greater again for 2-wheelers and small boats, particularly where electric propulsion is replacing two-stroke gasoline

engines (as these engines are less efficient again than four-stroke engines, making the efficiencies of electric propulsion more attractive still).

- The example of the e-bike has been provided to illustrate the significant reductions in CO_2e emissions that can be achieved through mode change (i.e., changing from a passenger vehicle mode to a pedal-assisted low-voltage mobility mode, made possible by the availability of new-generation mobility options). That said, the availability of new, accessible and affordable mobility options may also increase the consumption of energy in the transport sector. However, these vehicles are small, have small emissions footprints, and stand to achieve higher gains through enabling mode change, providing increased mobility and enabling healthier behaviours.
- The reductions in in-service CO_2e emissions are greater again as the level of solar PV generation increases, with total decarbonisation of in-service emissions if the electric vehicles are charged using solar PV (or other RE generation) only.

Use of new mobility options can result in significant GHG reductions

Note that the above results used a base of "typical," conventional petroleum-fuelled vehicles and it is worth considering a number of PICT variations to this:

- Some buses in PICTs belch black smoke from their exhaust, providing the impression that the buses involved would consume far greater amounts of fuel than if they were in good condition. However, black smoke can be the result of relatively minor over-fueling and the problem is more the inefficiency of older engines. Replacing these poorly performing buses with modern diesel buses stands to reduce CO_2e in its own right. The calculated 5%-15% lower CO_2e emissions for the use of an electric bus would be on top of this.
- The analysis also used non-hybrid gasoline cars as the base for comparison with the e-taxis and private EV cases, as non-hybrids are pretty much standard across PICTs. However, Fiji has been encouraging the import of (non-plug-in) hybrid electric vehicles (HEVs), and for good reason – their fuel consumption is typically around 30% less than for non-hybrid equivalents, which puts their CO_2e emissions reduction on par with switching to an EV charged with electricity generated from diesel, but through using a vehicle that has a fraction of the cost premium of an EV, and which does not require introducing technology that is radically different to what is already in the market. However, the emissions performance of the HEVs is fixed, whereas the CO_2e emissions of EVs will improve as the mix of the electricity used to charge them becomes more renewable – a change that is expected to occur over time. Hence HEVs could be seen as providing affordable, rapid reductions in CO2e emissions, whereas a shift to EVs could be seen more as a move to secure greater future benefit . Currently, either is a good solution.

D.2 Full Lifecycle Emissions (including build emissions).

The electric motors, batteries and controllers used in EVs contain much more copper and other metals and materials than are typically found in near-equivalent petroleum-fuelled vehicles. This additional material increases the amount of energy consumed in its extraction and processing in the course of EV manufacture. As a consequence, more GHG emissions are associated with the original build of EVs. This takes a number of years of lowered in-service emissions to repay. Figure 13 provides the results of modeling this, providing the estimated number of years that an electric vehicle will need to be operated in order to break even.

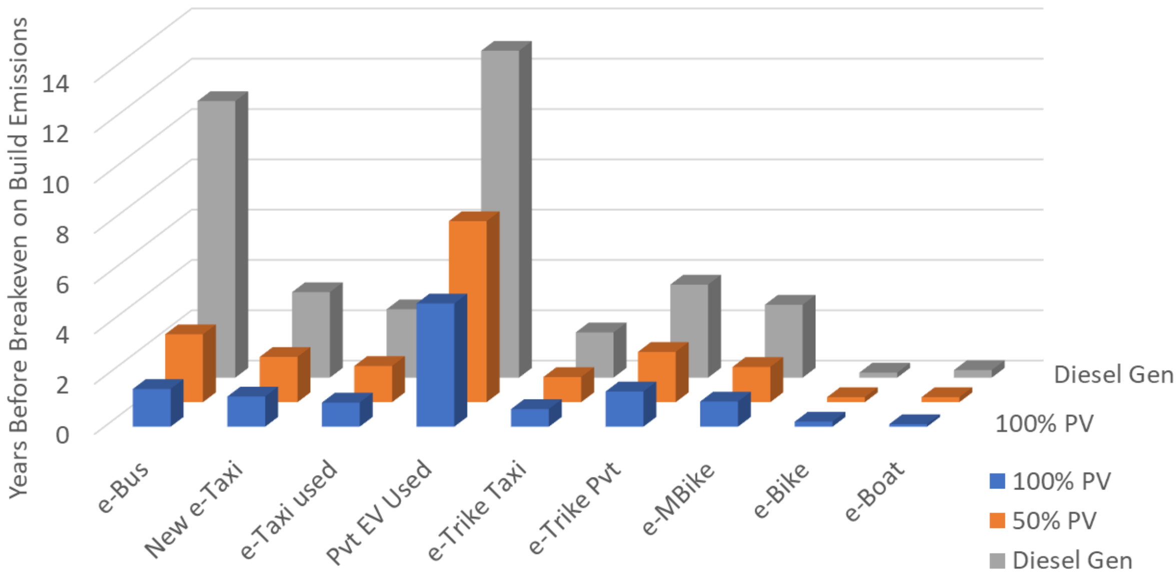

Figure 13: Years of Electric Vehicle Operation to Break Even on the Higher Build Emissions for Different Levels of Solar PV Charging

Referring to Figure 13:

- If charging using diesel-derived electricity only, electric buses and private-use passenger cars take more than ten years (calculated as 11 and 13 years, respectively) to break even on the increased build emissions associated with their electric drive trains. Up to the break-even point, the manufacture and operation of the electric vehicle has not resulted in any CO_2e savings at all.
- Addition of solar PV generation brings about significant step reductions in the time taken to achieve break-even on build emissions. For example, break-even on the additional build emissions of an e-bus are expected to shift from 11 years to around 3 years for a 50% solar PV (or other RE) mix, with operation thereafter resulting in a total life (manufacture plus operation) reduction in emissions.
- The long periods to attain break-even of build emissions for a private passenger car are significantly reduced when the same vehicle is used as a taxi. This is due to the higher kilometres traveled each year, and the accordingly faster accumulation of in-service emission reductions. Note that the break-even period for a used taxi is lower than for a new taxi to account for the proportion of its life (and proportion of emissions payback) the second-hand vehicle was previously used in another country.
- For vehicles on the right of this figure, e-bikes and e-boats have build emission break-even periods of only around two months, reflecting the small drivetrains involved and their correspondingly low build emissions.
- The break-even period for 2- and 3-wheelers is somewhere between that of a private passenger vehicle and an e-bike, owing to the medium-sized electric drive train of the 2- and 3-wheelers.

D.3 Financial – Simple Payback

Despite significant decreases in the price of batteries, motors and motor controllers over the last five years, electric vehicles still command a reasonable premium over their petroleum-fuelled counterparts. But electric vehicles are normally cheaper to maintain and the cost of energy used to operate them far lower. Consequently, the electric vehicle's premium may be recouped within a period that is acceptable to the purchaser, especially with the promise of savings in the pocket after that. Figure 14 provides a first-cut look at this by plotting the results of (simple financial payback) modeling using PICT-representative data. For this modeling, "opportunistic solar PV charging" means free charging through opportunistic capture of excess PV generation, with "100% PV" representing zero marginal energy costs for an EV. Another way to look at this is "50% PV" represents a 50% reduction in the price of electricity used for charging (which, for an average cost of electricity of US$0.34 per kWh[54] is 50% of US$0.34 per kWh, equals US$0.17 per kWh, for the purposes of this modeling – about twice the marginal cost of large hydroelectricity).

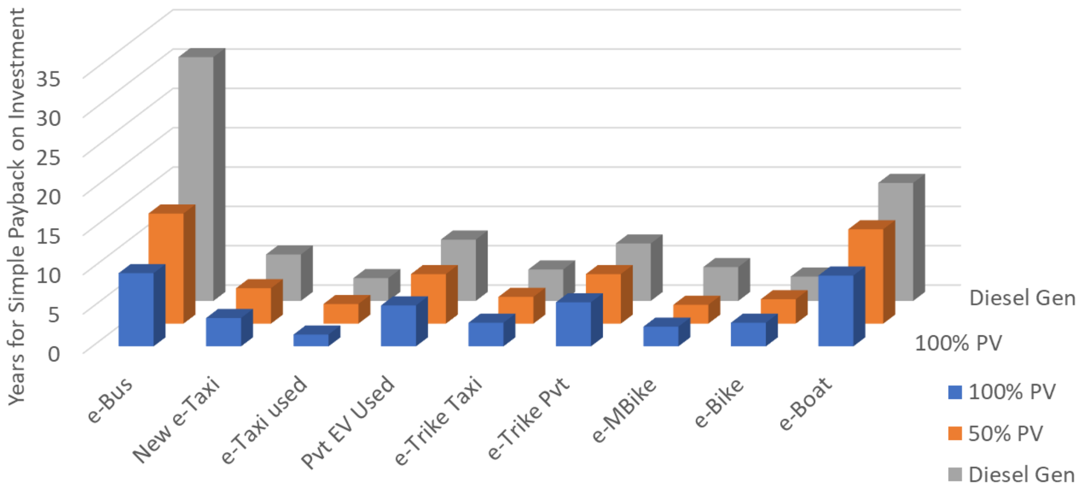

Figure 14: Years for Simple Payback on Initial Premium for an Electric Vehicle Relative to a Near-Equivalent Petroleum-Fuelled Vehicle for different Proportions of Opportunistic Solar PV Charging

Referring to Figure 14:

- These results indicate that, with simple financial payback periods of over 9 years, ownership and operation of e-buses and e-boats is not currently financially attractive, even with zero-cost electricity. This is a function of the very high price premiums involved for the vehicle option. This is expected to change as premiums on electric vehicles fall, but in the case of e-buses and e-boats, significant change could still be five to ten years away (and hence other than financial reasons would be required to justify such projects).
- The lowest payback period (ranging 1.5 to 3 years) comes from used e-taxis (i.e., using second-hand, imported electric passenger cars). Depending upon the supply country, the purchase price can also sometimes reflect the subsidies offered in the country of origin. Moving to a new e-taxi results in a higher price premium, requiring more years to achieve simple payback (ranging from 6 years for current average electricity prices to 2 years with zero-cost electricity/charging). Since private passenger cars are expected to cover less distance in any given year, it will take longer to accumulate the operational savings necessary to recoup the purchase price premium (resulting in a simple payback period of 5 to 8 years).

  Note that ready access to used imports with few controls on specification can result in the import of gasoline-fuelled passenger cars at very low prices that make it difficult even for used electric taxis to compete. In such circumstances, minimum safety, emissions and/or condition specifications and requirements may make an electric vehicle option more attractive. For example, Fiji demands that vehicles are less than five years old from the date of manufacture at the time of landing in Fiji.[55]
- For personal/private mobility, e-motorbike and e-bike options offer the lowest simple payback periods, of between 2.5 and 4.5 years respectively, depending upon the cost of electricity.

Some in the automotive industry believe that several electric vehicle models will be cheaper than their petroleum-fuelled counterparts within as little as 5 years, meaning that purchasers of electric vehicles could begin with a saving at the time of purchase and continue to save

[54] From Pacific Power Utilities Benchmarking Report 2017 Fiscal Year, Pacific Power Association (PPA), September 2018 http://prdrse4all.spc.int/data/pacific-power-utilities-benchmarking-report-2017-fiscal-year
[55] Fiji Customs Service: https://www.frcs.org.fj/our-services/customs/doing-business-in-fiji/motor-vehicles/

during the entire operational life of the electric vehicle. This turning point might be further off for PICTs if they continue to have access to lower-specification vehicles (especially if PICTs do not immediately follow the rest of the world in introducing increasingly stringent emissions standards, which would make it more difficult for EVs to compete). The import of used vehicles is also a significant vehicle source for many PICTs and, despite this providing access to more affordable EVs, their gasoline counterparts are also lower cost.

Appendix E: Background on the EV Market in PICTs

E1. Vehicle Supply to PICTs

PICTs are supplied new and used vehicles from a multitude of countries including Australia, China, Japan, Korea, New Zealand, Singapore, South America and the United States. Some PICTs have minimum vehicle standards at the point of import, including restrictions on the date of manufacture (for example, Fiji and its requirement for used vehicles to be less than five years old at the time of landing. This avoids vehicle dumping and also provides a de facto minimum safety specification when also coupled with vehicle origin requirements).

Direct trade with China allows easy import of all manner of small e-mobility options (although it is recommended that minimum standards are considered for PICTs to avoid a repeat of the "hover board" episode that saw many small, electric 2-wheelers catch fire around the world, as a result of the poor application of new technology).

While the nature of vehicle imports is generally known and some PICTs require annual vehicle registration, the precise makeup of the fleet beyond broad vehicle types is generally unknown.

There is currently a global shortage of light passenger EVs, driven by the European market which has high monetary penalties for manufacturers that do not meet the legislated fleet average fuel economy standards. Global availability of these electric vehicles is also limited by a constraint on battery supply. This situation is expected to change over the next 2-3 years as many new battery manufacturing plants come onstream.[56]

Globally there is currently an accelerating uptake of "micro" mobility with several service providers offering short-term (jump on, use and drop) hire of bikes and push e-scooters. The push e-scooters tend to use cheaper battery types than are used in larger road vehicles and their supply is not constrained as a result. Overseas, the uptake rates have surpassed those for shared mobility such as UBER and Grab[57] and rugged versions (already available at some PICT tourist destinations) have the potential to have wider application in PICTs.

Retrofit conversion to electric propulsion is generally not recommended unless performed by skilled labour and targeting special vehicles, trucks, buses and boats. Otherwise, retrofit is more of a hobbyist activity, although one that can provide valuable knowledge on the technologies involved, which can be an invaluable training tool for vehicle technicians. In this respect, technical courses that result in students building their own (low-voltage) drones or push e-scooters can provide invaluable understanding of electric vehicle technologies, potentially providing a solid foundation from which to enter the EV service industry.

[56] Various articles from European Federation for Transport and Environment AISBL, including https://www.transportenvironment.org/press/electric-car-models-triple-europe-2021-%E2%80%93-market-data

[57] Why You Should Pay Attention to Micromobility, Oliver Bruce, EV World, New Zealand, August 2019.

E.2 Electric Vehicle Market in the PICTs

Currently there are very few EVs in use in PICTs. However, these do include:

- Imported-new Hyundai and BYD (a Chinese manufacturer) light passenger EVs;
- A small number of used Japan-origin electric vehicles from both New Zealand (that were imported used into New Zealand before that) and Japan;
- Small numbers of electric motor-scooters (many made available to tourists);
- At least small numbers of e-bikes (many made available to tourists);
- Small numbers of heavy-duty e-scooters (many made available to tourists);
- At least a small number of push e-scooters; and
- At least one e-boat used to ferry tourists to and from a hotel in Bora Bora, Tahiti.

Some new vehicle suppliers have begun building EV support capacity in PICTs.[58] However, support anywhere other than in main islands is expected to be very limited for at least the near- to medium-term future. Related to this, there is a world-wide shortage of skilled electric vehicle technicians. Retention of those who do become skilled is a real concern to the industry in PICTs considering the attractive offers available overseas.

Apart from these examples, there appears to be very little knowledge of EVs in PICTs. Knowledge gaps create barriers to informed debate and can lead to myths, poor decision-making, higher than necessary costs, and early market failures which risk harming the emerging market. Knowledge gaps must be filled for the sector to progress.

Currently there also appears to be a lack of significant policy supporting or aiding the emerging EV market. While this keeps the market open to new opportunities, lack of guidance can come at a cost. For example:

- The market is not well protected against the import of low-quality equipment. The very early failure of some cheap models of solar PVs due to unsuitability to salty island environments is an example of a market failure, the equivalent of which should be avoided in the EV market.
- There are several charging connector options available to the market and early direction could avoid later user inconvenience and costs.
- Early guidance to direct the industry on the minimum standards required for various types of charging will lessen the risk of the industry establishing unsatisfactory "norms" of its own.

Standardisation of any battery-swapping arrangement (which is likely to be confined to small e-mobility vehicles) is also expected to provide many benefits relating to cost, safety and consumer protection.

As has been detailed in Appendix C, analysis of the economics of electric vehicle ownership and operation in the PICTs and their emissions footprint, indicates early opportunities for taxis and smaller vehicle mobility options, noting:

- The use of EV taxis has the secondary appeal of permitting many people to see and experience an EV themselves. Personal experience from seeing, riding in and/or driving an EV has been found to provide valuable normalisation of EVs, removing many of the barriers resulting from unfamiliarity with the new technology.
- Analysis indicates a reduction in global warming-related emissions even for an e-bus charged with electricity generated from diesel.

Currently electric light passenger cars, buses and trucks are designed more for operation on high-level roads, and not on "island back roads". The automotive industry in Europe is expected to provide the market with over 300 EV models by 2025.[59] However, few of these

[58] Interviews with various New Zealand-based vehicle suppliers that are also responsible for supply in the Pacific Islands.

[59] European Federation for Transport and Environment AISBL https://www.transportenvironment.org/publications/electric-surge-carmakers-electric-car-plans-across-europe-2019-2025

are expected to be fit for purpose for off-road use. This will limit the usefulness of these types of vehicles on some islands.

Many current models of electric 2- and 3-wheelers would be suitable for use in PICs.

E.3 EV Market Growth

There are many factors that need to be aligned in order to bring about EV market growth. These include the provision of charging infrastructure, EV models that are fit for purpose and (especially given the premium that EV buyers pay over the price of equivalent internal combustion engine models) consumer incentives and local policy actions to support their introduction. And fundamental to the adoption of EVs, like any new technology, is the need to supply the marketplace with quality and trusted information: without it, there will be large gaps in people's understanding that will contribute to anxiety, and even to the rise of negative mythology and misinformation. All have been shown to be barriers to the uptake of EVs. The situation in PICTs is no different and hence the development and deployment of an awareness and information campaign is vital to developing the EV market in PICTs.

It is also important to monitor the market to understand where effort is required to bring about change. This type of consumer monitoring and the way in which the findings are used to develop awareness material are exemplified by the regular work carried out by the Energy Efficiency and Conservation Authority (EECA), an agency of the New Zealand government. This results-based development of information is illustrated by the following:

- Consumer surveys found that there was skepticism about the global emissions benefits of electric vehicles, and concern that electric vehicles might actually have a net negative effect on the global environment due to the need for added mineral extraction in their construction and through their disposal. In response, EECA commissioned a life cycle analysis and environmental impact assessment from an international consortium and this work found that electric vehicles used in New Zealand are better for the environment across their lifecycle as well as in use.[60] The results have been woven into various information campaigns since and concern about the emissions benefits of EVs now have a low profile in consumer surveys.
- Consumer surveys also indicated uncertainty about battery life was second only to high price as a barrier to EV purchase. In response, EECA commissioned a report on battery life that provided reassurance on the expected life of the battery.[61] The citizen science study "Flip the Fleet"[62] also presented findings on battery life that provide more certainty over degradation rates. Despite this, EECA's 2019 EV consumer survey still indicates anxiety over battery life to be a significant deterrent to EV purchase, suggesting further promotion of these results is required.

E.3 Shared Mobility:

Among the attractions of electric vehicles are their controllability and low maintenance requirements, which have made them targets for autonomous vehicle use coupled with use in shared mobility platforms. The use of autonomous vehicles will likely come to PICTs in some form, but at this stage it appears very much in the distant future and will not be considered further in this report. Shared mobility platforms such as UBER, Grab and/or Gojek might also come to larger PICT cities, but the services provided are expected to be similar to those of current taxis and the findings concerning taxis in this report are expected to suffice for the time being.

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[60] See https://www.transportenvironment.org/publications/electric-surge-carmakers-electric-car-plans-across-europe-2019-2025 for the links to papers for this work.

[61] See https://www.eeca.govt.nz/news-and-events/media-releases/electric-vehicle-batteries-research-released/ for the links to papers for this work.

[62] Using Citizen Science to Promote Electric Vehicle Uptake in New Zealand Donald Love, Henrik Moller, Dima Ivanov, Daniel Myall, EVS 31 & EVTeC 2018, Kobe, Japan, October 1 - 3, 2018

Appendix F: PICT Electric Supply Market Backgrounder

F.1 Demand Profiles and Meeting Them

As has been described, the per capita demand for electricity is quite varied across and within PICTs. This is a function of many variables, including access to electricity, commercial and industrial use, and affordability of the electricity and the devices that use it, quality of life aspirations, etc., in the case of private use. At one end of the spectrum, a customer may have a fully air-conditioned dwelling/office space and many appliances including refrigerators and entertainment equipment. At the lower end of the energy-use scale, a customer's main electricity requirements may be for lighting (with use of tinned protein avoiding the need for the refrigeration of food).

Beginning with consideration of the main electricity markets, these are grid-supplied, catering to a mix of commercial and private customers. Figure 15, from Wilson et al,[63] shows what the demand profile on an island electricity grid can look like, in this case for Rarotonga.

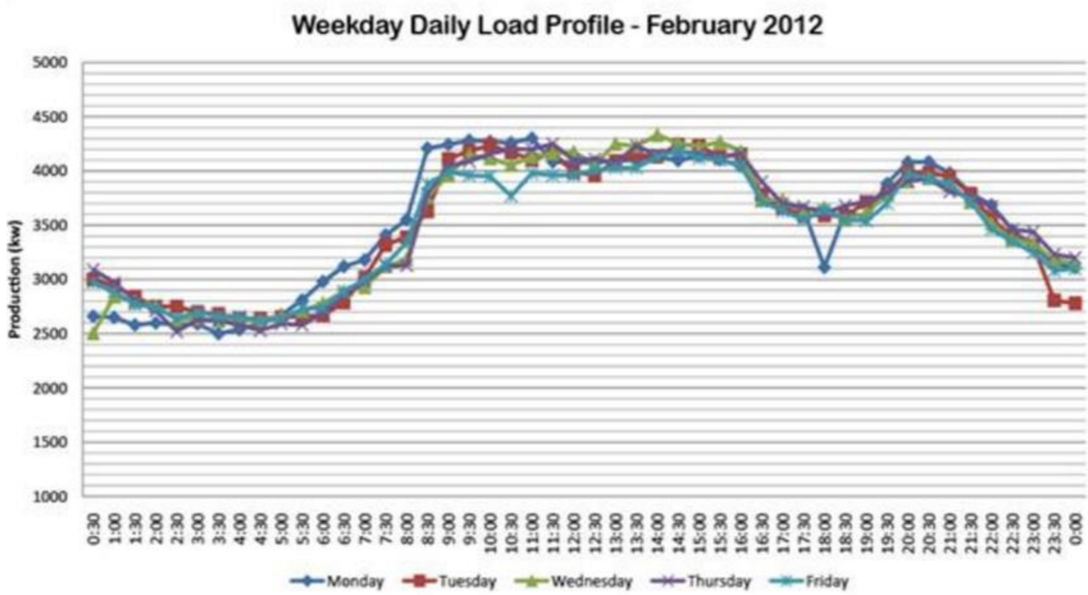

Figure 15: Example of an Electricity Demand Profile for Rarotonga (from Wilson et al)

This profile exhibits many classic features of simple dispatch of generation to meet (unmanaged) demand, noting:

- Lowest demand for electricity for the 5-6-hour period after midnight (likely due to falling demand from air conditioning, as it tends to be a lower demand in cooler climate countries);
- A peak in demand between 8:00 pm and 11:00 pm from (after-work and family time) household activity;
- A solid demand period between 8:00 am and 5:00 pm on working days, most likely from air-conditioning load from commercial customers (and the demand is far less during weekend days).

Putting some perspective on the demand for electricity involved, in terms of what might be provided from connected electric vehicle batteries, if the electricity during the period of darkness was only provided from electric vehicles, this 48,000 kWh would require 3,500 to 5,000 electric vehicles to be connected and actively involved in supporting the electricity grid,[64] which would be approaching half of the number of currently registered vehicles on

[63] Polynesian Pathways to a Future Without Electricity Grids This report was prepared by Peter Wilson (NZIER), Basil Sharp (University of Auckland), Kiti Suomalainen (University of Auckland), and Gareth Williams (Nexgen Energy Solutions).

[64] Based on a current, typical useful EV battery capacity of 20-30 kWh and contributing around 30-50% of this to the grid each evening.

Rarotonga. Such an en-masse involvement would be impractical for many reasons, indicating that in-situ electric vehicle batteries are not practical for providing at-scale base-load (i.e., at urbanised levels of personal energy intensity). Remember also that this battery-stored energy does not just materialise: it requires similar additional generation to charge the vehicles during the day, and then some to account for energy losses associated with charging and discharging batteries. Such an arrangement would also raise questions about battery life under such battery charge cycling, and how this might be compensated for.

However, as discovered through the work carried out in support of this report, there are other ways in which the integration of EVs with electricity supply can be useful. For example, if looking at a scenario where there is low energy intensity (for example, supplying dwellings with lower power requirement because of use of modern refrigerators, lighting and home entertainment systems and no air conditioning), then a single light passenger EV supplying a "village network" could support to the order of ten dwellings through a day, through transfer of less than half a full charge,[65] so long as the EV was available, plugged in, and charged at the beginning. This illustrates the potential of this arrangement in more remote settings. Note that powering older technology refrigerators, entertainment devices and lighting could consume twice as much energy, resulting in less effective use of this arrangement (and indicating the need to continue with demand-side interventions such as Minimum Energy and Performance Standards (MEPS)).

F.2 Electricity Pricing:

Figure 16 provides the average supply costs for electricity for 22 PICT power utilities surveyed in PPA's Pacific Power Utilities Benchmarking Report (2017 Fiscal Year)[66]. This found an average supply cost of around US$0.34 per kWh.

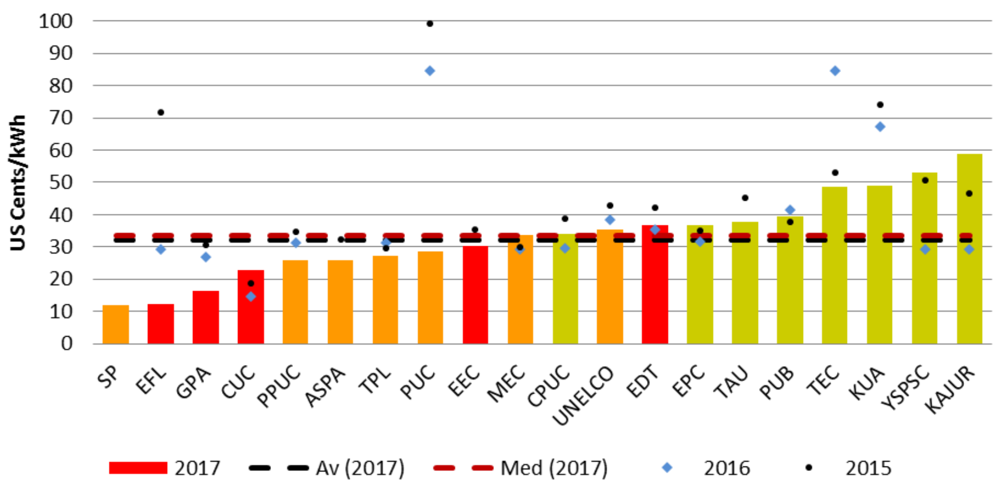

Figure 16: Average Supply Costs (US Cents/kWh) 2017, 2016 and 2015 for different Utilities Operating in the PICTs.

These costs do not provide a good indication of the cost to supply electricity. For example, a high proportion of the electricity of some of these utilities was generated from diesel, and the cost of fuel alone at the time of the survey would have been about US$ 0.32 per kWh.[67] The additional fees built into the above retail rates (only US$0.02 per kWh more, on average) would not cover the fixed costs, indicating that at least some electricity suppliers are subsidising the supply of electricity, or otherwise not charging for electricity at the full, levelised cost of electricity (LCOE). This does not lend itself to an open market and may make

[65] Or an e-motorbike might support a single non-air-conditioned home on half a charge per day.
[66] Pacific Power Association, Sept 2018. http://prdrse4all.spc.int/sites/default/files/2017-fy-benchmarking-report_publication_final-1_1.pdf
[67] The diesel generation fleet in the Pacific averages around 4.0 kWh per litre (PPA Benchmarking Report, 2017) and at the time of the benchmarking the cost of diesel was around US$1.15 per litre. Adding taxes of 10% results in a cost of fuel of around US$0.32 per kWh.

it difficult for new technology projects to compete. On the other hand, the island of Upolu (Samoa) is fortunate to have hydro-generation, which it may be able to dispatch at around US$0.10-0.12 per kWh (based on industry-typical figures), providing an opportunity for both the power company to profit (as the cost is well below the sales price) and EV owners also to benefit (as there is an opportunity to encourage the uptake of EVs, to gain new demand, through promoting lower cost electricity for EV charging).

F.3 Meeting the Demand for Electricity

In a grid situation, the demand for electricity created by customers is met by supply provided by the electricity utilities with the same or possibly separate companies generating, dispatching and distributing the required electricity. The provision of both lower-cost and high-quality power requires careful management of the generation fleet and distribution network assets (including the management of any power correction devices within this electricity supply system). Higher quality power comes at a cost and electricity companies invariably find themselves balancing many variables striving for least cost whilst also meeting minimum power quality specifications.

Providing examples of the sort of balancing required in operation, a partly loaded diesel engine provides "spinning reserve" capable of relatively fast dispatch to counter "events" such as where generators unexpectedly go offline. Hence spinning reserve provides added power quality and security. However, a partially loaded diesel generator is not as fuel-efficient as a near fully loaded one and this results in higher generation costs on a per-kilowatt-hour basis (or "per-unit" basis). Hence the provision of spinning reserve comes at added cost. This has particular relevance for grid systems with higher penetration of intermittent renewable energy (RE, such as solar PV and wind) as additional diesel generation spinning reserve is often called upon to make up for the intermittent nature of the generation from these sources.

Generating and distributing for the peaks in electricity demand is normally provided by "peaking plant" and it is normally both more costly and more carbon-intensive to generate for the peaks, compared with "base load" generation, although the differences are less where operating from a base diesel generation fleet. The peaks in demand might also be constrained by the capacity of the distribution network. The use of "demand response" measures can smooth out peaks — shift demand away from times when it is difficult to supply to times where it is easier. New technology is enabling more forms of demand response.

A common method used globally to encourage demand shift to periods of non-peak demand is TOU pricing of electricity. TOU may be relatively fixed for different periods of the day or it might change half-hourly, with the electricity supplier raising or lowering prices according to the cost to supply. The method is dependent upon the use of TOU- or smart-meters, that can determine what electricity was consumed and when. Samoa is currently preparing to begin a roll-out of smart meters on its main island, although the project had experienced a number of delays and had not started as at November 2019.

Several industries have interruptible demand which could also assist electricity supply companies in managing the demand-supply balance. For example, large fish processing facilities generally have high-demand chilling plant that could be turned down or off for periods of time without risk to their business. This can be a valuable service to an electricity supplier, and one that the electricity supplier may contract and pay for, even if only utilised intermittently.

F.4 Use of Renewable Energy

Use of renewable energy (RE) provides PICTs with mechanisms to lower the carbon footprint of electricity and mobility. The RE options in use in PICTs include dammed and run-of-river hydro, solar thermal, solar photovoltaics (PV), wind and biodiesel. Hydro (in non-dry years) and biodiesel provide dispatchable generation – supply can be called upon when required. Wind is less reliable in the PICTs. Solar thermal provides hot water and already has an easy storage mechanism – a hot water cylinder – to allow a delay between the time of generation and demand. For these reasons, consideration of integrated RE and EV battery storage will focus on solar PV in this report.

F.5 Solar Photovoltaics

Solar PV is a relatively flexible generation option due to the wide scale that it can be deployed at, from thumb-nail sized panels on wristwatches to vast arrays covering several hectares.

Photovoltaic panels themselves generate DC electricity and for small-scale solar PV systems, it is easy enough to generate and regulate a low-voltage DC electricity supply, including regulating for charging modern batteries. But there are also three main solar PV system configurations that provide mains-quality AC electricity, namely: grid-tie; off-grid (or island); and hybrid.

A grid-tied PV arrangement is dependent upon the grid for its operation, including the provision of a frequency signal for the solar system's AC inverter to follow – if the mains electricity supply goes down, so does the generation of electricity from the solar PV system. The connection with the grid also provides for load balancing, with the difference between demand from the consumer and PV generation provided by the grid, and including the export of electricity to the grid where PV generation is above local demand. Compensation for exported electricity is normally provided through a "net-metering" arrangement with the electricity provider. This arrangement normally accounts for both electricity imported and exported, and can use quite different tariff structures for the two such that, in cases where the return for exported electricity is small, it tends to be better to consume all electricity generated on site whenever possible.

The advantage of grid-tied systems to the user is that they avoid (costly) battery and related power systems, with an overall reduction in the total cost of electricity, together with the security of access to normal electricity supply from the grid. The advantage to the electricity supplier is the potential for distributed electricity supply at low cost (but only if generated in excess of the immediate site requirements). The disadvantages to the electricity supplier include the intermittent nature of the demand, the loss in revenue from reduced kWh sold, and the potential for peaks in demand (which for PICTs often occurs in the early evening when there is little PV solar generation) to be just as significant (with the associated fixed costs divided across less electricity consumption often resulting in a higher per-kWh cost to supply).

Off-grid or island systems operate independently from the grid and use battery storage to balance the time of generation with the time of demand. The required battery capacity is dependent upon the demand outside peak (sunshine) radiation hours and on what demand avoidance and/or backup systems are available should solar PV generation be low for a period (for example, in the case of a multi-day weather event).

Up until relatively recently, lead-acid batteries have been the most cost-effective battery storage option, despite the relatively high costs associated with their maintenance and disposal. The improved performance and robustness of modern lithium battery systems, and their falling costs, is changing this.

Hybrid systems, as the name suggests, are a hybrid of grid-tie and off-grid solar PV systems, the battery backup providing for off-grid operation should the grid go down. This tends to be the most expensive solar generation configuration because of the additional equipment involved in essentially providing two different systems, plus battery storage. However, circumstances might allow the use of a (lower-cost) lower capacity battery storage (i.e., with careful management and switching electrical load to a far reduced demand when the grid is down).

At a more detailed level, solar arrays are combinations of solar cells each with an open circuit voltage of around 0.66 to 3 volts, which generate a DC current when connected to an electrical circuit. For mains supply arrangements, the solar cells are connected in series and in parallel to provide the necessary supply voltage and current to the system's DC-to-AC inverter.

This system can be significantly downsized and simplified if only low-voltage DC power is required. Demand from marine and land-based mobile applications has resulted in the availability of a wide range of "plug-and-play" low-voltage PV and related componentry, mainly targeting 12V and 24V systems. It is likely that 48V will also become a common platform for these and other off-grid systems.

In a grid or local electricity network situation, first additions of solar PV can provide electricity at relatively low cost due to the ability to rely on the backup of the diesel generation (or other grid/network base generation) and to avoid the installation of battery systems. However solar PV becomes difficult above around 20% penetration on local networks and above around 40% if more distributed on a grid system, due to instability, and tends to require storage and/or other devices to maintain electricity security and quality. Note that these numbers are far from exact as an electricity generation and supply system can be highly complex and vary in robustness and how stressed they become – the more robust a system is, the higher the amount of solar PV penetration that can be tolerated.

These limitations come about because the generated output from solar PV panels is high under direct sunlight, and low even with partial shading. On a partly cloudy and windy day, which is a relatively common event in PICTs, output from a single array of panels can fluctuate wildly as the clouds pass over. If the panel arrays are more distributed, this on-off generation is less likely to affect all panels at the same time, allowing for greater PV penetration. Without some means of tempering these fluctuations, however, as the penetration increases the base diesel (or other) generation is pulled back and what remains operating has to work harder at load-following (with larger changes of load factor on each generator), which is harder to do. What's more, the remaining base generation fleet has less physical inertia to manage fluctuations in the electricity demand and supply balance, and is less efficient in generating electricity. Note that although new technology and power electronics have improved electricity regulation, they still do not have the presence that is provided by the inertia of spinning metal from hydro or the diesel generation fleet.

Poor quality electricity, possibly leading to outages, occurs when the demand and supply balance can no longer be maintained.

The inclusion of battery systems and other power regulation devices enables higher PV penetration to be deployed, while still maintaining power quality, but this comes at added expense. While the initial solar PV additions may have come at a relatively low "Levelised Cost of Electricity", or LCOE (which is the life-time costs of electrical plant divided by life-time electrical throughput, expressed in $/kWh for this report), subsequent solar PV additions require additional devices to maintain grid stabilisation and/or to provide for shifts in time between time of generation and time of supply, and the cost of electricity supply then incurs the cost of the additional LCOEs of those devices.

For example, the cost of solar PV could start at an initial LCOE of around US$0.15/kWh for a simple, large grid-based solar array installation. Increased penetration will incur additional balancing costs. Any shift in time of supply from the time of generation (providing similar flexibility to diesel generation) will require storage and incur LCOEs for that storage. This could raise the LCOE of solar PV along with necessary supporting systems to above US$1.00/kWh (over six-fold more), indicating that a careful balance is required when specifying such systems. (Note also that this LCOE is not directly comparable with the average supply cost of electricity provided earlier, which does not appear to have asset-related costs included).

F.6 Electricity Storage

Energy storage can take various forms including batteries and capacitors storing electrical energy directly, flywheels and pumped hydro (the latter which can provide at-scale energy storage with a long shelf life). Most storage incurs losses somewhere in the process of storing and retrieving energy. For example, even for modern batteries, around 10-20% of the electrical energy can be lost through the storage and retrieval process.

This project concerns the potential use of electric vehicle batteries for energy storage in support of non-transport electricity supply and therefore the focus of this report is on battery storage options.

There is a long history of the use of (then relatively expensive) battery storage in Uninterruptable Power Supplies (UPSs), used for protecting valuable electronic assets, and to provide convenience in off-grid electricity supply arrangements. Recent significant decreases in the costs of usable battery storage[68] have made many new technologies possible, from cell-phones to new mobility options. And the lowering costs are now also enabling the use of batteries to support electricity networks and grids, especially where they contain intermittent generation such as solar PV. The use of such Battery Energy Storage Systems (BESSs) will become more viable as the LCOE of battery storage systems continues to fall, which is recognised by the suppliers of grid power systems, with many actively involved in developing and tooling up for the manufacture of (often skid-mounted or containerised) BESSs to be market-ready within the next 1-2 years. There are, of course, some early leaders already in the field.

Battery storage can provide the following functions:

- Energy storage to provide for time shifts between electricity generation and demand/supply;
- Regulation, including that provided by “voltage up” and “voltage down” corrections; and
- Spinning reserve, or backup power (as it is more correctly termed for battery systems), for providing fast response to supply events on the networks.

There are also two ways that battery systems can be used to supply power:

1. All electricity running through the batteries, the batteries providing an almost isolated buffer between generation and supply. It is this arrangement that is used in UPSs for many remote, standalone power systems. It is also the configuration used in “series” plug-in hybrid electric vehicles where the battery stores electricity supplied by plugging into an external supply, or from a generator on the gasoline or diesel engine, and only carefully regulated electricity is then supplied from the battery to the electric motor.
2. Connected in parallel and managed to provide required export and import to the electricity network.

A recent example of the last is the installation of a 3MWh lithium BESS in Niue which, along with solar PV, has reportedly avoided the operation of diesel generators for up to 12 hours a day on sunny days.[69] As an addition to the grid (rather than the grid running through it), the BESS can be smaller. This can be used to delay the start-up of diesel generation as demand increases following its daily profile (i.e., and reduce the amount of diesel generation), and to bring about earlier diesel generation shutdown as demand decreases, following its daily demand cycle. The degree to which diesel generation can be avoided by this means depends upon the capacity of the battery storage, the intermittency of the generation at the time (i.e., the level at which diesel or other generation is required to provide grid stability) and the amount of solar PV generation on the day (to name but a few of the factors). The Niue example mentioned above could be considered to be a large storage capacity example of this, avoiding long hours of diesel generation. Smaller storage capacity may only afford an hour or more of diesel generation avoidance.

F.7 The Application of Electric Vehicle Batteries.

By their nature, the batteries used in electric vehicles are fast response (of the order of 3C[70]) compared to the type of battery normally specified for supporting power systems, making them well suited to supply quite variable and rapidly changing demand profiles if the associated power electronics can provide for this. This is why used automotive battery packs are sought after for power backup and off-grid electricity supply systems. There is the potential for a relatively small population of EVs to have a reasonable influence on the kind of smaller electricity systems found in PICTs in the near future.

[68] A function of improvements in technology increasing the practical number of possible discharge and recharge cycles, the “depth of discharge” of those cycles, and the energy density of batteries, resulting in much greater usable capacity over the life of the battery

[69] https://www.vector.co.nz/articles/turning-evs-into-power-sources-(1)

[70] A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. A 3C rate means that it will do this in 20 minutes (1 hour/3).

However, the ability to use an electric vehicle's propulsion battery, in situ, is complicated by a number of factors, including:

- Electrical access to the propulsion battery should only be made through the DC contacts of a vehicle's onboard charging port. Such contacts are only available on electric vehicles with fast-charge capability, which is not all EVs. Retrofit of vehicles to provide the equivalent is unwise due to the very high voltages involved and such practices should not be encouraged.
- Even then, draw from the propulsion battery needs to be managed and controlled following OEM protocols, in order to preserve the management of the battery and how the sate of charge (SOC), range and other parameters are reported by the vehicle's monitoring and display system. The industry reports that this integration has been successfully achieved for some model EVs that use the CHAdeMO protocol, but that vehicles that use the CCS protocol have proved to be more difficult to integrate. The risk is that use of the battery that is unregistered by the vehicle's systems could render many of the display functions useless, and/or result in false alarms (not to mention breach of warranty, if this applies, etc.) and will introduce compromises associated with these; and
- As vehicle onboard management systems are generally becoming more sophisticated over time, there is the risk that export of power from an in situ EV propulsion battery will become more difficult (and there is currently little incentive for OEMs to make it easy for third parties to have such access to the batteries).

Furthermore, a vehicle-to-grid (V2G) arrangement requires the export of electricity to the grid to be managed by those responsible for the supply side of the grid, requiring a grid-to-vehicle, vehicle-to-grid and owner-to-system communication (the ability of the vehicle to export electrical energy, including the requirements of the vehicle owner's needs to be known at any time the vehicle is connected), entailing relatively complex communication protocols and encryption, complex control algorithms and robust, integrated grid-and-vehicle control systems. Market-proven methods of how to compensate a vehicle owner for the use of their vehicle's battery (and possible earlier degradation because of this use) have also yet to be developed.

A dispersed V2G storage service appears years away from becoming commercially ready. Because of these timeframes, and how much may change in the meantime, it is difficult to forecast what preparedness is required for the transition. It is therefore recommended that a watching brief only be maintained on V2G developments.

Avoiding those parts of a V2G system that are unlikely to become commercially available in the near future entails removing the ability of the vehicle's systems to communicate with the electricity supplier, which leaves the possibility of creating a vehicle-to-local premises electricity supply (i.e., vehicle-to-home (V2H) and vehicle-to-business (V2B), and possibly a vehicle-to-local village network service, as an extension of this). In a simplified version of this arrangement, a V2H device is plugged into the fast charging port of the EV and the device's power inverter changes the DC supply into an AC supply suitable for supplying local, isolated circuits. A more sophisticated arrangement is for the V2H device to be connected to the premises' switchboard and for the inverter to produce an AC waveform that matches that of the grid; management of the current from the V2H device allows export from the vehicle's battery but not export from the premises to the grid.

From the point of view of increasing the overall proportion of RE use, V2H only makes sense if the vehicle were charged with RE-derived electricity (otherwise there is no saving in petroleum fuel use: in fact, petroleum fuel use would be expected to increase for V2H supply from diesel-derived charging due to the inefficiencies of charging and discharging batteries).

Both simple and grid-connected CHAdeMO V2H devices are on the cusp of commercialisation with many units involved in demonstration projects around the world, a small number of suppliers in China advertising availability of simple V2H units, a smaller number advertising grid-connected V2H devices, and some notable OEMs taking interest in this market sector and expected to provide approved product within the next year.

The next simplification of this use of the vehicle's battery is removing the ability of the vehicle to perform the necessary communications to export electricity, which reduces the arrangement to one of controlling when, and possibly at what rate, charging occurs. Many models of EVs and/or chargers now provide some degree of "set-and-forget" management of charging: for example, allowing an EV operator to set the start of charging when electricity rates switch to low rate.[71] This is sometimes referred to as "smart charging". An unintended consequence of this is many EV owners may choose to start of charging at the moment the low rate electricity period begins and produce a secondary peak in demand at that time if there are many EVs involved.

Use of electricity smart meters or other two-way communication systems with compatible, controllable chargers enables (far smarter) third-party control of charging events (still without the need to enter into detailed communication with the vehicle's systems) and provides a base for "managed charging", sometimes also referred to as "unidirectional managed charging" (or V1G). There can be reasonable flexibility in when a vehicle's battery is charged and managed charging can take advantage of this by shifting the "new demand" from charging of a growing EV fleet to periods when it is cheaper or otherwise advantageous to generate and supply electricity, including the low-demand periods when supply infrastructure has available capacity.[72] In such a situation, cost savings are normally shared with clients through reduced electricity fees and/or participation credits (thus providing incentives for voluntary participation in managed charging).

Managed charging also enables the electricity supplier (or other third-party controller) to reduce demand in response to supply system events, with the potential to make essential supply more reliable.

Managed charging normally requires an element of communication with the electric vehicle's owner to ensure that the vehicle has the required range when required. Simple client-need models that have been used for this include the owner simply signalling an "opt out" of third-party control of charging on a particular day.

Similar to V2H, third-party managed charging technology has been demonstrated around the world and is on the cusp of entering a more open-market phase of development.

Continuing on this pathway, on-site managed charging is a step simpler again than third-party managed charging. Management of charging is performed on-site and in concert with other on-site demand for electricity (e.g., to avoid total demand from the site exceeding permitted thresholds) and/or on-site RE generation (for example, to minimise the export of RE generation to the grid). Compared with third-party managed charging, this can be achieved with the use of relatively simple control systems and the fact that control is on-site avoids the need for two-way communication with third parties. With EVs actively charging, this arrangement can also smooth any export supply to the grid and, in theory, higher penetration of solar PV should be possible with this distributed RE model. However, a risk with this approach is the dependence on charging EVs to provide stability. An electricity supplier would likely demand greater reliability than this.[73]

As an illustration, let's apply these to the example of Samoa's main island, which normally has significant spare hydro-generation capacity, and spare distribution capacity to deliver it over the late evening to early morning low electricity demand period. TOU electricity pricing for EV charging has the potential to encourage a significant proportion of EV charging to these off-peak periods, with the benefit that such charging could provide the electricity supplier with significant new demand that could be met with minimal upgrade to the grid infrastructure

[71] Electricity suppliers might set different time-of-use tariffs to encourage a shift in demand to times when it is more economic to supply electricity and/or to avoid peaks in demand

[72] Electricity suppliers sometimes refer to this as placing new demand in times when the additional costs to supply electricity are at "marginal cost" which, for petroleum-fuelled generation, is only at the cost of the additional fuel consumed.

[73] In theory, this risk could be better managed through knowing the availability of charging EVs, but this circles back to requiring real-time communication with the grid electricity supply controllers, and this communication would arguably be better used for third-party managed charging control.

(i.e., limited to the deployment of TOU or smart metering), with the additional electricity supplied at near marginal costs, and the EV owner benefiting from the lower off-peak tariffs.

Further upgrade to include managed charging would allow the electricity supplier to manage the new demand more cleverly. Sharing the cost advantages with the EV owner would incentivise high participation (and make EV ownership more attractive), and hopefully avoid many EV owners opting out of the management of their EV's charging by the electricity supplier (e.g., through the likes of the use of portable EV chargers simply connected to non-managed mains socket outlets, and electricity supplied at normal electricity tariffs).

Due to these benefits, the potential for EV charging to develop into a significant component of overall electricity demand for larger islands, and the expected small incremental cost to provide managed charging once it becomes globally mainstreamed, it is recommended that a watching brief is maintained on global managed charging developments and appropriate international standards are adopted as soon as they become sufficiently developed to provide a strong signal of intent to the marketplace.

Note that it would normally be more efficient to use non-dispatchable RE (i.e., solar- and wind-derived generated electricity) directly at the time of generation rather than go through the inefficiencies and additional costs associated with electricity storage and re-supply. This being the case, for integrated RE/EV options to be useful, there would need to be times when the dispatchable RE generated is in excess of total demand.

Further consideration of the potential for these various electric vehicle-electricity supply combinations is provided in the main body of the report.

F.9 Other Vehicle Battery Options

Another multi-purpose battery arrangement that might work for both electricity supply and mobility is battery swapping. Battery swapping is where a battery is removed from the vehicle for charging, and the vehicle is fitted with a charged battery, avoiding any significant downtime. There are a few models of battery swapping in several overseas markets, including China and Europe for buses and taxis, and the Philippines for e-trikes. This creates an opportunity for a number of different service provider arrangements, from independent providers offering charging-only services, to models where ownership, maintenance and charging of the batteries is provided by a third party and the end-user pays a service or hire fee for the use of the battery.

The Philippines e-trike battery-swap example is technology that appears to be suitable for some PICT circumstances. In the case of the Philippines, the e-trikes were fitted with two 1.1kWh batteries that were simply lifted out and swapped during the day, as required. The expected daily electricity demand from a dwelling for lighting, refrigeration and entertainment is less than 1 kWh, and safely within the capability of 2.2kWh of battery storage. For this situation, the exercise would be one of ensuring that charging and swapping of several batteries provided the required energy for both dwelling and transport.

Applying the same battery-swap solution to a dwelling only requiring lighting, small device charging and entertainment, this demand would be well within the supply capabilities of a low-voltage battery used on an e-bike, which could be direct-charged using a simple low voltage solar PV system.

Appendix G: PICT Profiles

In developing this report, a wide variety of information and statistical sources for the PICTs, relevant to the topics covered, were identified and consulted. A summary of these is presented in five tables:

- Table 3: Most relevant Nationally Determined Contributions Targets;
- Table 4: Key socio-economic and geographic statistics;
- Table 5: Key vehicle sector statistics;
- Table 6: Key fuel sector statistics;
- Table 7: Key electricity sector statistics.

Notably these show the significant variation in the datasets amongst the individual PICTs. This makes it near-impossible to prescribe a one-size-fits-all solution to meeting individual Nationally Determined Contribution targets under the protocols of the 2015 Paris Agreement on Climate Change.

PICT	Summary of relevant Nationally Determined Contribution Targets [74]
American Samoa	--
Cook Islands	100% renewable electricity by 2020
Federated States of Micronesia	Unconditionally reduce by 2025 28% of GHGs below emissions in year 2000
Fiji	Approach 100% renewable electricity by 2030
Guam	
Kiribati	Reduce emissions by 13.7% by 2025 and 12.8% by 2030 compared to a BaU projection
Marshall Islands	Reduce emissions to at least 32% below 2010 levels by 2025 and to at least 45% below 2010 levels by 2030
Nauru	Replace substantial part of diesel electricity generation with a large-scale grid-connected solar PV system
Niue	--
Northern Mariana Islands (CNMI)	--
Nouvelle-Calédonie	15% reduction in emissions from the transport sector from 2010 to 2030
Palau	45% renewable energy by 2025
Papua New Guinea	100% renewable energy in electricity generation by 2030, subject to funding
Pitcairn	--
Polynésie Française	15% reduction in emissions between 2020 and 2030
Samoa	Conditional 100% renewable energy in electricity generation through to 2025
Solomon Islands	Reduce emissions by 12% below 2015 level by 2025 and 30% below 2015 level by 2030 compared to a BaU projection
Tokelau	
Tonga	50% of electricity generation from renewable sources by 2020
Tuvalu	100% reduction in emissions in electricity generation by 2025; reduction in energy sector emissions by 60% below 2010 level by 2025
Vanuatu	Approach 100% renewable electricity by 2030 subject to financial and technical support
Wallis et Futuna	50% renewable energy by 2030 and energy autonomy by 2050

Table 3: Most relevant individual Nationally Determined Contributions Targets under the protocols of the 2015 Paris Agreement on Climate Change

[74] https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx

PICT	Population, 2018 [75]	GDP per capita, USD [62]	Land area, km² [62]	Paved and unpaved roads, km [76]	Urbanisation 2018, % [77]
American Samoa [78]	56,700	$11,667	199	241	87
Cook Islands	15,200	$19,183	237	320	--
Federated States of Micronesia	105,300	$3,154	701	388	23
Fiji	888,400	$4,274	18,333	3,440	56
Guam	172,400	$34,177	541	1,045	95
Kiribati	120,100	$1,533	811	670	54
Marshall Islands	55,500	$4,032	181	2,028	77
Nauru	11,000	$9,393	21	30	100
Niue	1,520	$15,586	259	120	--
Northern Mariana Islands (CNMI)	56,200	$22,298	457	536	92
Nouvelle-Calédonie	285,500	$31,418	18,576	5,622	71
Palau	17,900	$16,262	444	--	80
Papua New Guinea	8,558,800	$2,384	462,840	9,349	13
Pitcairn	49	$2,353	47	--	--
Polynésie Française	277,100	$18,231	3,521	2,590	62
Samoa	196,700	$4,208	2,934	2,337	18
Solomon Islands	682,500	$1,647	28,230	1,390	24
Tokelau	1,400	$7,069	12	--	--
Tonga	100,300	$4,024	749	680	23
Tuvalu	10,200	$3,537	26	8	62
Vanuatu	304,500	$2,682	12,281	1,070	25
Wallis et Futuna	11,700	$10,938	142	--	--

Table 4: Key Socio-Economic and Geographic Statistics

[75] https://sdd.spc.int/topic/population-estimates-and-projections
[76] https://www.cia.gov/library/publications/the-world-factbook/rankorder/2085rank.html
[77] https://data.worldbank.org/indicator/sp.urb.totl.in.zs
[78] https://americansamoa.prism.spc.int/

PICT	Registered vehicles per 1,000 people[79]	Registered vehicles all, 2013 [67]	Registered buses, 2013 [67]	Vehicle Right Hand Drive (RHD) or Left Hand Drive (LHD) [80]
American Samoa [81]	--	9,395	--	RHD (LHD common)
Cook Islands	669	12,453	31	RHD
Federated States of Micronesia	81	8,337	138	LHD (RHD common)
Fiji	100	86,535	--	RHD
Guam	--	--	--	LHD
Kiribati	32	3,452	289	RHD
Marshall Islands	40	2,116	63	LHD
Nauru	--	--	--	RHD
Niue	--	--	--	RHD
Northern Mariana Islands (CNMI)	--	--	--	LHD
Nouvelle-Calédonie	--	--	--	LHD
Palau	405	7,102	--	LHD (RHD common)
Papua New Guinea	11	94,297	10,812	RHD
Pitcairn	--	--	--	RHD
Polynésie Française	--	--	--	LHD
Samoa	92	17,449	236	RHD
Solomon Islands	79	45,000	--	RHD
Tokelau	--	--	--	RHD
Tonga	78	8,154	--	RHD
Tuvalu	--	--	--	RHD
Vanuatu	53	14,000	--	LHD
Wallis et Futuna	--	--	--	LHD

Table 5: Key Vehicle Sector Statistics

[79] https://www.adb.org/publications/key-indicators-asia-and-pacific-2018
[80] Rental car websites and individual PICT driving guides
[81] https://americansamoa.prism.spc.int/

PICT	Fuel imports, % GDP 2015 [82]	Gasoline consumption in transport 2016, 1,000 tonnes per year [83]	Diesel fuel consumption in transport 2016, 1,000 tonnes per year [84]	Average retail gasoline price inc. taxes, USD per litre 2018 [85]	Average retail diesel price inc. taxes, USD per litre 2018 [72]
American Samoa	--	31	--	0.94	0.98
Cook Islands	5.9	6	7	1.58	1.53
Federated States of Micronesia	12.9	18	7	1.11	1.26
Fiji	11.2	114	100	1.03	0.89
Guam	--	--	--	1.15	1.23
Kiribati	10.3	3	5	0.91	1.15
Marshall Islands	11.9	12	16	1.40	1.58
Nauru	9.6	1	2	--	--
Niue	11.8	1	>1	1.83	1.84
Northern Mariana Islands (CNMI)	--	--	--	--	--
Nouvelle-Calédonie	--	71	127	1.40	1.18
Palau	12.9	3	3	1.17	1.22
Papua New Guinea	6.6	360	360	1.13	1.03
Pitcairn	--	--	--	--	--
Polynésie Française	--	51	28	1.29	1.31
Samoa	6.4	26	18	1.06	1.08
Solomon Islands	7.1	7	7	1.16	1.19
Tokelau	--	--	--	0.96	0.86
Tonga	11.2	15	>1	1.23	1.26
Tuvalu	16.3	1	--	1.44	1.43
Vanuatu	5.3	8	26	1.39	1.39
Wallis et Futuna	--	1	11	1.86	1.71

Table 6: Key Fuel Sector Statistics

[82] Pacific Fuel Price Monitor
[83] UN Data http://data.un.org/Data.aspx?d=EDATA&f=cmID:MO&c=2,5,6,7,8&s=_crEngNameOrderBy:asc,_enID:asc,yr:desc&v=1
[84] UN Data http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aDL
[85] Pacific Fuel Price Monitor http://prdrse4all.spc.int/sites/default/files/pfpm_2018_final.pdf

PICT	Electricity Consumption per capita, kWh per year [86]	Renewable electricity share of total electricity output 2015, % [87]	Access to electricity, % of population 2017 [88]	Average domestic electricity price if consuming 200 kWh/month, USD/kWh [89]
American Samoa	2,806	0.9	--	0.58
Cook Islands	1,411	8.2	--	0.84
Federated States of Micronesia	493	1.6	80.8	0.48
Fiji	925	45.0	96.0	0.16
Guam	9,188	0.0	100.0	0.15
Kiribati	174	7.3	98.6	0.30
Marshall Islands	1,415	0.2	94.8	0.36
Nauru	2,250	0.4	99.6	0.19
Niue	1,858	2.0	--	--
Northern Mariana Islands (CNMI)	6,068	--	--	--
Nouvelle-Calédonie	10,801	14.1	100.0	0.34
Palau	3,475	0.0	100.0	0.35
Papua New Guinea	480	34.5	54.4	0.26
Pitcairn	--	--	--	--
Polynésie Française	2,253	32.0	100.0	0.25
Samoa	601	30.4	99.9	0.10
Solomon Islands	141	2.3	62.9	0.79
Tokelau	--	--	--	--
Tonga	463	5.9	98.0	0.19
Tuvalu	716	28.2	100.0	0.34
Vanuatu	219	21.3	62.8	0.75
Wallis et Futuna	1,194	0.0	--	--

Table 7: Key Electricity Sector Statistics

[86] https://unstats.un.org/unsd/energy/pocket/2018/2018pb-web.pdf
[87] https://datacatalog.worldbank.org/dataset/sustainable-energy-all
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