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Renewable Energy in the Pacific Islands:

An overview and exemplary projects

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INTRODUCTION

The Agence Française de Développement confided this study to the Airaro[1] consulting firm, which is based in French Polynesia, in consultation and unanimous agreement with the Polynesian Ministry of Public Works, Energy and Mines, the services of the High Commission of the French Polynesian Republic and the Agence pour le Développement et la Maîtrise de l'Energie (ADEME, Agency for the Development and Management of Energy).

The objective of this study was to provide an objective documentary source, relevant and usable for institutional and economic players at a regional colloquium on renewable energies which was to be organized by the French Polynesian community and the High Commission of the Republic in the second quarter of 2014. However, the date was put back due to local political changes which occurred following the last territorial elections (mid-2013).

More largely, in the context of the fight against climate change, the subject of renewable energies takes on considerable importance. A large number of island States in the Pacific zone are extremely dependent on fossil fuels, and in the coming years, will face major impacts related to climate change (biodiversity, rising sea level, food security, ...). It should be noted here that the small island countries (notably those of the Pacific) which belong to the intergovernmental organization AOSIS (Alliance of Small Island States), constitute a real lobbying force in the face of large industrialized countries at climate negotiations. Images of the Maldives' Council of Ministers meeting underwater demonstrate the will of small island States to make themselves heard at the highest levels. The notion of "climate refugees" is not a mere idea; it could soon become a veritable legal concept.

This study in no way claims to meet these challenges, but strives to highlight some solutions which are working ("good practices" in donors' terms), in order to propose adapting or replicating them. The accepted approach is thus above all positive and constructive: solutions exist, sometimes at low cost, and the projects help give Pacific peoples the feeling that they belong to wider global community, not to mention a sometimes small but important part of their harmony.

The Agence Française de Développement wishes to thank all institutional and economic partners, as well as the intergovernmental bodies of the Pacific region, whose documents and analyses made this study possible.

1 Context and energy maps of the different countries

1.1 Introduction

<u>Data sources</u>

The documentation on renewable energy in the Pacific is rather rich, considering the size of the territories in question. Many attempts at harmonizing this data have been made in recent years. Key data, such as the production of energy by source, is now available for nearly all Pacific Island Countries and Territories (PICTs)[2]. Here, the work performed by the International Renewable Energy Agency (IRENA) and the Secretariat of the Pacific Community (SPC) must be recognized.

Among the recurring documents are a large number of master plans, investment plans and declarations of intent which are regularly renewed. The documents set high ambitions: 50, 75 and 100% renewable energy in the energy mix by 2015 or 2020. Unfortunately, the lack of funding, time or political coherence, it is common to see that the resulting number of concrete projects is much lower, and the corresponding feedback is even less. Finally, in order to go beyond the bibliographic study, we have chosen to expand the number of information sources and contact the various project leaders directly.

The different bibliographic sources can be found at the end of this document.

<u>What is an exemplary project?</u>

A project may be exemplary under several criteria: high impact on the energy mix, innovative financing, respect for the environment during project implementation, development of local resources, beneficial social aspects, etc. Even if the impact on the mix was the determining factor, we have done our utmost to choose examples varying in size, setup and implementation.

In the end, the criterion defined with AFD was to select projects **<u>whose replication elsewhere is desirable</u>**. Thus no project was chosen for "negative exemplarity", and to the degree possible, in each case we have insisted on the conditions necessary to renew the approach on other islands.

For all that, none of the projects presented here are perfect. All have certain points which could be improved, or points where vigilance must be exercised in the event that similar projects are carried out, and we have done our best to highlight this.

<u>Scope and limits of the study</u>

The geographical scope of the study initially included all small island States of the Pacific, Australia, New Zealand, and French territories in the Pacific (New Caledonia, French Polynesia and Wallis and Futuna).

However, given the hugely different sizes of these countries, the issues at hand are not always comparable. In particular, Australia and New Zealand develop their energy sectors on a continental scale, whereas all the other countries (with the possible exception of New

Caledonia) manage much smaller networks. Figure 1 illustrates these differences: Australia consumes 45 times the energy as all the island States combined[3]. New Zealand's consumption is 7 times that of the other area countries.

Figure 1. Electricity production comparing Australia, New Zealand and the totality all other area countries

Australia 244 GWh

New Zealand 40 GWh

Others N Cal 5.4 GWh

Source: International Energy Agency (IEA), IRENA.

Consequently, most New Zealander and Australia projects, by their very size, are impossible to duplicate on the other Pacific islands. For this reason, readers will find no New Zealander or Australian example in this study: they do not meet the "replicability" criterion.

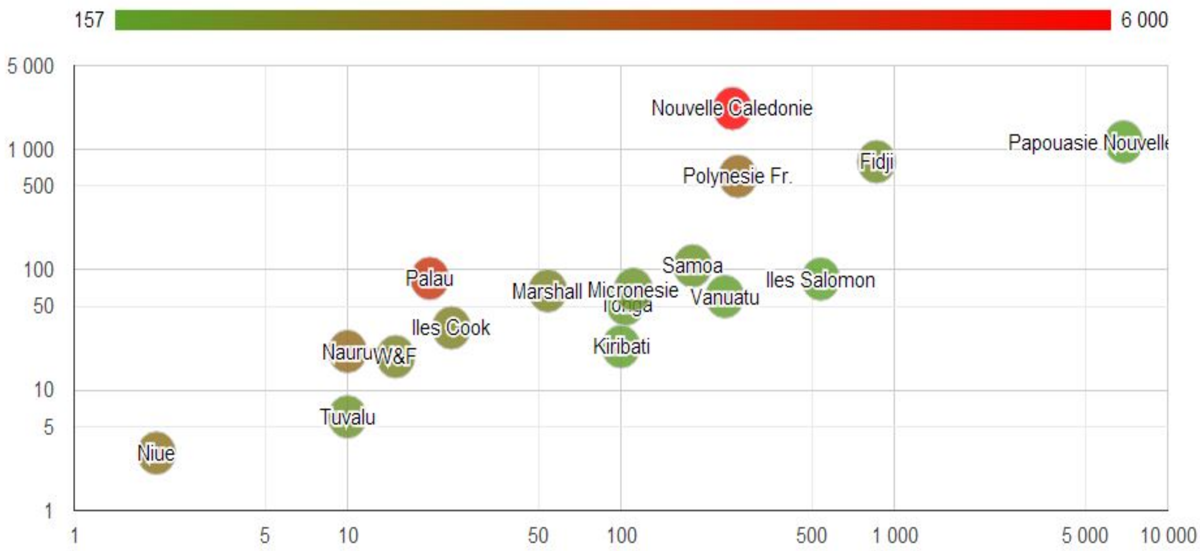
Although New Caledonia produces half of the energy of all countries considered in this study, faces the same issues and problems as the other Pacific countries considered in this study, and is therefore included.

1.2 Deployment of electricity in the Pacific

1.2.1 Variable sizing

Figure 2 compares island States using two criteria: population on the x-axis, and electricity production on the y-axis. The color indicates per capita annual consumption.

Figure 2. Population and electricity production by country (2010 data)



Cook Islands
Fiji
French Polynesia
Kiribati
Marshall
Micronesia
Nauru
New Caledonia
Niue
Palau
Papua New Guinea
Solomon Islands
Samoa
Tonga
Tuvalu
Vanuatu
W&F

Note: This figure uses logarithmic scales. Indeed, populations range from 1,400 inhabitants on Niue to more than 6 million on Papua (of whom only 13% are connected to the grid). New Caledonia is the largest consumer of electricity, mainly due to its high energy needs for mining. French Polynesia, where per capita GDP is second highest of the AREA, is also above average in its per capita electricity consumption. Also noteworthy is Palau, whose consumption, mostly related to tourism, is high.

1.2.2 Electrification rates and development strategies

With the exception of Papua New Guinea (PNG; 13% connected to grid), the Solomon Islands (15%) and the Federated States of Micronesia (65%), the electrification rate (access to an electricity grid, even local) is over 90% for all the countries studied.

Three notes must be added to this observation.

1/ For the populations of the States named above and who are not yet connected to a network, the question of absolute need for a connection can be posed. For example, some inhabitants of Papua New Guinea do not want "progress" to upset age-old customs.

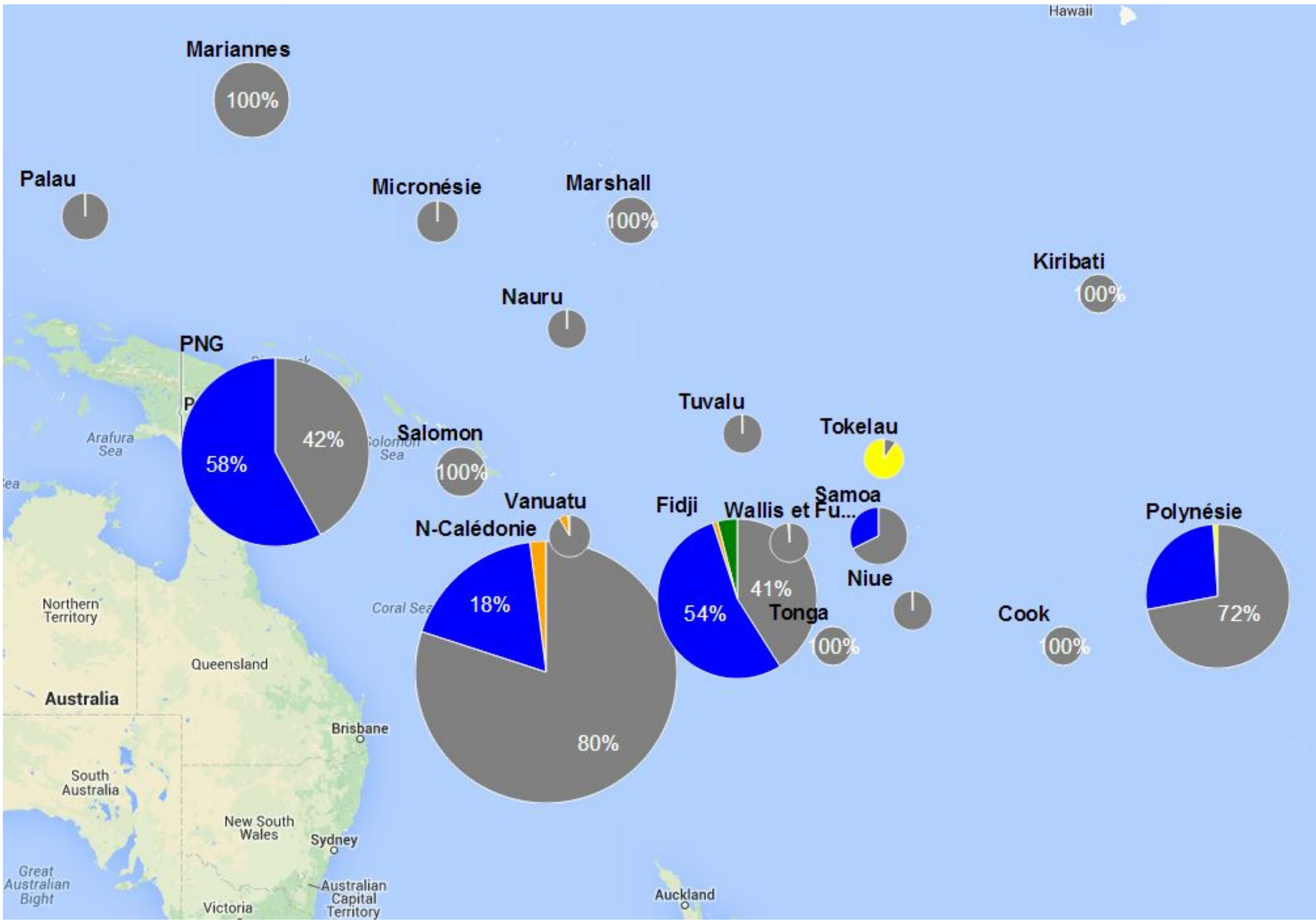
For the micro-communities which desire it, the VILLAGE micro hydroelectric project of the Solomon Islands, appears to be an exemplary project from all points of view. For the Solomons and Papua New Guinea, thanks to their terrain and annual rainfall, micro electricity and biomass seem to be the most promising avenues, under the condition that of using simplified financing and strongly implicate civil society in the earliest phases of the project (see the Solomon Islands projects in paragraph 2.2.1, as well as the Samoa Islands biogas projects described in 3.1.1). Thus, for these populations which lack access to an electric grid, there is a real opportunity to avoid dependence on fossil fuels by DIRECTLY implementing renewal solutions and adapting them to local needs (requiring prior and often lengthy social dialogue, as well as regular maintenance of equipment).

2/ For the second group, comprising the largest grids, it seems possible to return to proven industrial solutions, and often, again, to microgeneration for the most isolated sites. Only the largest and most concentrated grids of the region, those of New Caledonia, Fiji and French Polynesia, provide a sound economic footing for industrial generation capacity comparable to what is found outside the area, that is generation levels equaling dozens of MWp. Here again, pedagogy and time are the key elements to the success of these projects: the use of the tax exemption CALENDAR alone, for French overseas communities, cannot be the only deciding factor.

3/ The remaining countries are already 90% equipped and are between 80 and 100% dependent on fossil fuels. In spite of their being very spread out, their total capacity is just a few MW; Tuvalu, for example, is similar to the island of Tahaa in French Polynesia, with a 1 MW grid, and Tahaa represents just 1% of Tahiti's power consumption. For these States, it is possible to draw up an RE financing and implementation policy on a regional scale. Given the Pacific area electricity prices, it is simple to find RE technology which is economically sustainable. It is in this light that the Tokelau project seemed exemplary to us, albeit with some reservations, notably on the calculated forecast costs and savings (see 4.2.1).

1.3 Deployment of renewable energy

Map 1 recapitulates the energy mix by country. Pie chart sizes correspond proportionally to energy generation. Note that the smallest islands are the most dependent on fossil fuels.



Map 1. Renewable energy mix on the islands

Cook Islands
Fiji
French Polynesia
Kiribati
Mariana Islands
Marshall
Micronesia
Nauru
New Caledonia
Niue
Palau
PNG
Solomon Islands
Samoa
Tokelau
Tonga
Tuvalu
Vanuatu

Wallis & Futuna

Fossil
Hydroelectricity
Wind
Solar
Biomass
Geothermal

Source: IRENA

1.3.1 Development potential

Table 1. Development potential

<table>
<tr><th>Country</th><th>Population</th><th>Topography</th><th>Electricity per inhab. (kWh)</th><th>Rate of access to electricity</th><th>Power capacity (MW)</th><th>% capacity RE</th><th>Electricity produced (GWh)</th><th>% production RE</th><th>2020 goal</th></tr>
<tr><td rowspan="2">Papua New Guinea</td><td>6 900</td><td>Large island</td><td>486</td><td>13 %</td><td>722</td><td>41</td><td>1 160</td><td>58</td><td>0 %</td></tr>
<tr><td colspan="9">High potential for those who wish. Geothermal, hydroelectricity, photovoltaic, biomass, biofuel. New producer of hydrocarbons.</td></tr>
<tr><td rowspan="2">Islands Solomon</td><td>538</td><td>High island</td><td>142</td><td>15 %</td><td>36</td><td>0</td><td>84</td><td>1</td><td>50 %</td></tr>
<tr><td colspan="9">Very little electrification; high islands therefore possibility of hydroelectricity</td></tr>
<tr><td rowspan="2">Vanuatu</td><td>240</td><td>High island</td><td>270</td><td>27 %</td><td>31</td><td>20</td><td>65</td><td>19</td><td>65 %</td></tr>
<tr><td colspan="9">Very little electrification; high islands therefore possibility of hydroelectricity. Intensifying use of biofuels. Cost of electricity makes many RE attractive.</td></tr>
<tr><td rowspan="2">Federated States of Micronesia</td><td>111</td><td>Mixed</td><td>560</td><td>65 %</td><td>28</td><td>18</td><td>69</td><td>4</td><td>50 %</td></tr>
<tr><td colspan="9">Relatively little electrification. Hydroelectricity, photovoltaic, biomass, biofuel.</td></tr>
<tr><td rowspan="2">Tokelau</td><td>1</td><td>Atoll</td><td>0</td><td>90 %</td><td>1</td><td>93</td><td>1</td><td>90</td><td>90 %</td></tr>
<tr><td colspan="9">The construction of three hybrid PV power plants boosted the RE energy mix from 10 to 90% in 5 years</td></tr>
<tr><td rowspan="2">Kiribati</td><td>100</td><td>Atoll</td><td>194</td><td>90 %</td><td>6</td><td>5</td><td>23</td><td>3</td><td>10 %</td></tr>
<tr><td colspan="9">PV, biofuel, small wind turbines have high impact due to low consumption. Electricity mix could be totally modified in a few years</td></tr>
<tr><td rowspan="2">Marshall Islands</td><td>54</td><td>Atoll</td><td>1 032</td><td>90 %</td><td>17</td><td>0</td><td>67</td><td>0</td><td>0 %</td></tr>
<tr><td colspan="9">PV, biofuel, small wind turbines</td></tr>
<tr><td rowspan="2">Fiji</td><td>861</td><td>High island</td><td>850</td><td>90 %</td><td>215</td><td>56</td><td>794</td><td>59</td><td>100 %</td></tr>
<tr><td colspan="9">Best example in the region of a real will to have predominately renewable energy on an industrial-size grid</td></tr>
</table>

Country	**Population**	**Topography**	**Electricity per inhab. (kWh)**	**Rate of access to electricity**	**Power capacity (MW)**	**% capacity RE**	**Electricity produced (GWh)**	**% production RE**	**2020 goal**
Tuvalu	10	Atoll	489	92 %	4	2	6	3	100 %
	PV, biofuel, small wind turbines, high impact due to low consumption. Electricity mix could be totally modified in a few years								
Tonga	104	High island	487	95 %	12	1	52	0	50 %
	PV, biofuel, small wind turbines, high impact due to low consumption. Electricity mix could be totally modified in a few years								
Pays	**Population**	**Topography**	**Electricity per inhab. (kWh)**	**Rate of access to electricity**	**Power capacity (MW)**	**% capacity RE**	**Electricity produced (GWh)**	**% RE generation**	**2020 goal**
Samoa	183	High island	384	95 %	42	29	108	41	80 %
	PV, biofuel, small wind turbines								
New Caledonia	256	Large island	8 655	96 %	494	24	2 200	20	0 %
	Specific characteristic: 2/3 of demand comes from nickel industry. No solution. RE cannot currently compete with coal for a large industrial customer								
Niue	2	Flat island	1 875	97 %	2	2	3	3%	100 %
	PV, biofuel, small wind turbines. High impact due to low consumption, thus electricity mix could be modified in a few years								
French Polynesia	268	Mixed	2 468	98 %	140	36	662	26	50 %
	Biofuel + PV for the islands. Maximize hydraulic potential. Best site for first commercial OTEC unit > 10 MW								
Cook Islands	24	Mixed	1 235	99 %	8	10	33	0	100 %
	PV, biofuel, small wind turbines. High impact due to low consumption, thus electricity mix could be modified in a few years								

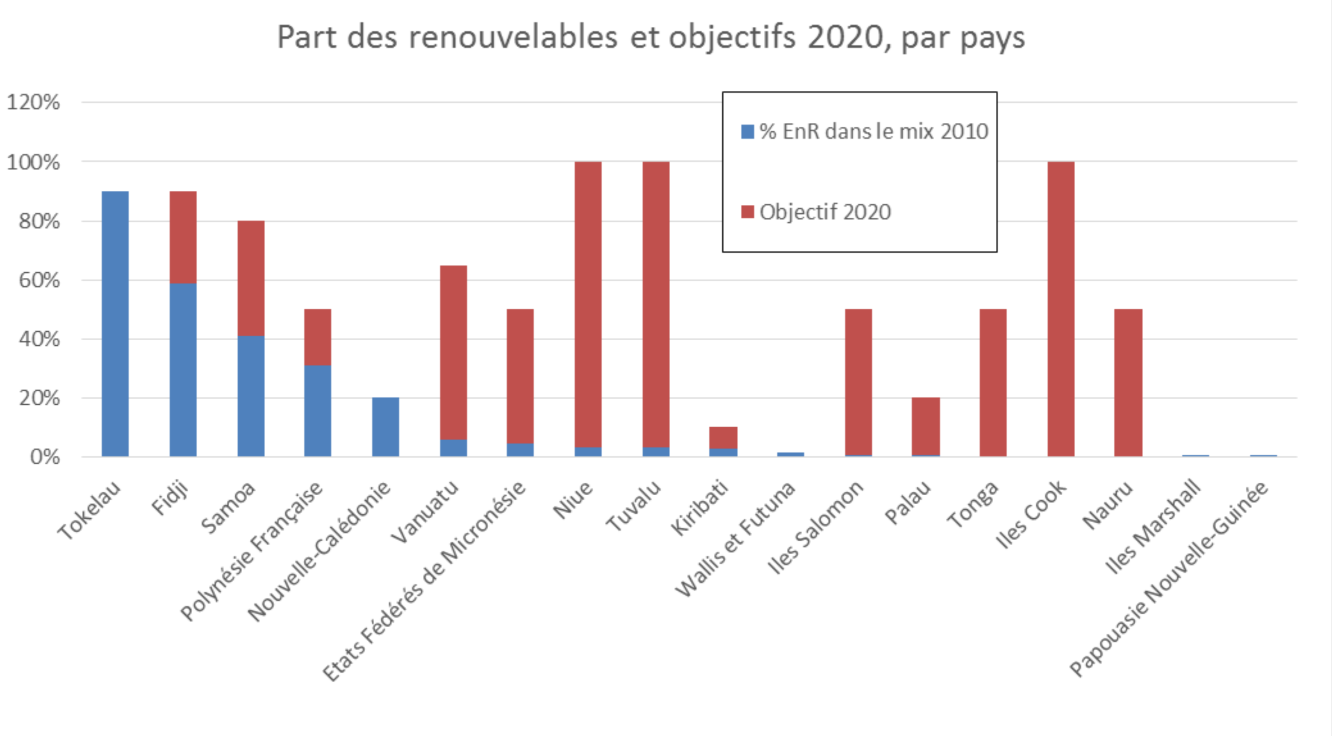
Country	Population	Topography	Electricity per inhab. (kWh)	Rate of access to electricity	Power capacity (MW)	% capacity RE	Electricity produced (GWh)	% production RE	2020 goal
Palau	20	High island	3 372	99%	39	1	85	1	20 %
	PV, biofuel, small wind turbines								
Nauru	10	High island	2 057	100 %	5	1	21	0	50 %
	PV, biofuel, small wind turbines. High impact due to low consumption. Electricity mix could be totally modified in a few years								
Wallis and Futuna	15	High island	1 266	100 %	9	2	19	1	0 %
	PV, biofuel, small wind turbines. High impact due to low consumption. Electricity mix could be totally modified in a few years								
New Zealand	4 400	Large island	10 376	100 %	9 500	69	40 000	76	90 %
	Not studied, but virtuous and pragmatic policy								
Australia	22 300	Large island	10 453	100 %	56 900	18	244 000	8	20 %
	Not studied, but country is among the highest energy consumers in the world, each inhabitant consuming six times more than a New Zealander								

Source: IRENA figures

1.3.2 Stated ambitions

As emphasized in the introduction, even if renewable energy deployment is non-existent on many islands, this does not stop many States or communities from setting ambitious RE coverage goals, ranging from 50 to 100%, as illustrated in Figure 3.

Figure 3. Share of renewable energy and 2020 goals, by country



Share of renewables and 2020 goals, by country

[*encadré*]
[*carré bleu*] % RE in 2010 mix
[*carré rouge*] 2020 Goal

Tokelau
Fiji
Samoa
French Polynesia
New Caledonia
Vanuatu
Federated States of Micronesia
Niue
Tuvalu
Kiribati
Wallis and Futuna

Solomon Islands
Palau
Tonga
Cook Islands
Nauru
Marshall Islands
Papua New Guinea

The majority of these stated goals are inconceivable for the countries concerned. In the case of the smallest economies, the GOAL is mainly to define a project which justifies donor financing. Technically, the goals are high but realistic. Indeed, for the most sparsely populated islands like Tuvalu (under 10 000 inhabitants), a rate of 90 to 100% is attainable once adequate financing is found (see the example of Tokelau in paragraph 4.2.1). For larger grids like that of French Polynesia, for example, a less costly energy mix is necessary. The 50% RE forecast for French Polynesia (for 2020, according to local government declarations) will necessarily be less expensive (per kWh generated) but more complicated to set up, compared to a hybrid power solution.

1.4 The limits to the development of renewable energy

1.4.1 The physical limits linked to the territories

High islands

These islands are often the sites of the largest urban centers, therefore the levels of electricity generation/consumption are the highest. For the majority of islands and the hearts of their urban centers, similar levels can be found: around 85% of demand for electricity and 70% of generating facilities. This is the case for Port-Vila on Vanuatu, Papeete in French Polynesia, or Rarotonga in the Cook Islands, for example; New Caledonia is an exception, where 66% is tied directly to nickel (mining and processing activities).

A high concentration of demand, as seen on the largest of the high islands, makes industrial solutions conceivable, all in staying at low power levels compared to industrialized countries.

Only the high islands can conceive of hydroelectric solutions. Nonetheless, they must still maximize the marginal output of each dam, often limited by the amount of land available, with the exception of Papua New Guinea.

For solar and particularly for photovoltaic generation, priority should be given to equipping the northern expositions of high highlands: these mountainous islands, often forested and wet, develop daytime cloud cover linked to forest evaporation, and the southern flanks are badly oriented to the sun's path, and also in the shade of landscape-generated clouds. With these principles in mind, a 35% differential between one side and the other is possible.

For wind power, it is recommended to locate the plateaus and ridges which are best exposed to the trade winds, the goal being to find sites receiving onshore winds with no disruption in laminar flows.

The high islands thus require transmission systems which connect renewable energy generation sites (like dams or wind farms on ridges) with areas of high consumption, concentrated on coastal plains. These systems, often located on very rugged terrain, can have a significant impact on project costs.

Low-lying islands

Low-lying islands and atolls are the most common island types in the Pacific: they are found in all of the region's archipelagos. They feature sparse populations on strips of land which are a few hundred meters wide, separating the ocean from lagoons. The principal economic activities of the atolls are copra cultivation, tourism, nautical activities (fishing, pearl culture ...).

These small populations require capacity ranging from a few dozen kW to a few MW for islands with hotels. These islands are often distant, sometimes isolated, and above all require equipment with proven resistance to salt air and very high UV levels, and that is also easy to maintain and use.

All equipment not meeting these simple specifications will have a short lifespan (maximum two years).

Thus, for low-lying islands, it is recommended to favor coconut oil-powered generators in co-generation with intermittent energy such as wind and photovoltaic, replacing fossil fuel-powered generators which are omnipresent in the region.

Low demand also limits the implementation of renewable energy. In the case of marine energies (hydrokinetic, wave energy, off-shore wind farms ...) for example, natural production sites exist, but the production units proposed by companies are unsuitable for the specific demand of the atolls (several hundred kW for the hydrokinetic or wave energy prototypes, for example).

1.4.2 Socioeconomic constraints

Remoteness

Despite varying economic situations, the Small Island Developing States of the Pacific are situated in the region furthest from major economic poles and also from principal trade routes. This is equally true inside the zone: the same photovoltaic system costs twice as much in Tuvalu as it does in Tahiti.

The additional costs run throughout both the setup and the operation, obliging a form of operational hardiness common to all remote areas.

Small markets

Apart from Papua New Guinea, Fiji and the French overseas communities, every country's electricity market is too small to justify large projects.

Customary property and land rights

For the Melanesian countries, property rights require particular attention and a true capacity for empathy (adaptation to the cultural understanding of the interlocutor), both by the project initiator and the funding organization. In French Polynesia and on other islands, land issues can run up against property obstacles, and the institutional solutions adopted in New Caledonia (example in the North Province) are not necessarily adaptable or transposable to French Polynesia. Once again, cultural adaptation and the capacity to demonstrate the advantages of adopting change are important factors in successful installing new projects which will foster favorable development for local populations.

The will to "make others happy" in spite of themselves

Not all inhabitants of remote territories clamor for access to better energy technology: the social, cultural and economic equilibrium of these territories must be taken into account, considering social, economic and cultural specificities of the concerned populations (thus their real needs) and the energy policies conceived at a more global level (the technologies implemented), at the risk of implementing unsuitable solutions apt to cause resistance to change.

1.4.3 The abundance of players

The impossibility of financing an energy transition with their own resources seems to justify the intervention of regional or even international donors. However, while the latter organizations have, among themselves, developed vocabulary, practices and even common codes to analyze projects, the Small Island Developing States of the Pacific are often powerless in the face of donors' demands: the energy departments of these countries often consist of one or a few key people, who sometimes have little experience dealing with donors. The following difficulties are commonly encountered:

- a lack of information on available financing: the energy department has little or no participation in high-level discussions between the donors and the country.
- the constitution of files does not correspond to donors' expected formats, requiring recourse to consultants (perfectly at ease in this domain) who, in the end, drive up the cost of the project, sometimes without verifying that their recommendations correspond to the real needs of populations or even governments. It is the age-old

issue of "financing seeking a project", whereas donors' main guiding philosophy should be more that of a "good project" which must naturally find financing.

- donors often find themselves facing "bicultural" interlocutors, that is, interlocutors educated abroad (sometimes at the same institutions as donors' experts), and this appears to favor mutual understanding, but ultimately prevents the true understanding of island issues as lived by the local population.

It is true that the number of agencies and development banks likely to intervene in the Pacific zone is high. The Australian, New Zealand and Chinese development banks are geographically closest. The World Bank and the Asian Development Bank are equally present, but tend to engage in sizeable projects (at least several million USD). The English-speaking islands maintain close ties with the Commonwealth or the United States, and the French islands regularly appeal to the Agence Française de Développement -- AFD (present in Nouméa, Papeete and Wallis) -- or the European Investment Bank -- EIB (which has an office in Sydney). Other countries, like the United Arab Emirates or Italy, intervene occasionally. These numerous operators provide many opportunities for financing, but simultaneously complicate tasks for beneficiaries, since each operator has its own mode of functioning and own demands (see 2.1 and 3.1 for concrete examples).

We also note a general lack of knowledge about these territories (as much among donors as between countries in the zone; there are few interregional exchanges): donors consider the Pacific zone to be a zone of the future (because it is at the center of geopolitical stakes between the great powers of the United States and China), and vice versa: the small countries of the zone sometimes tend to "create" programs or projects to "feed" the interest of these large financial institutions, knowing that the latter generally take little risk (in banking terms) as they most often demand sovereign guarantees pegged to the value of the American dollar.

Similarly, information agencies and development programs are numerous and sometimes compete with one another. Among all these institutions, we once again draw attention to the continual efforts of the Secretariat of the Pacific Community (SPC) which coordinates and trains different island country players, associating French overseas collectivities and France (the French Ambassador to the Pacific is its permanent representative).

2 Hydroelectricity

2.1 Large-scale hydroelectricity

2.1.1 Selected project: hydroelectric dam of Nadarivatu, Fiji

The Nadarivatu dam, seen from the lake

Photo: Fiji Electricity Authority

Type of project	Hydroelectric dam		
Country	Fiji	**Date**	2012 (startup)
Installed power capacity	• Capacity: 42 MW • Generation: 100 GWh/year		
Setup	• Design: MWH Global (NZ) • Construction: Sinohydro Corporation of China • Financing: o China Development Bank (USD 70 million), o Fiji Electricity Authority bonds (USD 50 million), o ANZ Bank (USD 30 million)		
Criteria for selecting project	• Impact on energy mix • Financing issues		

On Viti Levu, the main island of Fiji, electricity is predominately produced by two dams: Monasavu (Wailoa), which dates from 1978, and the much more recent project of Nadarivatu, which was put into service in 2012.

<u>A "delicate" history</u>

The hydroelectric project of Nadarivatu was originally planned as a partnership between the Fiji Electricity Authority (FEA) and the Australian company Pacific Hydro Limited. Pacific Hydro ultimately withdrew from the project because of insufficient profitability. The project was then taken over by the FEA in a partnership with the European Investment Bank (EIB). But in 2009, the consolidation of the military regime installed by Frank Bainimarama put an end to the partnership. It was then the Chinese Development Bank which accepted to supply the USD 70 M needed for the project, and Australia and New Zealand Banking Group (ANZ) provided a complement of USD 30 M.

Both banks set conditions: design would be handled by New Zealand technical offices, and construction would be led by Sinohydro.

A positive end result for Fiji

The savings resulting from the dam are very high: 20 M USD per year, with the dam producing more than 12% of Fijian electricity. It is therefore the largest Fijian dam after that of Monasavu (connected to the Wailoa power plant, built in 1978), which today still supplies main island Viti Levu with 50% of its electricity.

Moreover, some of the mistakes made during the construction of Monasavu were not repeated. Particularly, inhabitants living closest to the dam were the first connected to the grid and the project was accompanied by an extension of the telephone and road networks. A genuine valley development project was thus drawn up beforehand.

Locally, the environmental impact of the Nadarivatu dam remains limited. It concerns an installation called "go with the flow" which features just one retention basin, much smaller than a retention lake. This implies a smaller impact on the local environment, but also a lower energy storage capacity. On Viti Levu, the Monasavu dam already provides the island with a large storage capacity. This is why a larger retention facility was technically unjustified, above and beyond financial issues.

This question of dam lake size arises in the case of upcoming hydroelectric projects, in particular on islands where hydroelectric resources are limited relative to demand. For example, in the case of Tahiti and the Vaiha valley (the last large valley which can be equipped in Tahiti), the question of sizing works is primordial. The larger the facility, the greater the negative impact on the valley, but conversely, an undersized facility, which generates electricity only from water flow, will have a small impact on the electricity mix and will not allow for increased energy storage capacity. This would therefore be the equivalent of "killing the resource," jeopardizing the chances that the country could reach 50% RE in 2020 and 100% in 2030.

Construction problems

The main criticisms of the project concerned the choice of Sinohydro and the construction methods used. The company's international history is indeed far from irreproachable. Before Nadarivatu, it was accused of ill-treatment of workers in several countries. The Chinese government's supervisory commission also assigned it a grade of D (E being the lowest) for non-compliance with safety and environmental standards.

In Fiji, several complaints about the company were made:

- non-compliance with health and safety standards
- unjustified withholding of wages and unpaid overtime
- use of unskilled Chinese personnel at the expense of local labor

In the end, the different hydroelectric projects carried out in Fiji have enabled it to have the highest RE use of all the Pacific islands (with the exception of atolls equipped with solar power plants; see below). The long expected lifespan for these dams makes them key elements in Fiji's development, in both environmental and financial terms. The question of whether other valleys should be equipped has now been raised. Indeed, nearly the entire population is connected to the grid and enjoys a "basic" level of comfort. Monasavu alone provided 90% of Viti Levu's energy in the early 1990s against 50% today. The question of energy development in Fiji also concerns the policy of controlled demand and the question of industrializing the territory.

2.1.2 Replicability of the project

Technical feasibility	Hydroelectric dams are civil engineering works well mastered by a few companies in the world. The main difficulty consists in properly sizing the facility and finding companies prepared to work on remote islands.
Financial feasibility	Hydroelectricity is the cheapest available energy source on the high islands. Nonetheless, it requires a high initial investment, paid back only over a minimum of ten years. For the Pacific island countries, this investment is very often too high, even when including aid from development banks. In this case, a public/private partnership is conceivable.
Keys to the success of the project and pitfalls to avoid	The success of a hydroelectric project depends: • on initial sizing • on the prime contractor's work methods Bad initial sizing can have disastrous consequences on the environment (an oversized project leading to the destruction of the valley upriver) or the contrary "killing the resource" in building a run-of-river dam where a larger retaining dam could have been placed. The evaluation of flow and power is thus essential. However, outright project failures are rare. It is more often the construction methods which are decried, particularly along the lines of the Health Safety Environment (HSE) threesome.
Target countries	All high islands with varied landscape and a developed grid, depending on the available resources.

2.1.3 Similar projects

Papenoo dam, Tahiti

Overflow at the Tahinu dam, Papenoo, Tahiti

Photo: www.fleuraustrale.fr

With three power plants and five dams, the Papenoo hydroelectric installation is the largest in Tahiti (20% of the island's consumption). The Papenoo is the longest valley on the island of Tahiti, made up of a vast mountainous cirque (ancient eruptive center), exposed to the north and surrounded by the imposing landscapes of Orohena (elevation 2 241 meters) to the west and Tetufera (1 799 meters) to the southeast.

The Papenoo dam is noteworthy for the particular care taken in integrating it into the valley landscape. Its impact on the energy mix is also essential for Tahiti.

There is little information on the construction methods used to build this dam, erected in the early 1990s, with the notable exception of "the study of natural risks in the lower Papenoo valley" (ORSTOM, 1997). Also of note are that environmental standards of the time were still low and have greatly evolved since then.

2.2 Micro hydroelectricity

2.2.1 Selected project: Solomon Islands hydroelectric projects

Installation of the Pelton turbine in Masupa, Solomon Islands

Photo: Pelena Energy.

Type of project	Micro-hydroelectric community projects		
Country	Solomon Islands	**Date**	Since 2000
Installed power capacity	Total for the Solomon Islands: 130 kW (5 installations) Bulelavata: • Capacity: 24 kW		
Setup	Pelena Energy		
Criteria for selecting project	• Low investment projects, no call for tenders • Community-based projects		

Since 1999, Australia-based company Pelena Energy has been carrying out small hydro power projects for isolated communities. The projects have primarily targeted the Solomon Islands (5 power plants installed) but also Papua New Guinea (1 project) and Australia (1 project).

Below we will provide a detailed description of the Bulelavata project in the Solomon Islands. This micro hydro power system was installed in 1999, the first constructed according to the model recommended by Pelena. It can be supposed that the company has since gained experience, and that Bulelavata is not the most advanced of the program. It is nonetheless the best documented, notably in Woodruff (2007), as well as on the APACE[4] project site. For better understanding, we invite the reader to watch the film shot for the construction of the Masupa power plant. The video is available on the Internet[5].

Micro hydro power system of Bulelavata

Bulelavata is an isolated community in the West province of the Solomon Islands. It is accessible only by sea and is inhabited by about 300 people.

Prior to the installation of the power system, the community's energy supply came from biomass, as well as a kerosene generator and batteries. The hydro system made possible:

- the electrification of the school,
- the installation of a common cold room used to conserve fishery products, which are afterwards sold in town,
- a general rise in comfort for each household (lighting, water heaters, radios, and in some cases refrigerators),
- the end of the rural exodus
- an improvement in the condition of women's lives:
    - rise in self-esteem, through their participation in works
    - improved safety thanks to outside lighting
    - possibility to read and sew at night (after doing household chores).

The retained technical option is a run-of-river system featuring a small retention basin. Continuous power generation from the turbine is 14 kW, giving an annual production of about 120 000 kW. The "low cost" option recommended by Pelena made it possible to keep costs relatively low: 270 000 USD for installation of the whole system, which included restoring the distribution grid to the village and the school. The cost of electricity over 20 years is thus 12 XPF/kWh, very competitive for an installation of this size.

Analysis and reflection on the community projects

The philosophy behind these types of projects is the following:

- minimization of costs: limit imports to what is strictly necessary. All framework, for example, is carried out locally,
- construction and also conception of the power system by the ensemble of the community, using local skilled workers (carpenters, masons, etc.), who in turn appropriate the project,
- rapid construction site: the Masupa construction site required 13 days,
- simplicity of administrative procedures, in particular no public invitation to bid, which consequently limits the role of donors.

On this last point in particular, our discussions with Peter Lynch of Pelena Energy pointed up several essential elements which explain why today the company is no longer oriented towards international financing:

- the demands of public invitations to bid systematically exclude local specialists, ill-prepared to answer to these types of demands,
- the projects submitted to an invitation to bid are ill-conceived since they are based on a scaled reduction of large size dams. As a result, the costs are systematically too high, which is also worsened by ignorance of the terrain, transport costs and the use of Western methods which minimize labor and thus require much equipment. Bids 20 to 25 times above real costs are not unheard of,
- finally, the communities are not integrated into the early phases of the projects, nor do they participate in financing. As a consequence, the benefits rendered by the project are less acutely felt, and implication in maintenance is diminished.

On the other hand, it is regrettable that the low-cost projects defended by the company do not always seem to respect certain rules now in effect for most RE projects:

- local environmental protection (river instream flows, construction site impacts)
- safety precautions at construction sites

Pelena Energy's remarks confirm a certain number of specifications and recommendations already described, and, and the fact that this time they come from a specialized company means they deserve consideration, not only for hydroelectric projects but for all community-scale projects. The low involvement of atoll inhabitants is one of the negative points often encountered in hybrid power plant projects. Examples of outright failures exist in French Polynesia, whereas following many recommendations (institutional, economic, financial) could have prevented them from occurring. The conditions leading to the success of an RE project are therefore not essentially financial (or even fiscal); they must above all answer some essential questions: is the project useful to local inhabitants, or does it merely serve the short-term interests of its promoters? Can the local population maintain the project for a low cost? Is the project useful to the entire community concerned or to certain members of that community? The preliminary answers to these questions by local and public officials will greatly facilitate future interrogations about the technical and financial support which may be sought.

2.2.2 Replicability of micro hydroelectric projects

Technical feasibility	The technology is simple and robust. The technical feasibility is foremost affected by the choice of terrain, which must be made case by case. In the perspective of a low-cost community project where in-depth hydrological studies are inconceivable, it is the project leader's experience which will guarantee the feasibility.
Financial feasibility	Like the preceding point, financial feasibility largely depends on the context and the experience of the project leader. It should be noted that the relatively low costs achieved by Pelena imply high volunteer implication from the entire community. It seems clear that a similar project, led solely by civil engineering professionals, could not reach the same levels of profitability.
Keys to project success	The key points have already been evoked; the following should be retained: • the experience of the prime contractor • the implication of the entire community in the design, construction and use of the facilities, • the choice of robust equipment, permitting minimal maintenance • training inhabitants in maintenance as well as use (energy savings), • compliance with environmental rules and basic safety.
Target countries	Micro electricity can potentially be developed on all the high islands, with each valley to be studied case by case.

3 Biomass energy

3.1 Biogas

3.1.1 Selected project: Merremia project in the village of Piu, Samoa

The invasion of Merremia Peltata on the Samoa Islands

Photo: BioEnceptionz

Name of project	Piu village Merremia project		
Type of project	Biogaz		
Country	Samoa	**Date**	2014 Prototype depuis 2012
Installed power capacity	12 kW Annual production estimated at about 50 MWh		
Setup	BioEnceptionz		
Criteria for selecting project	The project corresponds to several issues: • production of renewable energy for remote populations • improvement of sanitary conditions • fight against invasive species • production of fertilizer for agriculture.		

Context

The Samoa Islands, like many high islands in the Pacific, are rich in biomass. Among the different species which proliferate locally, the Merremia Peltata vine is considered one of the most invasive. Expert opinions vary on the introduction of Merremia Peltata in Samoa. It is sometimes considered an outside species, sometimes a species introduced many years ago, or even an endemic species, but is nonetheless a threat to other species under certain conditions. Sometimes used as a fast-growing ground cover (thus limiting erosion), it proliferated after Cyclones Ofa and Val which struck in 1990 and 1991, respectively. Today, it constitutes a threat to ground biodiversity and low-growing vegetation.

Piu Village has about nine households for 40 inhabitants. The high cost of electricity in Samoa prompts families to use wood as cooking fuel, creating health problems linked to daily smoke inhalation.

Project description

The project aims to use Merremia to produce biogas, which will in turn be used for cooking and lighting (biogas lamps). With the help of a generator, the surplus will then be transformed into electricity, which will be sold on the grid. In all, the project will be comprised of two 100 m^3 biodigesters and 5x50 m^3 biogas storage tanks. This should allow for the production of 170 m^3 of biogas per day, thus fueling two 11 kW generators and produce 260 kWh of electricity per day. This large quantity of electricity will be sold on the grid.

Biogas production units in Piu village

Photo: BioEnceptionz

A demonstration unit (3 biodigesters) was installed on site to show the project's viability. After installation, about ten days are needed to generate sufficient gas pressure for cooking purposes.

Biogas is only composed of 60% methane, which means specific material is required. Possible applications include:

- cooking (biogas burner, rice cooker),
- heating water,
- lighting (biogas lamp, electronic ignition),
- generation of electricity (biogas motor).

Generally, it is estimated that a 10 m^3 biodigester can be installed in one or two days, and can supply two families with biogas for cooking and lighting[6]. Moreover, the digestion bi-product is a rich fertilizer which can therefore be used to improve agricultural yields.

Financial analysis

The project is being led by the BioEnceptionz company. The prototype has been built with funds from the British High Commission in New Zealand. After an unsuccessful attempt at raising money through participative funding on the Internet, the project is currently being funded by the Samoa Islands government and the United Nations Development Programme (UNDP).

All profits from biogas production will go to the inhabitants of Piu village. This is a development project, so financial profitability is not the main focus, but a brief analysis is nevertheless possible. The financial profitability of a biogas project largely depends on the reliability of the organic resource. In the case of Piu Village, the proximity to a large reserve of Merremia, which is moreover renewable, inspires confidence for future production. However, the daily amount of Merremia required to operate the installation will be 1 700 kg of vines, which, according to BioEnceptionz estimates, can be gathered by three full-time workers equipped with machetes. The production of 264 kWh, given a purchase price of 30 XPF/kWh, would generate 7 900 francs per day, allowing for a monthly salary of 55 000 XPF per worker, excluding the installation's amortization costs.

The project is conceivable in countries where the cost of labor is low, but cannot be replicated (unless there is a large public subsidy) in countries where salaries are higher. This is partially linked to the low efficiency of biogas motors (20%). Nevertheless, it concerns a project which could be viewed as having a public interest, thus conceivable in the form of assisted jobs.

3.1.2 Replicability of biogas projects

Technical feasibility	An anaerobic digester is technically quite simple to set up. However, it must be ascertained that the organic resource (green waste, human or animal feces) is available in sufficient quantity.
Financial feasibility	Financial profitability is not certain for this type of project. The relatively high installation cost requires several years to amortize. If biogas is used directly (cooking, lighting), the investment is profitable even for an individual. However, in the case of electricity production, the low efficiency of biogas motors hampers the financial profitability of projects. Biogas fuel cells are now appearing, and this could greatly increase efficiency in the coming years. Finally, it should be noted that the benefits of biogas installations go well beyond the financial aspects linked to energy production: waste treatment and fertilizer production must also be taken into account.
Keys to project success	Biogas projects are above all destined for populations with no access to gas and who already use biomass resources for cooking, for example. Small units should be favored.
Points to improve and pitfalls to avoid	Overly centralized projects with complicated logistics should be avoided. Further, a biodigester must be inspected and maintained regularly in order to avoid gas leaks.
Target countries	In the case of Merremia, Aitutaki, the Cook Islands and the islands of Vanuatu can be targeted. Other invasive species can be considered. For systems using organic waste and feces as raw materials, installations are possible on all the Pacific islands. Agricultural populations with little access to gas or electricity should be targeted first.

3.2 *Biofuels*

3.2.1 Selected project: Use of coconut oil to generate electricity, Vanuatu

Type of project	Use of coconut oil in existing facilities		
Country	Vanuatu	**Date**	Since 2005
Installed power capacity	30% coconut oil for 2 x 4 MW, which is the equivalent of 2.4 MW		
Setup and financing	COFELY Vanuatu (GDF Suez) No outside financing		
Criteria for selecting project	The project proposes to integrate coco oil into an existing installation, requiring little investment It is easily replicable. It is well documented.		

The coconut tree is an essential component of the island ecosystems and economies of the Pacific, and traditionally copra is a significant source revenue and resources for many islands. Many products are made from coconut trees: softwood timber, copra meal for animal feed, coconut milk, oil used for cooking, candle making and monoï (for application to skin and hair).

Several studies were carried out as early as the 1980s to try to use different oils, including copra oil, in existing generators. Tests at the time showed there was no effect as long as the percentage of oil did not exceed 20%. Above this threshold, there was a risk of reducing the lifespan of the motor.

Compared to other oils, experts observe that copra oil performs relatively well, and fewer deposits have been observed compared to other plant-based oils. It must be recalled that deposits on pistons, valves, injectors and carburetors can cause significant losses of performance and can damage generators (for which the transport of spare parts represents veritable economic and time issues).

Studies by the University of the South Pacific in Fiji, as well as experiments carried out by UNELCO[7] in Vanuatu in the 1980s, showed that an ordinary generator could operate with 100% copra oil under certain conditions. However, the lifespan of the equipment suffered, causing this option to be abandoned. Many other attempts at using copra oil for energy purposes were made in the 1990s (200 minibuses functioning with a mix of copra oil -- diesel oil, generator operating with copra oil, use of copra oil as a boiler fuel).

Operation with generators

The incorporation of copra oil into the mix occurred gradually. From 5% in 2005, the percentage has reached 30% today. Metering pumps are activated once the charge reaches 75% (equal to 3 MW), allowing a high exhaust temperature to be maintained and achieving good combustion.

The oil is preheated using the heat produced by the generator (SEE DIAGRAM BELOW). Two preheats thin the oil to better separate impurities. The oil is filtered at 5 microns to maximize combustion and minimize clogging up.

UNELCO, under these operating conditions, observed no change in the generators after more than 12 000 hours of operation.

The objectives now set are the following:

- limitation of gumming
- limitation of coating on the liners
- maximization of combustion
- reduction of deposits on the injectors

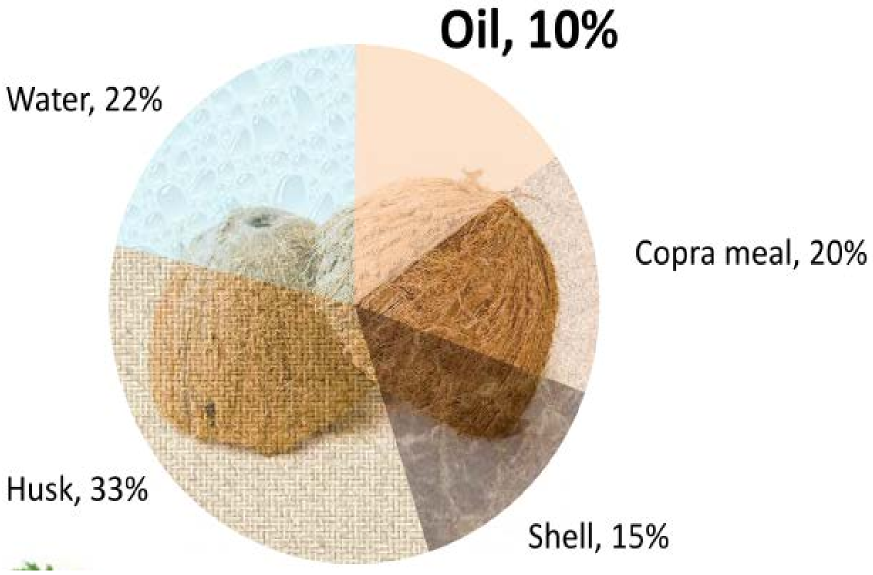
Development of the copra sector and its by-products

One of the keys to the success of a biomass project consists in assuring raw material supply. Nevertheless, in the case of a coco-diesel mix, the question is purely financial since, in the event of a lack of biomass, production can be assured with diesel fuel.

In the case of the UNELCO project, contracts were signed directly with several copra producers. Today, most of the production comes from other islands, creating supply problems. GDF Suez is considering a proprietary plantation at *Undine Bay* in order to secure a supply of copra. This approach is applicable on islands where space permits, as it does in Vanuatu and Fiji, but would pose problems on islands where land is in short supply.

Copra oil production can also enable the making of by-products, as shown in Figure 4.

Figure 4. Copra oil and by-products



Source: UNELCO.

The oil represents just 10% of the mass of a coconut. The by-products obtained during production are notably soy meal (copra meal), generally used as animal feed, and valued at about 200 XPF/kg. That allows for profits on the one hand, but also gives value to the most nutritional part of copra, thus demonstrating that copra oil production is only partially in conflict with copra produced for agricultural purposes.

For the other by-products, such as the shell and the husk, the following sectors can be considered:

- gasification,
- manufacture of activated carbon,
- manufacture of simple charcoal.

3.2.2 *Replicability of copra oil-based projects*

Technical feasibility	The project is easily replicable on many Pacific islands. In cases where the oil is locally extracted, a trained technician must attend to maintenance of the system locally.
Financial feasibility	Financial feasibility poses more problems. It depends largely on the cost of the raw material (kg of copra), which itself is directly related to land and labor costs. Nonetheless, it could be argued that with the high unemployment on most of the islands, the implementation of assisted jobs or subsidies could partially resolve the problem of labor.
Keys to project success	The key points to the project's success are the following: • a sound financial setup, • the secure supply of the raw material, • the inclusion of maintenance servicing for remote islands.
Points to improve and pitfalls to avoid	In some cases, such as French Polynesia, the copra sector is regulated and the centralized production of oil is authorized for only one entity (Tahiti oil mill), which benefits from subsidized prices per kg of copra. Competing entities do not benefit from these prices, thus they cannot buy the raw material from producers for a lower price. Just as diesel fuel prices are subsidized on the islands of Polynesia, the costs are distorted. Another essential point is that the extraction of oil for the production of electricity does not conflict directly with other uses, notably in agriculture or the food industry. For example, the Tuvalu islands have until now been opposed to copra oil-based electricity for this reason.
Target countries	All Pacific countries use diesel-powered generators and most of them produce copra, therefore this project is technically replicable on all the islands. The countries where labor (and copra) are the least expensive compared to imported diesel fuel (see explanation in 3.2.3) should be the priority targets.

3.2.3 Similar projects

Fijian program for biofuels

With a view toward the promotion of electrification and as a demonstration, the Fijian Department of Energy, with the support of the Secretariat of the Pacific Community and the French government, installed two copra oil-powered generators on the islands of Vanua Balavu (2000) and Taveuni (2001).

The diesel generators were adapted by adding a dual tank system as well as a fuel preheater, allowing the generator to start and stop with diesel fuel. Copra oil is used only in the hot engine cruise state as it requires preheating to avoid gumming the motor.

Calculations of profitability were made for both of these operations. The additional cost linked to the adaptation of the generator is minimal, and the comparison mainly concerns the cost of copra compared to that of imported diesel. The prices of diesel and copra vary depending on the island. SOPAC analyzed these differences as early as 2005:

Figures 5 and 6

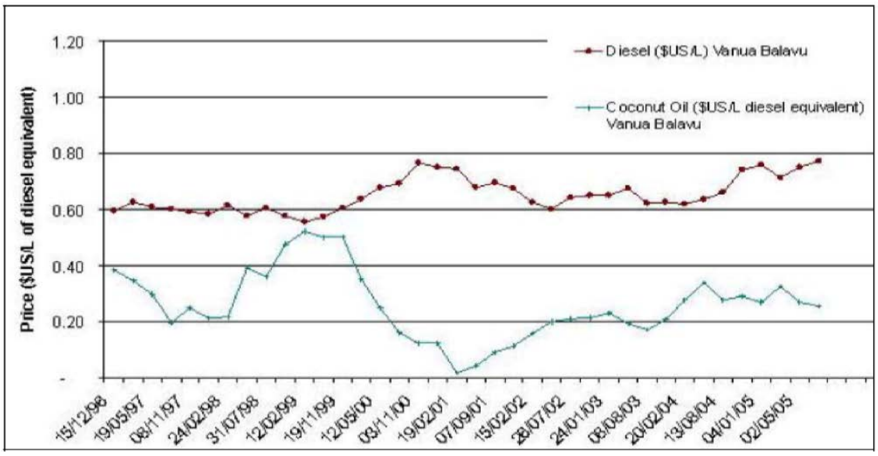


Figure 5. Price of diesel and coconut oil for Vanua Balavu, Fiji

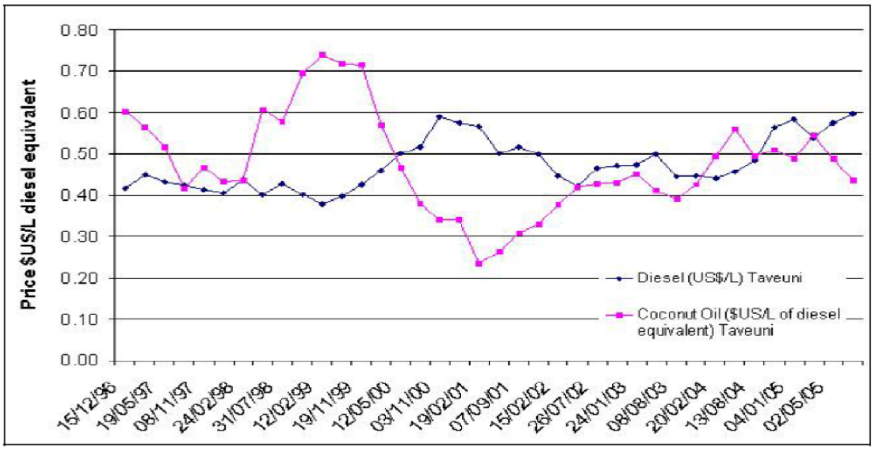


Figure 6. Price of diesel and coconut oil for Taveuni (Walagi), Fiji

Source: Woodruff, 2007.

Differences in cost are notable for both diesel and for copra. On Vanua Balavu, copra is financially attractive thanks to the low price of copra and the high price of diesel (due to high transport costs). However, to benefit from this difference in costs, coconuts must be pressed locally.

In the case of Taveuni, the situation varied until at least 2005. The price of diesel is lower thanks to the shorter distance from the Suva oil terminal. Consequently, the copra solution is less attractive, though production could be centralized on the island of Suva.

It should be noted that over the long term, increases in the price of diesel should make the copra solution viable for all the islands.

3.3 Other existing biomass projects

Using bagasse

Bagasse is a cane sugar by-product produced during grinding. The Fiji Sugar Corporation today produces some of its electricity from bagasse. The supply of biomass is seasonal since bagasse is only available during cane grinding, in the dry season. To date, the generated power has been 31 MW in the dry season. FSC deems that the potential is 90 MW, and in September 2013 secured a loan for USD 19 M for a new project in Labasa.

This process is well known and has been used by many island states that produce cane sugar.

Using wood

Another Fijian project, this one led by Tropik Wood Industries, has been using wood offcuts to produce electricity since May 2008 in a classic biomass boiler system. Currently, 9.3 MW have been installed, but project officials say that could be increased to 24 GWh per year if all the available biomass is used. The fact that it uses a by-product keeps production costs very low (slightly lower than that of bagasse). The investment in the project was 23 million dollars (FJD). The company is engaged in the production of wood pellets for rural as well as international biomass gasification projects.

The Fiji Energy Authority estimates that up to 140 GWh (24 MW of capacity) could be produced by Fiji sawmill offcuts.

Gas generators

See the "Small is beautiful" project in 6.2.

4 Solar photovoltaic

4.1 Electrification projects for individual houses / remote sites

4.1.1 Project selected: PHOTOM program

Name of project	Programme PHOTOM		
Type of project	Photovoltaic; electrification at a remote site		
Country	French Polynesia	**Date**	1997-2010
Installed power capacity	1.8 MW (1 500 installations)		
Financing	French Polynesia (50 %), ADEME (50 %)		
Criteria for selecting project	It is the largest remote site electrification project in the Pacific using standard technology. The project is replicable.		

The goal of this program is to allow households or isolated groups to access electricity. The installed equipment is an autonomous generation system consisting of two photovoltaic panels, batteries and inverters, allowing the connection of equipment at 220 V. The rated output of the first installed panels was 600 Wp, was then increased to reach 1 800 Wp (2 500 VA inverter). This corresponds to eight lamps, a 300-liter freezer and a 200-liter refrigerator. This program above all concerns the houses on the Tuamotu islands located outside of villages. Some remote houses on the high islands (on valley bottoms, or on coral-sand islets called "motus") have also benefited. In all, between 1997 and 2010, about 1 500 installations were carried out on 29 islands for a total power capacity of 1.8 MW. Today, about 75 kWp are being installed each year.

In 2011, an audit performed by the Alliance Soleil company produced the following results:

- 97% of the audited photovoltaic generators were operational,
- 99% of users met were satisfied with the rendered service,
- 100% of users observed an improved quality of life linked to their photovoltaic generator,
- proven resistance to cyclones: only 1% of audited installations were damaged by Cyclone Oli in 2010,
- no theft of a photovoltaic unit had occurred,
- monthly fee payment,
- many new requests for installation coming from the islands (about 200 pending).

The audit nonetheless pointed out very mixed maintenance, depending on the island, and suggested favoring solar-diesel hybrid installations for grouped populations or sites benefiting from an existing system.

4.1.2 Replicability of the project

Technical feasibility	The project is easily replicable at many remote sites in the Pacific. Photovoltaic technology has been mastered and has proven itself. The question of maintenance is the most sensitive. Indeed, maintenance is necessary to optimize the operation of the installation.
Financial feasibility	The price of the installation, high for the first programs (about €20 per Wp installed for PHOTOM), could fall in view of technological progress on PV panels and batteries. Nonetheless, the share linked to logistics remains high due to the rise in price of hydrocarbons. For many potential candidates in the Pacific, the "rent" charged to the beneficiary still remains too high (110€). An adaptation in the amount of subsidies will be necessary in function of the beneficiaries' income.
Keys to project success	We note two: • A first issue is to define the minimum amplitude of the project in order to benefit from an attractive price based on volume. • The issue of maintenance is primordial. The success of the PHOTOM program is principally thanks to the mandatory maintenance contract.
Points to improve and pitfalls to avoid	In the case of PHOTOM, the panel dimension specifications radically reduced the number of possible suppliers. Ideally, healthy competition in the Pacific could develop based on performance and durability specifications.
Target countries	All Pacific islands

4.1.3 Similar projects

Solar electrification project of Ha'apai, Tonga

Electrification of 40 houses on the remote islands of Ha'apai.
Installed PV power capacity: 150 Wp per house + 12V batteries
Other characteristics: 13V bulbs supplied
Maintenance included in the form of a monthly payment

Investment: USD 94 000

1 000 roofs project, Tuvalu

The goal of the project is to decentralize photovoltaic production and limit land use by using existing roof surfaces

Forecast PV power capacity: > 1 MW

Other expected benefits:

- improved roof shading
- rainwater collection

4.2 Hybrid power plants

4.2.1 Selected project: Tokelau, 90% of electricity from renewable energy

Photovoltaic installation in Tokelau

Photo: Government of Tokelau

Name of project	*Tokelau Renewable Energy Project* (TREP)		
Type of project	Solar farm with batteries		
Country	Tokelau	**Date**	2012
Installed power capacity	930 kW spread over three islands 775 MWh yearly		
Setup and financing	Financing: *New Zealand Aid Programme* (NZAID) Prime contractor: PowerSmart Solar (New Zealand), IT Power (Australia) Technology: SMA		
Criteria for project selection	Tokelau is the first country where 100% of the electricity is produced from renewable sources for a majority of the time (90% RE per year) The installation is a hybrid solar/diesel power plant whose future development is desirable in the Pacific, even if the costs today are very high (see below).		

<u>Project description</u>

The Tokelau renewable energy project (TREP) was launched in 2010 by the government of Tokelau and the New Zealand Ministry of Foreign Affairs and Trade (MFAT). This project consists of the construction of three hybrid solar-diesel power plants for each of the three Tokelau atolls: Fakaofo, Nukunonu and Atafu. The last of the three systems was completed in October 2012. Thus this system replaces the diesel generators that were used previously.

The strategic energy plan drawn up in 2004 and renewed in 2010 projected a considerable reduction in the country's dependence on fossil fuels. The country is well on its way: the project has accounted for about a 30% drop in hydrocarbon imports.

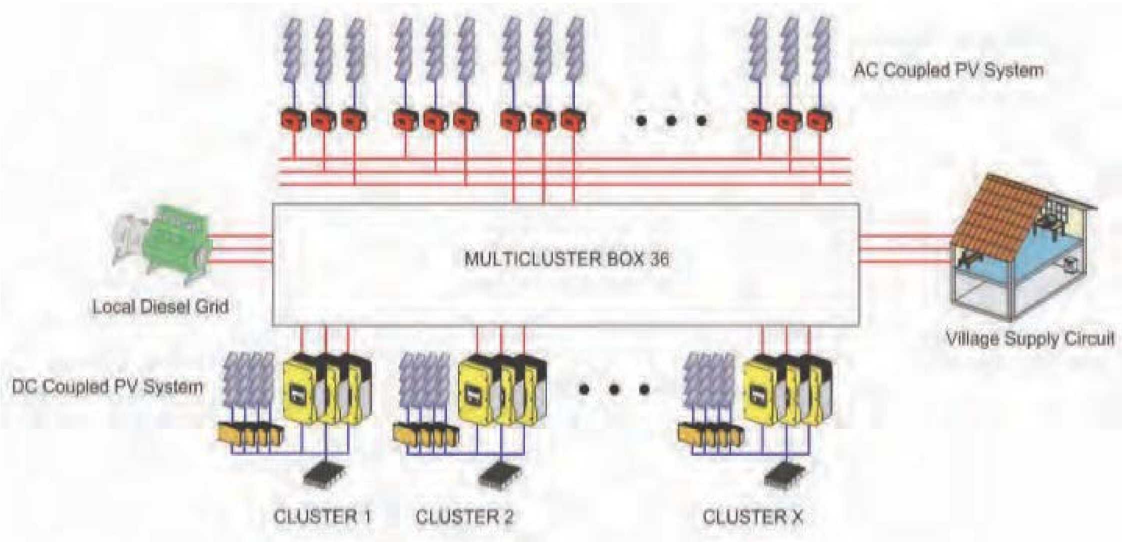
The project was launched in 2010 for a partial startup in 2012 (it was completed in 2013). Each of the power plants is composed of photovoltaic panels, batteries, equipment to manage the balance of power as well as a diesel generator for periods when the photovoltaic equipment is insufficient (several days of cloud cover or high demand).

<u>Technical choices and financial analysis</u>

The technical choices were decided in compliance with the MFAT's design rules for small-scale renewable energy systems[8]. These rules guide donors and project leaders in the design of unconnected networks and hybrid solar-diesel farms in the Pacific. They take into account the specific Pacific island climate conditions.

Given this context, SMA's multi-cluster technology was chosen, each cluster consisting of an array of panels + string inverters + storage (DC converter + batteries + battery inverters). Panels manufactured by the Sunrise company were chosen. Better performing panels exist, but Sunrise's products meet the new IEC 61701 standard which assures their operation in a highly corrosive marine environment. The aim here is not to go into details of a technical configuration; readers can refer to the Tokelau Renewable Energy Project Case Study (2013).

Diagram 1. Technical diagram of the Tokelau installation.

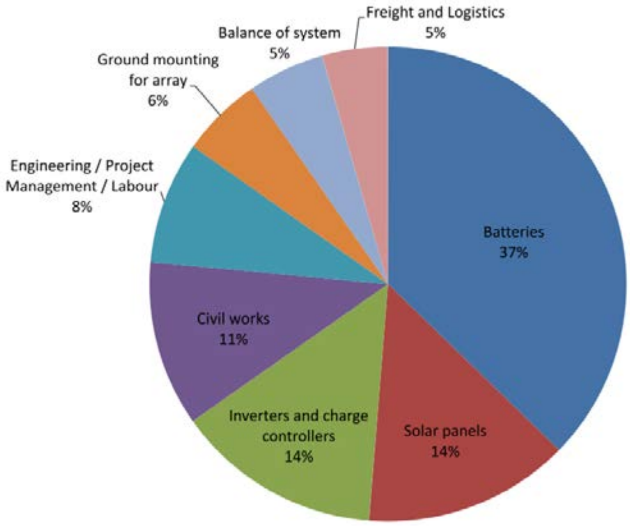


Source: SMA.

Battery sizing is the key to achieving the most economical arrangement. If too many batteries are installed, the investment has no or limited savings over the period compared to the diesel solution. If, on the other hand, there are too few batteries, this would cause the diesel component to start too frequently, reducing the achieved efficiency and savings.

In the case of Tokelau, more than 8 MWh of batteries were installed, quite considerable in that they can store nearly two days[9] of consumption without sunshine. The cost impact is high because the share of the batteries and the system equipment exceeds 40% of the entire investment. The impact on the local environment must also be considered: in the case of a battery leak, lead pollution would be a serious concern. The government of Tokelau raises this concern and states that maintenance and recycling were anticipated in the construction phase, without providing details about treatment.

Figure 7. Breakdown of costs for the Tokelau photovoltaic project.



Source: MFAT.

In the financial analysis requested by MFAT, full costs (with discounting at 8%) are 1.35 NZD/kWh, which is 100 XPF/kWh. These costs are slightly lower and thus coherent with those of hybrid Polynesian power plants built in 2010 and 2011. There is more doubt about the reference cost for diesel-produced electricity, estimated at 110 XPF/kWh.

4.2.2 Replicability of the project

Technical feasibility	The technology has been mastered and is applicable nearly everywhere in the Pacific as long as there is sufficient sunshine. The only technical constraints concern the availability of land and the state of the grid, which could require modernization.
Financial feasibility	The goal is clearly that Tokelau become as independent as possible of fossil fuels. In this sense, the project is a success since 90% of Tokelau's energy is now solar. The cost of such 100% PV and battery projects is still very high today, and none are profitable without subsidies. A mix including copra oil, for example, would make it possible to regulate some of the intermittency and thus to reduce the share covered by batteries.
Keys to project success	The first key to success is identifying the best islands to locate hybrid power plants (see below). Such a project should also consist of: • a thorough study of the demand for electricity, accompanied by village plans for energy savings, in order to avoid oversizing the installation, • a discussion of the most appropriate choice of technology (multi-cluster system, centralized, etc.), • consideration of the impact of batteries on the local environment, particularly once they must be disposed of, • a study of the possible use of generators powered by copra oil, the latter produced locally, if possible, in order to reach 100% energy independence.
Target countries	All Pacific countries with remote villages. This type of project is especially adapted for atolls where: • land questions have been resolved, • annual consumption is between 100 and 400 MWh, • maintenance is an important criterion (photovoltaic technology requires less maintenance), • the cost of diesel delivery is very high.

4.2.3 Other photovoltaic projects

Solar farms with unregulated connections to the grid

Numerous solar farms connected to electric grids now exist in all the Pacific island countries. Nevertheless, in the case of battery-free solar farms, the intermittent nature of production prevents reaching the generally acknowledged threshold of 30% of the grid's power consumption, for 5 to 10% of annual energy consumption.

Hybrid power plants in French Polynesia

A solar-diesel hybrid power plant was first built by EDT in 2000 in Makatea and reinforced in 2005 (45 kWp solar energy). Six other power plants have been built through two programs led by the country and supported by the European Union (European Development Fund) and the French Overseas Exceptional Investment Fund. These power plants are operating in villages in the Tuamotu Archipelago. The total renewable power demand is 640 kWp of solar energy. Between 50 and 100% of needs are currently covered by the solar field, depending on the site and the season. Four new power plants are under construction in the Tuamotu islands.

5 Other technologies

5.1 Wind

5.1.1 Selected project: Kaféate wind farm (New Caledonia)

Kaféate wind farm

Photo: Aerowatt.

Type de project	Wind		
Country	New Caledonia	**Date**	2005-2006
Installed power capacity	11.55 MW for 28 GWh annual production		
Setup and financing	Setup and operation by Aerowatt company Financing by Aerowatt, New Caledonia, the French State (tax exemption) and Banque calédonienne d'investissement (loan)		
Criteria for project selection	The most emblematic wind project in the Pacific, corresponding to cyclone criteria and therefore the most replicable.		

<u>Project description</u>

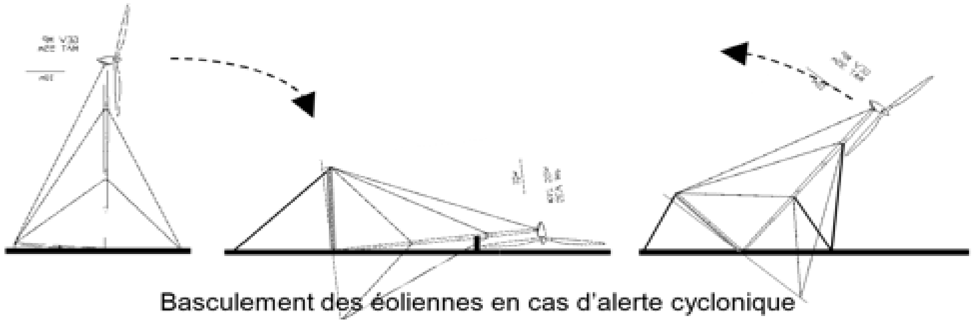
The Kaféate wind farm is the largest anti-cyclone wind farm in the world. Located in the North Province, the production of this farm equals twice the consumption of the combined population of the three surrounding communities: Voh, Kone and Pouembout.

The project was divided into two neighboring farms:

- Kaféate I, put into operation in 2005, with 22 wind turbines and a power of 6.05 MW,
- Kaféate II, put into operation in 2006, with 20 wind turbines and a power of 5.5 MW.

The installed wind turbines are Vergnet anti-cyclone turbines of 275 kW. In the event of a cyclone, the turbines can be tilted to the ground in order to protect them. The blades and towers are attached to the ground.

Diagram 2. Tilting of wind turbines in the event of a cyclone alert



Tilting of wind turbines in the event of a cyclone alert

Source: Vergnet.

5.1.2 Similar projects

Wind farm at La Pointe du Diable, Vanuatu

Photo: Vergnet

History:

- 2004 to 2006: installation of “Met masts”,
- 2007: installation of a first 275 kW turbine (392 MWh produced in 6 months),
- 2008: financing arrangement with the European Investment Bank
- 2009: installation of ten additional turbines.

The project was closely followed by GDF Suez in order to manage intermittency production. Indeed, wind power production frequently reaches 70% of power demand. UNELCO has thus developed a specific load sharing system in order to improve wind energy penetration to avoid sudden grid changes in case of drops in production.

5.1.3 Replicability of project

Technical and financial feasibility	There are many conditions for achieving a quality wind energy project: • Sufficient wind quality (speed and regularity) • Sufficient power demand from grid (minimum power is 275 kW per tower for the Vergnet wind turbines) • Conditions favoring a long lifespan of material: - limit to corrosion linked to sea spray; in particular, the mechanical parts are significantly exposed on the atolls, - need for regular maintenance, therefore specific local skills required to monitor the installed material. o
Keys to project's success, pitfalls to avoid	The success of a wind power project in the Pacific is principally linked to two elements: • the quality of the wind power study • the lifespan of the equipment Low-cost equipment which is unsuitable for tropical conditions should be avoided (on this subject, see trials carried out on Tuamotu atolls ...).
Target countries	Most of the islands of a sufficient size have sites for wind power projects, but profitability varies greatly in function of location. Notable are Papua New Guinea, Fiji, the Vanuatu islands and New Caledonia, as well as Tahiti and Nuku Hiva in French Polynesia.

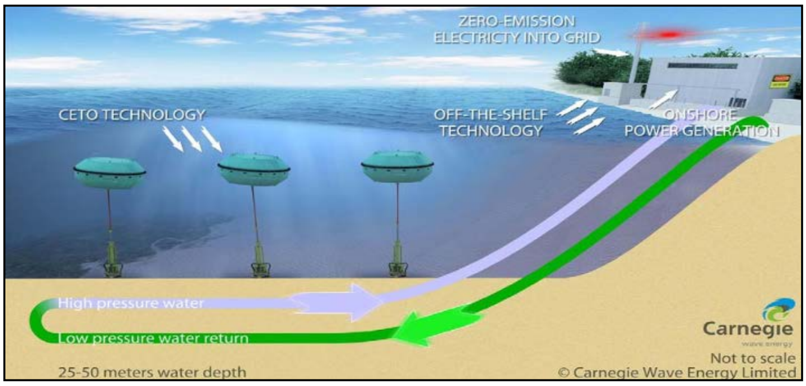
5.2 Ocean wave energy

Currently, no industrial operation using ocean wavy energy exists in the Pacific. The few existing systems are currently being developed. The same is true elsewhere in the world.

In the Pacific, principally in Australia, there are some processes which have gone through several phases of research and development:

The CETO© process has reached the commercial phase with an ongoing installation on Garden Island. There are three CETO buoys which can each generate 240 kW of power (Western Australia).

Diagram 3. Installation diagram of a CETO wave energy system



Source: CETO.

OceanLinx© systems, based on oscillating water column technology, have been tested at 1/3 scale since 2005, and a 1 MW GreenWave system project unit is being installed at Port MacDonnell (South Australia).

OceanLinx oscillating water column system

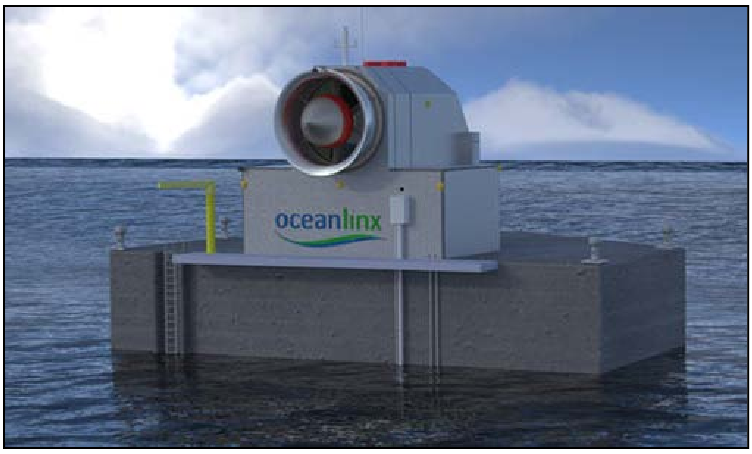


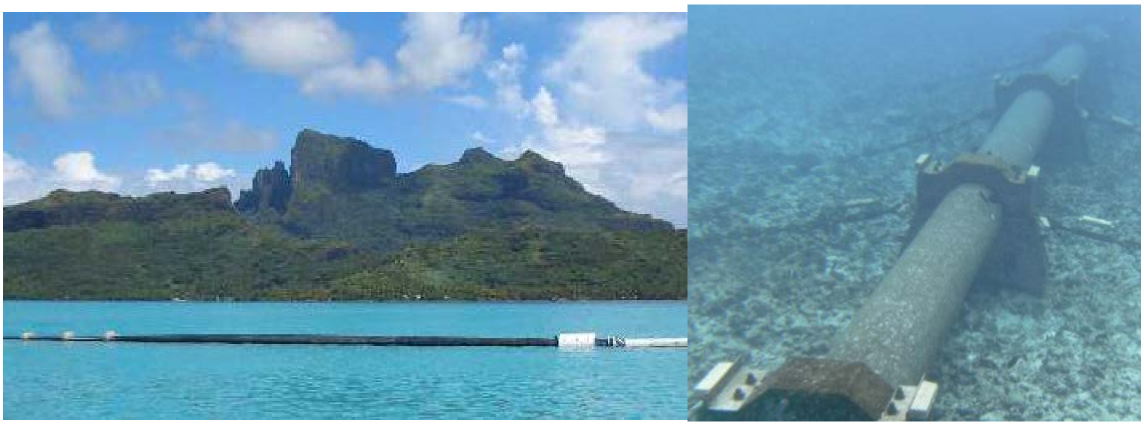
Photo: OceanLinx

In general, experts have insufficient feedback on wave energy processes. Furthermore, it is notable that the development perspectives of the different processes are aimed at characteristics (power, potential, installation conditions ...) which are often very different from those found on South Pacific islands. Development work targeting island conditions must be carried out to come up with processes which would be both adapted and efficient for the islands.

5.3 Seawater air conditioning (SWAC)

5.3.1 Selected project: Intercontinental Thalasso and Spa of Bora Bora, French Polynesia, 2006.

SWAC of the Intercontinental awaiting immersion and immersed SWAC, Bora Bora



Photos: ODEWA.

The SWAC (Seawater Air Conditioning) of the Intercontinental Hotel Thalasso & Spa on Bora Bora was installed in 2006. It is the world's first commercial installation drawing on deep ocean water. The characteristics of the works are as follows:

- refrigeration power: 1 500 - 1 600 kWf,
- depth of water extraction: 915 m,
- diameter of extraction pipeline: 400 mm,
- length of extraction pipeline: 2 412 m.

This installation allows the hotel to reduce its electricity consumption by more than 40%. For the air conditioning section alone, the power necessary for a conventional solution of 500 kVA (generators producing chilled water) are replaced by a pump of less than 20 kVA.

The system has been perfectly and continuously functioning since the hotel opened in May 2006.

5.3.2 Similar project - SWAC of Tetiaroa - French Polynesia - 2013.

Immersion of maritime pipelines - September 2011

Photo: ODEWA.

Another SWAC system was installed between 2011 and 2013 for the Brando hotel on the atoll of Tetiaroa. The characteristics are as follows:

- Refrigeration capacity: 2 400 kWf,
- Depth of water extraction: 960 meters,
- Diameter of extraction pipeline: 450 mm,
- Length of extraction pipeline: 2 579 m.

The electrical power of a conventional air conditioning solution (800 kVA) are replaced by extraction pumps totaling 30 kVA.

5.3.3 Replicability of project

Technical feasibility	The technology has now been mastered and is applicable to any zone with a favorable bathymetry and is close to great ocean depths.
Financial feasibility	SWAC installations are costly, notably for the maritime aspect, which can reach 80% of the total investment. SWAC is economically attractive only when the demand for cold extraction and the associated consumption are high, concentrated and near the shoreline.
Keys to project's success	The first element of success consists in identifying a large need for "cold" and a compatible chilled water system. Such a project also requires: • thorough reconnaissance of the marine environment (bathymetry, geophysics ...) • execution by companies experienced in the marine environment
Target countries	All Pacific countries with large infrastructures and buildings, air conditioned with a chilled water system, close to the sea and featuring reasonable bathymetric profiles.

A SWAC project is in progress at the Taaone hospital (French Polynesia) under the supervision of French Polynesia, and is being co-financed by AFD, EIB and ADEME. Designed to reduce hospital electricity expenses by nearly half, it should be operational in the second half of 2015.

5.4 Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion (OTEC) makes electricity generation possible by using the temperature gradient between surface waters and deep waters. This makes it possible to vaporize and condense a fluid, thereby driving a turbine. Unlike SWAC, which is a substitute for electricity consumption, OTEC produces electricity.

While the principle has been tested since the 1930s (Georges Claude), there are few facilities (a few units ranging from 120 kW to 1 MW tested but never well proven). One of the key difficulties is the rise of large volumes of cold water (several m^3/s) for which pipelines do not exist to this day.

Nevertheless, although many technological obstacles remain, the attractiveness of this energy is great because it is a resource which is accessible throughout the Pacific and is considered permanent, unlike other renewable energies (except geothermal). The yields are significantly higher, but above all, the power generated can be considered a guarantee to facilitate its acceptance by the existing grid.

Moreover, this technology only concerns the intertropical population where the temperature gradient between the surface waters and deep waters is sufficient and greater than 20°C.

Beyond the work by Georges Claude, the first OTEC installation was carried out on the island of Nauru with a gross capacity of 120 kW in 1981. An onshore power plant of 5 MW was planned in the 1980s before being abandoned following a drop in oil prices.

Today, the Pacific islands and French Polynesia are priority targets for the development of OTEC projects: the temperature gradients there are very favorable, conditions conducive to generating extreme cyclones are relatively moderate, distances to coasts are often short, and supplying fossil fuel is complicated.

Be this as it may, even if large companies very interested in the technology, a viable solution is only conceivable the medium term.

5.5 Geothermal science

Selected project: Geothermal power plant of the Lihir gold mine (Papua New Guinea)

Lihir gold mine, Papua New Guinea

Photo: Newcrest

Type of project	Geothermal		
Country	Papua New Guinea	**Date**	
Installed power capacity	56 MW 319 GWh produced annually 216 000 t CO_2 avoided annually		
Financing	Private funds monetization of carbon credits through the UNFCC		
Criteria for project selection	It is the only use of geothermal resources in the Pacific Islands, excepting New Zealand.		

The Lihir mine is an open-pit gold mine located above a source of steam near the earth's surface. Initially, wells were drilled in order to depressurize the steam zone and thus cool the ground before removing the ore. The use of steam to generate electricity began in 2003 with a capacity of 6 MW, then 36 MW in 2005, and today 56 MW. The mine consumes the totality of the electricity, which was initially produced with heavy fuel oil.

5.5.1 Replicability of geothermal projects in the Pacific

Technical and financial feasibility	An adequate steam source sufficiently close to the earth's surface is necessary to assure the profitable exploitation of a geothermal source. The greatest difficulty consists in evaluating the resource, which requires a significant (sometimes fruitless) investment. Once a sufficient resource is identified, geothermal electricity is generally inexpensive. For example, New Zealand estimates that the production costs for its geothermal power plants are 6 XPF/kWh, compared to about 25 XPF/kWh for fuel oil-based production in Tahiti[10].
Target countries	A 2009 study drew up a list of eligible countries (of 20 countries, including French Polynesia): • high potential countries: Papua New Guinea and Fiji, • medium potential: Vanuatu, Solomon Islands, North Mariana Islands • moderate potential: Samoa, Tonga, New Caledonia.

6 Examples of mixed projects

The projects described in this part have been selected because they gather several technologies or approaches to form a coherent whole. As this unique type of project is designed case by case, we will not discuss the question of replicability.

6.1 The Brando hotel of Tetiaroa, French Polynesia

6.1.1 Project Description

The Brando hotel, Tetiaroa

Photo: www.etahititravel.pf

Name of project	The Brando hotel - Tetiaroa - French Polynesia		
Type of project	Hotel		
Country	French Polynesia	**Date**	2014
Installed power capacity	2 819 kW (899 kWp PV - 1 920 kVA copra oil generators)		
Financing	Private		
Criteria for project selection	100% RE objective		

The Brando hotel, located on the Tetiaroa atoll in French Polynesia, opened for business in mid-2014. This hotel, by its target clientele, remoteness and atoll history, is strongly oriented towards the concept of sustainable development in integrating green energy as a key point, has a goal of "100% renewable energy."

This extremely ambitious objective is the cornerstone of this project which aims to win the highest possible LEED distinction of Platinum (Leadership in Energy and Environmental Design - Certification from the US Green Building Council). The ecodesign was thus integrated very early in the conception of the villas in terms of materials and insulation. However, it is the production of energy from renewable resources which is this unique project's greatest challenge.

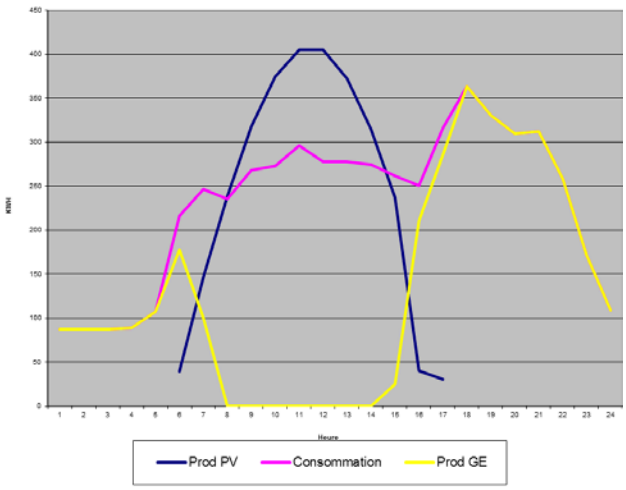
<u>Characteristics of the installed energies:</u>

The goal of achieving an entirely energy-independent hotel hinges on three complementary technologies:

- the seawater air conditioning system (SWAC), which removes a significant amount of traditional hotel power demand (40-50% of electricity consumption for air conditioning),
- photovoltaic-supplied electricity,
- coconut oil-powered generators

The regulation of these different sources of energy is facilitated by the use of flow cells. They make it possible to optimize the use of photovoltaic-supplied energy in the daytime while absorbing high power variations. The installed solar capacity is enough to meet maximum demand of the hotel. At night, the coconut oil generators complete the mix.

Figure 8. Typical daily consumption/production curve for The Brando hotel



PV Production Consumption GE Production

Source: Energie de Tetiaroa.

Table 2. Annual distribution of capacity and production supply

Energy	Capacity	Production
Photovoltaic	899 kWp	1 GWh/year
Coconut oil-powered generators	6 generators at 160 kVA (phase 1) + 6 generators at 160 kVA (phase 2)	1 GWh/year – phase 1 2.455 GWh/year – phase 2
Refrigeration	2.4 MWf	SWAC – Pipeline 450 mm
Storage	Flow cells	ZBB – 40 units at 50 kWh

Source: Energie de Tetiaroa.

The mix shown in Table 2 is interesting because it is reproducible on many Pacific atolls. It is recalled that copra oil has many advantages in this type of project:

- an excellent carbon footprint (the carbon is biogenic and not from a fossil fuel source);
- the possibility to regulate intermittent energies such as wind or photovoltaic. Indeed, the generator functions like a diesel generator and makes it possible to regulate the voltage and the frequency. In the case of The Brando, the photovoltaic capacity is large and also requires a large number of batteries, on the same economic model as Tokelau;
- Oil production can be local. In the case of The Brando, the oil is bought from the oil mill in Tahiti. Nonetheless, as UNELCO proved in Vanuatu, small-scale production is conceivable on the atolls, thus largely increasing local added value.

Besides the technical challenges met at the core of the project, it is important to highlight certain notable advances in the level of the country as a whole. The signature of agreements related to the local sale of coconut oil as a fuel is a major precedent for using this biofuel in French Polynesia.

6.2 "Small is Beautiful" project, Tuvalu

6.2.1 Project description

Name of project	*Small is Beautiful* (SIB), Amatuku micro model		
Type of project	Mixed		
Country	Tuvalu	**Date**	2004
Installed power capacity	Unavailable		
Financing	ADEME, Pacific Fund, SOPAC, PIGGAREP		
Criteria for project selection	Project combining several approaches. It also concerns one of the first uses of gasification technology on an atoll.		

The project "Amatuku: the pilot islet" is part of the Tuvalu islands' ten-year plan called "Small is Beautiful" (SIB), whose initial objective is to help Tuvalu become model nation in terms of environmental respect. As the Tuvalu islands are particularly threatened by climate change, the program has a dual objective:

- to make Tuvalu an environmentally exemplary country
- to prepare institutions and the population to adapt to climate change, as well as rehabilitation on a future land of asylum.

Action has been taken in the domains of water, waste, energy, air and soil erosion. In this context, Amatuku's project aimed to create an energy pilot islet, whose lessons could be applied by other Pacific islands. Thus the islet did not have production or profitability objectives, but rather aimed for training and awareness. Above all, it was a matter of offering inhabitants a practical learning experience through a micro model, a micro example to inspire them to reproduce the technologies in their communities. The different technologies discussed here are already treated separately above, but Amatuku represents one of the only attempts to mix many solutions using biogas. A specific paragraph concerns gasification, a largely underused technology.

Beyond the Amatuku experience, many details of the Small is Beautiful can be learned at the website www.alofatuvalu.tv.

<u>Renewable energy</u>

Numerous renewable energy options were studied for the pilot islet project, the first being biomass. All these trials were led with a training objective, implicating different communities and interest groups (women, producers, other organizations, churches, government directorates, including the Tuvalu Electric Corporation (TEC)).

The following possibilities were considered, often with a demonstration prototype:

- biogas production: installation of the first digester ever carried out on a coral atoll,
- biodiesel production: Alofa Tuvalu made several demonstrations of the production of filtered coconut oil, using a diesel mix (20% of oil in mix),
- ethanol production: ethanol produced from local alcohol (the todi produced from the sap of new coconut shoots) through distilling. Trials finished with an estimated production potential of about 2.25 liters of fuel per day per coconut tree, enough for two scooters,
- electricity from gasification (see "gas generator case" below),
- wind turbine,
- photovoltaic panels.

Gas generator case

A gas generator has been installed on the islet of Amatuku in order to produce electricity using coconut tree biomass. It is one of the rare units of this type functioning on an atoll for which figures are available[11]. The following findings are those obtained by Gilles Vaitilingom, a biomass energy specialist for the Small is Beautiful program:

"In application of the electrification by electric generator, the gas generators, with a specific consumption of 1.3 kg of wood (at 12% humidity) per electric kWh, gives an overall practical equivalent of 4.3 kg to substitute for 1 liter of diesel fuel. These results are particularly interesting for the areas where wood is an abundant resource.

"In the small Pacific countries, one has to be careful when using ligneous energy resources. But if we look at the coconut tree, we reach a renewable potential in coconut shells and husks of about 32 Kg/tree/year. That is the equivalent of 7.5 liters of diesel used in generators."

It must be recalled that a coconut tree produces about 7 liters of oil per year (the oil represents 10% of the mass versus 50% for the dry material). We can thus conclude (all in taking great care with the figures, given the absence of a large-scale trial) that the energy potential of the dry material is quite equivalent to that of copra oil. It could be a good complement to energy production on the islands. Nonetheless, the gas generator technology is difficult to set up without the intervention of a specialist, and its generalization to the atolls would require significant training. In fact, as of today no trial beyond that of a simple prototype has been set up.

7 Control of energy demand

Promoting Energy Efficiency in the Pacific (PEEP)

A consultation launched by the Asian Development Bank (AsBD) in 2007 allowed five Pacific countries to be identified (Cook Islands, Papua New Guinea, Samoa, Tonga and Vanuatu) as volunteer and priority countries to lead a program in reducing fossil fuel consumption.

The PEEP project aims to reduce fossil fuel consumption in these countries by acting on the demand rather than the production side. The project is divided into two phases, the first of which finished in May 2011 and mainly made it possible to define the current state of affairs and program orientations. The second phase was to end in November 2014. The actions carried out in the scope of the PEEP are described below.

Many projects aiming to improve energy efficiency could have been cited here. To our knowledge, this project is one of the most structured and complete. In each paragraph we will state whether equivalent programs exist.

Effective urban lighting

This part of the program aimed at improving the quality of street lighting while reducing community electric bills. Indeed, the replacement of aging urban lighting of the countries concerned by LED technology yielded a healthy return on investment (5-year payback period) for a total investment of 8 M USD. It concerns a relatively simple action to implement, and whose profit goes directly to the communities.

We note the exception of the Vanuatu islands where the lighting was already quite efficient and electricity less costly; the payback period there is estimated at 15 years. Renewing urban lighting is thus to be studied case by case according to the country, or even islands and communities.

Training in energy diagnostics

A training program in energy diagnostics was launched, destined for contracting authorities but also consultancies and technical departments.

A different choice was made for French-speaking territories, which had favored the subsidy for energy diagnostics and assessments of greenhouse gases, with the participation of the ADEME. This method, which requires the services of existing consultancies, has proven itself, since the allocated credit for these subsidies is sought in its entirety by companies and communities, and has generated quite substantial savings for the beneficiaries of studies.

Energy labeling and minimal performance standards

One program priority concerns inefficient large household equipment, which makes up the greatest source of energy savings for households in the countries concerned by the PEEP project. The objective is to inform the consumer at the time of purchase, or even to forbid importing the least efficient products.

The objectives for this part are the following:

- implementation of energy labeling for household equipment,
- implementation of regulation of minimal performance standards for domestic appliances,
- information and awareness-raising for stakeholders (importers, resellers, users),
- implementation of a dedicated data base,
- implementation of import monitoring procedures and financial sanctions for offenders.

It should be noted that this labeling program has now been extended to all countries in the Pacific zone and is now under the control of the Secretariat of the Pacific Community (SPC).

New Caledonia has also launched an energy labeling program (begun in 2012) and progressively modified its regulations. French Polynesia, following New Caledonia's lead, has also launched a labeling project, which, at the time of this study's writing, had not been put into operation.

Revision of the building code

On most islands, the industries which consume the most energy are very small or absent. Consequently, most consumption is related to the operation of residential, touristic and commercial buildings. The decision has been made to work on revising building codes in order to integrate energy-related aspects at the design level.

The objectives for this part are as follows:

- draw up minimal performance specifications for new buildings, the envelope, lighting and brightness, air conditioning equipment, etc.,
- train engineers and architects,
- implement new norms and set up monitoring procedures for new buildings.

Action related to green construction has also been launched in New Caledonia and French Polynesia. In these two territories, the program is the following:

- training and awareness-raising of construction professionals (architects, engineers as well as contracting authorities) in the issues linked to green construction,
- creation of an entity charged with creating a green construction guide (in French Polynesia, "the house of green builders"),
- setup of regulations.

Revision of procurement policies

The aim of this part is to integrate energy performance criteria into the rating grids for calls for tenders. It also seeks to improve the energy spending follow-up and monitoring mechanisms for projects financed by the countries.

8 What renewable energies for the Pacific of tomorrow?

8.1 Thoughts on the evolution of prices and technologies

All technologies follow a similar life cycle: research/development (including prototyping), industrialization/marketing. Once in the phase of industrialization, prices (in the vast majority of cases) follow a decreasing curve to approach, at maturity, an asymptote corresponding to the optimization of production processes, choices in raw materials and the supply/assembly chain.

Among the processes presented in this report, all are of course not in the same phase of development. But above all, they do not evolve at the same rate. In Table 3, we have indicated the state of the art for each technology. Not being the object of this report, these are only estimations, in function of Airaro's monitoring of technological developments. Cost evolutions do not take price inflation into account.

Table 3. Expected evolution of renewable energy technologies in the coming years

Technology	Phase	Technological evolution / processes	Expected price evolution for the islands
Hydroelectricity	Mature	Quasi-nil	Stable
Micro-hydroelectricity	Mature	Weak	Stable
Photovoltaic (silicon panels)	Mature	Strong in recent years. Very near maturity for silicon panels. No technological leap expected in coming years, therefore no price drop.	Slight drop
Wind	Industrialization	Strong on the optimization of large units (several MW). No technological leap expected in fundamental mechanical processes	Slight drop, or stability. With scarcity of sufficiently windy zones in the Pacific zone, no volume effect conceivable
PV + batteries Wind + batteries	Industrialization	Very strong. Enormous progress made and expected in batteries	Strong drop expected in the coming years.
Wave energy and hydrokinetic	R&D; industrialization in the North countries on large capacity units	Functional systems exist but, at this stage, industrialization has not been foreseen for small units	No evolution as long as island markets are unattractive to companies: not in coming years. A similar evolution to that of wind seems most plausible. The small tidal range on Pacific islands limits potential to a few zones.

Technology	Phase	Technological evolution / processes	Price evolution expected for the islands
Ocean thermal energy	R&D	Industrialization planned for the islands, but for 5 MW units minimum. Technological stakes ride principally on manufacture of pumping hose	Unknown. For a given capacity, sharp drops are improbable given the nature of technical issues. Economies of scale are expected for units larger than 10 MW
Biogas	Industrialization	Processes mastered for small and large units. France is historically late on small units, but the gap is gradually closing. Progress can be expected for biogas-powered fuel cells, giving a better yield for electricity production	Stable for methanation. Need to systematically optimize installation to the first available organic matter which unfortunately implies cost of studies cannot be reduced, but standardization of small units (notably kits from China) results in fall in some construction costs
Biofuels / copra oil	Mature	Small	Stable
Geothermal	Mature	Small. Projects are studied case by case, but no technological breakthrough is expected	Stable
Gas generator	R&D	The process is known but has never reached widespread industrialization due to difficulty in controlling reaction. Progress is however expected thanks to renewed interest in this technology in recent years	Unknown
Mastery of demand	In expansion	Increasingly energy-efficient technologies (industry and residential) are numerous and in full expansion. Similarly, promotional techniques of mastery of energy demand are improving and producing substantial results	Steady decrease

Reading Table 3 leads us to believe that certain resources will never be profitable on the islands. Indeed, if we take the example of an atoll on which a channel is found, the most relevant choice today consists of installing photovoltaic panels until saturation of the grid by the intermittent energy (around 30% of power consumption). That allows for the production of 5% renewable energy [12].

To increase the penetration rate of RE, the choice can be summarized by the following technologies:

- photovoltaic + batteries,
- wind + batteries,
- biomass (copra oil, possibly biogas or gas generator) > production limited by the resource
- hydrokinetic

So far, the PV+battery systems are still very expensive (around 100 XPF/kWh) and several Polynesian atolls await small hydrokinetic units on the market in order to equip channels, for a price which can be close to retail, that is around 50 or 60 XPF/kWh. But the rapid evolution of battery research leaves hope that the price curves of the two technologies could cross before (or a few years after) an industrial hydrokinetic solution is in place in the Pacific. Today, however, photovoltaic energy remains by far the most attractive solution based on price and ease of maintenance.

Consequently, the premature choice of hydrokinetics by a "pioneer" atoll could be harmful to development, making the atoll dependent on a technology unmaintained by manufacturers due to its absence elsewhere in the Pacific zone. More generally, isolation and the multiple constraints of terrain mean that the majority of Pacific islands are not appropriate testing grounds for new renewable energies, with the exception of SWAC and OTEC for which the natural conditions are sufficiently favorable to justify the costs inherent in geographic remoteness. We therefore favor the technologies which are the best proven and the easiest to maintain: hydroelectricity, solar (thermal and photovoltaic) and the biomass technologies.

8.2 What are the desirable energy projects for the Pacific of tomorrow?

Proven technologies ...

All renewable technologies have one or several attractive features in terms of exploitation for the geographies of the South Pacific. Nevertheless, considering the conclusions of each chapter and the notes on cost evolution in 8.1, we distinguish three which seem the most promising to us:

1. **Hydroelectricity**, despite the notes above, remains the energy which has the greatest moderate-cost potential for the high islands with positive moisture balances. It is also one of the only energies which offers energy storage capacity and thus a capacity guarantee, essential for small electric grids.

2. **Photovoltaic solar energy** should be promoted, provided that it is accompanied with batteries to regulate the intermittency, and that the treatment/recycling phase of batteries is integrated at the time of project design. On this subject, the next five years should hold great promise, as storage technologies are evolving very fast;
3. **Biomass**, and in particular the management of the carbon cycle with the help of biogas/copra/gas generator systems. Such a grouping could be very effective on the majority of atolls as a complement to photovoltaic energy, on the condition that the inhabitants are associated with the projects.

As explained in the preceding paragraph, these technologies are mature and are also easier to maintain. Although certain energies (notably marine) have better known images, the production efficiency and the reliability of the investment are superior for these three technologies.

... but a differentiated financial setup for each project

While we recommend rather classic choices for technical reasons, our exchanges with the different project developers confirm that the standardization of procedures and methods can harm the proper functioning of projects.

The case of Nadarivatu (Fiji) is the most radical in this sense since the financing and the general organization are imported in the form of a package supplied by the Chinese development bank and the company Sinohydro. Beyond Sinohydro's direct responsibility in leading the works, it is the "all integrated" setup which deprived the Fijian state and local authorities of their capacity of control. From the outset, there has been no place for local people or any sort of regulatory action.

Quite the opposite case exists for the hydroelectric projects on the Solomon Islands and the biogas projects of the Samoa Islands. These projects are remarkable in the way they have implicated local people in both the definition of needs and the execution of the project. Still, Pelena and BioEnceptionz chose to use self-financing, since the conditions for obtaining international subsidies were too constraining. If donors wish to invest in rural development in the form of numerous small projects, a new financing model should be invented, one which would simplify procedures and grant greater leeway to project directors.

Indeed, the thresholds and procurement procedures of international donors are incompatible with the projects cited. It is recalled that, in the Solomon Islands, a gap of 1 to 25 existed between the true cost of the project (carried out by villagers with no respect for any international, social and especially safety norms) on the one hand and on the other hand the standardized calls for competitive bids, thereby compliant with donor procedures.

It is thus necessary to use an intermediate structure between the international donors and the project developers destined for micro-communities. The Pacific community (or another) could welcome a unique consultant, remunerated by donors, whose mission would be:

- the selection of projects,
- verification of the correlation between the answers provided by the project developers and realities on the ground,

- the drawing up of new rules allowing the realization of micro projects, at an affordable cost for these people and responding to real needs.

It must be remembered that the projects which take nearby inhabitants into consideration and associate them with the works (inhabitants who are often beneficiaries of the electricity produced), from the project design to the maintenance phase, are the projects which are the most efficient and above all the most sustainable. If a choice has to be made, these projects deserve to be qualified as exemplary.

FOOTNOTES

1 BP 140 435 - 98701 ARUE, Polynésie française, RCS Papeete TPI 12 51 B - N° Tahiti A14412. Email address of the principal correspondent of the study: Jean.hourcourigaray@airaro.com

2 The Overseas Countries and Territories, that is, New Caledonia, French Polynesia and Wallis and Futuna, will be included in the PICTs.

3 Countries appearing in green in Figure 1., including New Caledonia.

4 Appropriate Technology for Community and Environment, project led by the University of Technology, Sydney.

5 See BioEnceptionz (2012).

6 About 10 kWh per day, which is the average consumption of a Tahitian household.

7 UNELCO, a subsidiary of GDF Suez, is a concessionaire for the production and distribution of electricity in Vanuatu.

8 MFAT's Renewable Energy Mini-grid Common Design Principles.

9 50-hour capacity at maximum grid load, which in practice is somewhat less than 2 days.

10 Ex-power plant price.

11 Source: F. Héros and G. Vaitilingom of the AlofaTuvalu program

12 Effectively, the PV capacity is equal to 30% of the peak noontime capacity, during about 1 300 hours per year. Ultimately, photovoltaic production will therefore be about 5% over the year.

GLOSSARY OF ABBREVIATIONS

ADEME	Agence du développement et de la maîtrise de l'énergie / Agency for the Development and Control of Energy
AFD	Agence Française de Développement
APACE	Appropriate Technology for Community and Environment
AsDB	Asian Development Bank
EIB	European Investment Bank
RE	Renewable Energy
OTEC	Ocean Thermal Energy Conversion
IRENA	International Renewable Energy Agency
LEED	Leadership in Energy and Environmental Design
MFAT	Ministry of Foreign Affairs and Trade (New Zealand)
NZAID	New Zealand Aid Program
NZD	New Zealand Dollar
ORSTOM	Office de la recherche scientifique et technique outre-mer
	(now IRD - Institut de recherche pour le développement / Research Institute for Development)
PEEP	Promotion of Energy Efficiency in the Pacific
PICTs	Pacific Island Countries and Territories – includes independent States as well as autonomous territories linked to a continental State
PNG	Papua New Guinea
PPA	Pacific Power Association
SPC	Secretariat of the Pacific Committee
SWAC	Sea Water Air Conditioning
TEC	Tuvalu Electricity Corporation
TREP	Tokelau Renewable Energy Project
UNELCO	Subsidiary of GDF Suez which produces and distributes electricity in Vanuatu (formerly Union électrique coloniale)
XPF	French Pacific Franc

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