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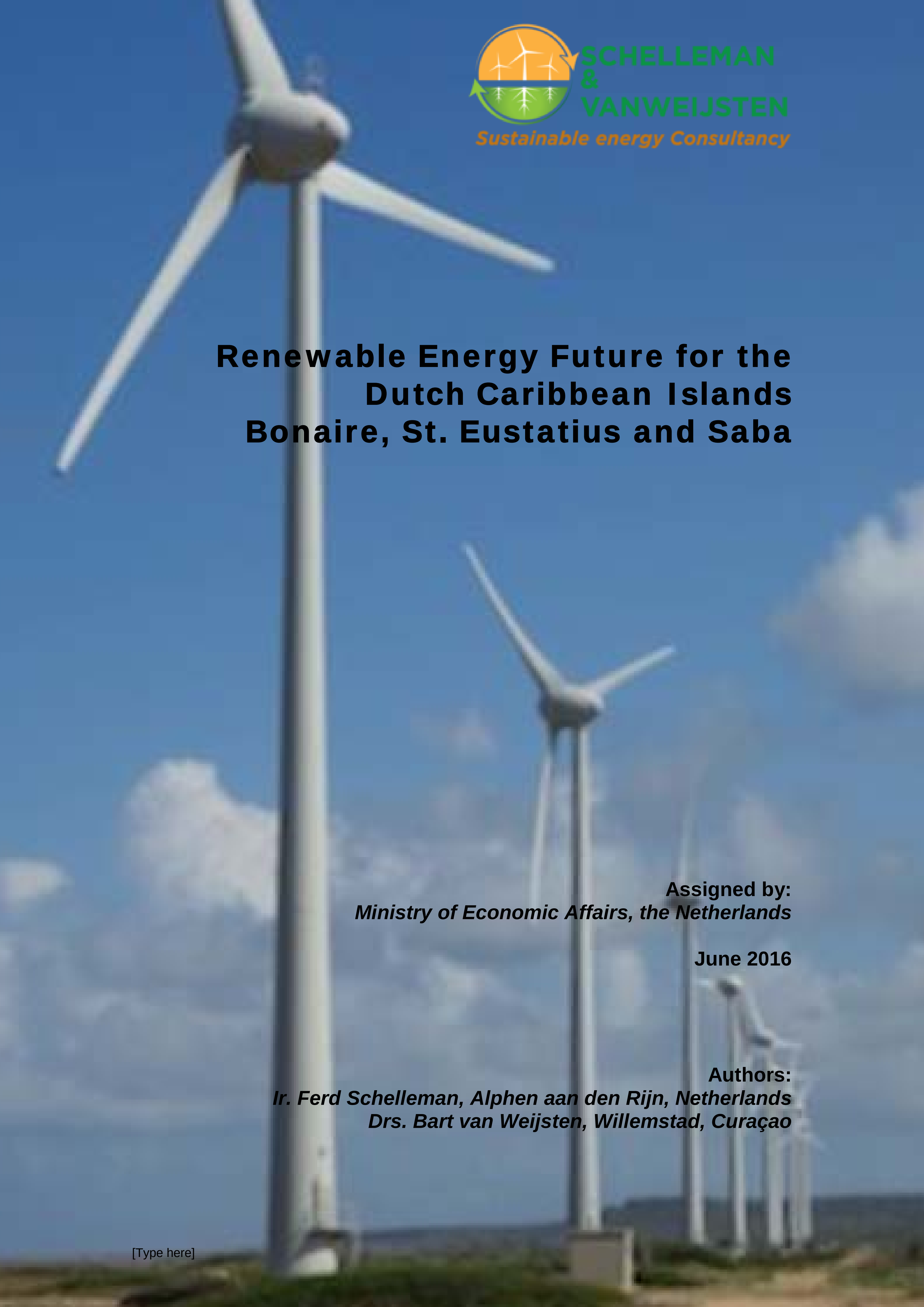

Renewable Energy Future for the Dutch Caribbean Islands Bonaire, St. Eustatius and Saba

Assigned by:
Ministry of Economic Affairs, the Netherlands

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Date:
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Abbreviations

ABC	Aruba Bonaire Curacao
BBL	Barrel
BES	Bonaire, St. Eustatius and Saba
BoS	Balance of System
CARILEC	Caribbean Electric Utility Services Corporation
CREF	Caribbean Renewable Energy Forum
CO2	Carbon Dioxide
DoE	United States Department of Energy
ECN	Energie Centrum Nederland
GDP	Gross Domestic Product
GEBE	Utility Company of St. Maarten
GFI	Grid-forming Inverters
GWEC	Global Wind Energy Council
GW(h)	GigaWatt (hour)
HFO	Heavy Fuel Oil
HOMER Pro©	Simulation software HOMER
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre
KEMA	Keuringsinstituut voor Elektrotechnische Materialen
kW(h)	kilo Watt (hour)
LED	Light Emitting Diode
LFO	Light Fuel Oil
Li-Ion	Lithium-Ion
MW(h)	Mega Watt (hour)
MEA	Ministry of Economic Affairs
NRE	Non Revenue Electricity
OUR	Office of Utility Regulations
OCT	Overseas Countries & Territories
OGEM	Overzeese Gebiedsdelen Energie Maatschappij NV.
OTEC	Ocean Thermal Energy Conversion
O&M	Operations & Maintenance
PPA	Power Purchase Agreement
PoS	Probability of Success
PV	Photovoltaic
SEC	Saba Electric Company
STUCO	St. Eustatius Utility Company
SWAC	Seawater Air Conditioning
TNO	Instituut voor Toegepast Natuurwetenschappelijk Onderzoek
U.S.	United States
USD	United States Dollar
WEB	Water- en Energiebedrijf Bonaire N.V.
WTI	West Texas Intermediate (oil price)

Executive Summary

The Dutch Caribbean islands Bonaire, St. Eustatius and Saba (CN-islands) all have small electricity grids powered by diesel generators fueled by expensive fuel oil. Electricity costs on these islands are therefore high, ranging from US$ 0.35 to US$ 0.38, despite subsidies by the Ministry of Economic Affairs.

These islands have on the other hand favorable circumstances for renewable electricity generation: high solar irradiation, good wind climate, especially for Bonaire. All of the islands have experience with these renewable energy sources, although the first solar park of 1 MW for Saba will be realized in the near future. St. Eustatius recently commissioned its first 1.89 MW solar park. Bonaire has 11.1 MW of wind power installed and a small solar plant of 0.25 MW. Bonaire already realizes approx. 40% of the renewable electricity generation, the St. Eustatius solar park will generate approx. 23% of the electricity demand of the island. To enable absorption of these variable renewable electricity generation, Bonaire and St. Eustatius also have electricity storage included.

Power generation	Bonaire	St. Eustatius	Saba
Diesel generators	14.4 MW	3.3 MW	2.3 MW
Wind power:	11.1 MW	-	-
Operational solar power	0.2 MW	1.9 MW	-
Operational energy storage	0.1 MWh	0.6 MWh	-
Planned solar power	-	2.0 MW	2.0 MW
Electricity demand	103,400 MWh	13,700 MWh	9,376 MWh

Renewable energy technologies:

Several renewable energy technologies can be applied to further increase the share of renewables on the CN islands. The following technologies have been assessed on their technical, economic and sustainability effects on electricity generation and cost developments, the technical and economic characteristics of the technologies are summarized below:

1. Wind energy: wind turbines are now widely applied in the Caribbean. Bonaire has a relatively large wind park in very good wind conditions. Saba and St. Eustatius have a less favorable wind climate and have problems identifying suitable locations on their small islands although initial feasibility studies look promising.

2. Solar energy: solar PV can be realized in larger solar parks (100 kW up to several MWs) or through small scale, decentralized installations on houses, hotels etc. These installations have capacities of several kW up to 1 MW for larger users. Decentralized solar power is practically not applied on the CN islands, because it is forbidden for customers of the electricity distributors to also supply themselves. With the new BES Electricity Law this restriction is now lifted.

3. Electricity storage: both wind and solar are variable renewable energy sources. Due to the variations in power output over the year (seasonal variations), day and even hours and minutes, the wide scale introduction of wind and solar power requires electricity storage to enable effective balancing with demand and back up diesel generators. Electricity storage has already been installed on Bonaire and St. Eustatius and with further extension of solar and wind power additional storage capacity will be required.

4. OTEC, Ocean Thermal Energy Conversion, is a new technology using the temperature difference between ocean surface water (27 – 29 degrees Celsius) and the temperatures at approx. 1,000 meters deep, 5 degrees Celsius. This system requires a large diameter cold sea water pipe to a depth of 1,000 meters, several kilometers long, large heat exchangers, pumps and turbines to produce electricity. OTEC can also provide fresh water and cold seawater for cooling purposes. It can be applied on all three BES islands.

5. Geothermal energy: research in the past has shown that there is a 21% chance that Saba can develop geothermal energy for its power generation. The potential could be very large, however, Saba has a very limited electricity demand. Studies have shown that a connection with St. Maarten, requiring a long sea cable for electricity transportation, could result in attractively low electricity costs. The risks of geothermal energy exploration and development however, are high. Regional development is increasing and should be watched.

6. Other renewable energy sources like biomass and biofuels, waste to energy, wave and tidal energy a/o are not available on the islands and are not expected to be able to contribute to electricity generation for the coming 15 years.

Energy efficiency may also contribute in reducing energy costs of the islands. Unfortunately, no information was available on the energy consumption in different sectors, penetration of specific energy consuming appliances and quality of housing and other buildings.

Parameters for Wind energy:	**Bonaire**	**Statia /Saba**
Capacity factor	40%	35%/27%
Yearly output/ in MWh per MW	3.500	3.066/2.365
Lifetime	15 years	15 years
Capital costs	2.400 $/kW	2.700 $/kW
Fixed O&M costs	54 $/kW-yr	81 $/kW-yr
Variable O&M costs	0,02 $/kWh	0,02 $/kWh
Parameters for Solar Energy:		
Capacity factor	18 – 20%	18-20%
Yearly output in MWh per MW	1,577 – 1,752	1,577 – 1,752
Lifetime	25 years	25 years
Capital costs	US$ 1,800 – 2,000 /kW	US$ 1,800 – 2,000/kW
O&M costs	US$ 15/kW-yr	US$ 34/kW-yr
Parameters for OTEC:		
Capacity factor	95%	95%
Yearly output in MWh/MW	8,300	8,300
Lifetime	20 years	20 years
Capital costs	30.000 $/kW	41.000$/kW
Fixed O&M costs	800 $/kW-yr	1,100 $/kw
Parameters for Geothermal energy (Saba only):		
Capacity factor		99%
Yearly output in MWh/MW		8,670 MWh
Lifetime		20 – 30 years
Capital costs		US$ 8,500 /kW
Fixed O&M costs		US$ 200/kW-yr

The above-presented costs for renewable energy investments do **not** include costs associated with storage for reducing curtailment or ramp rate control, infrastructure and site preparation, grid connection and enhancement, project management, administrative procedures and environmental requirements. A mark-up has been included to cover for these costs in the final calculations and scenario assessments.

Renewable energy scenarios for the CN islands:

Based on the above information concerning the electricity sectors of the islands and the renewable energy technology parameters, three scenarios have been prepared for each of the CN islands:

- 60% renewable electricity generation;
- 80% renewable electricity generation, and
- 100% renewable electricity generation.

Using HOMER Energy software, for each share of renewable electricity, the optimal combination of different energy technologies and storage has been found, together with the associated information on kWh-production of each technology, fuel savings in conventional electricity generation and potential for kWh cost reductions and CO2 emission reduction. As the islands have already operational renewable production and planned additions, the scenarios are referenced to the as-is situation with regards to additional investments and associated fuels savings.

For Bonaire, in addition to the above scenarios, we have assessed the possibility of scenarios based on decentralized renewable energy. The other scenarios, called utility scenarios, also depend on agreement with CGB.

The scenarios for the three islands are then as follows:

Bonaire Utility	Solar (MW)	Wind (MW)	OTEC (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	0.25	11.1	0	0.1	38%	16,717	N/A
Scenario 1	0	+8.1	0	0.1	62%	10,270	6,425
Scenario 2	10	+10.8	0	0.1	81%	5,211	11,483
Scenario 3	0	0	15		100%	0	26,887
Bonaire decentral	**Solar (MW)**	**Wind (MW)**	**OTEC (MW)**	**Storage (MWh)**	**Renewable %**	**Fuel usage (m3)**	**Fuel savings (m3)**
Scenario 1	2	+2.7	0	+1	50%	13,524	3,193
Scenario 2	8	+2.7	0	+5	60%	11,019	5,698

St. Eustatius	Solar (MW)	Wind (MW)	OTEC (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	3.89	0	0	4.6	42%	2,174	N/A
Scenario 1	3.89	1.6	0	4.6	69%	1,161	1,013
Scenario 2	3.89	3.2	0	4.6	86%	532	1,642
Scenario 3	0	0	2.3	0	100%	-	3,724

Saba	Solar (MW)	Wind (MW)	GEO (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	2	0	0	1	31%	1,593	N/A
Scenario 1	2	2	0	1	63%	873	720
Scenario 2	2	3	0	6	81%	448	1,144
Scenario 3	0	0	1,5	0	100%	-	2,321

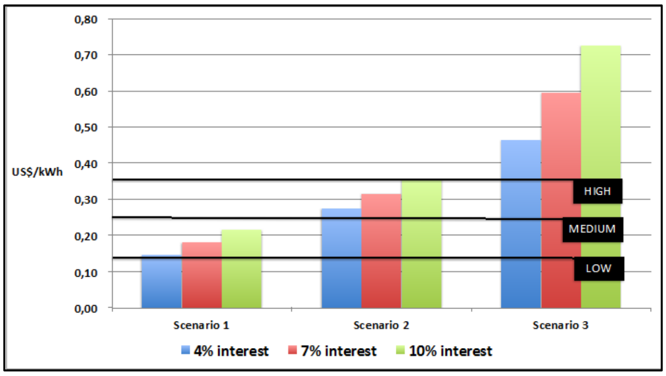
The fuel savings in scenarios 3 relate to the situation without any other renewable electricity generation, where all electricity would have been produced with diesel generators. OTEC and geothermal energy do not need back up for electricity generation. It is also expected that now or quickly available renewable energy sources will have reached their lifetime and will be dismantled at the time OTEC or geothermal energy will have been developed and implemented.

For each of these scenarios a kWh-cost has been calculated for the additional renewable electricity generation, which has been compared to the fuel costs of conventional electricity production with the diesel generators as the alternative option. In case this kWh-cost is lower than the fuel costs, this scenario will result in reduced overall electricity costs. The results of this comparison are shown in the below graphs. The kWh costs have been calculated using three interest rates: 4% with Dutch financing support or guarantees; 10% based on almost fully commercial financing, and an intermediate rate of 7%.

The fuel prices applied are based on world oil market developments:

WTI crude oil price (per bbl)	US$ 50	US$ 90	US$ 130
HFO	US$ 0.51	US$ 0.91	US$ 1.32
LFO	US$ 0.73	US$ 1.32	US& 1.90

These fuel cost prices have been used to compare the kWh-generation costs of the renewable electricity generation with the fuel costs of conventional, diesel power generation.



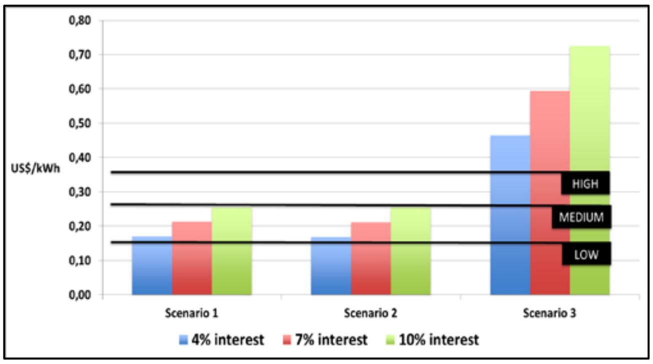
For Bonaire, Decentral scenario 1, extension of solar and wind power up to 50% of electricity generation, comes close to the current fuel costs. All scenarios will result in an increase of kWh costs when the fuel price is low. At the medium fuel price, Decentral scenarios 1 will help in keeping the kWh costs at approx. the same level. The relatively small effect of increased renewables is primarily a result of the lower fuel price at Bonaire. OTEC is too expensive at the current estimates of investment costs. Further development and experience is required to effectively exploit this renewable energy source. This potentially attractive option needs to be monitored closely.

When developing renewable energy at utility scale, 80% renewable electricity can be reached applying more wind, which has a better capacity factor and lower kWh-costs. With 8.1 MW wind, 60% of renewable electricity generation can be reached without adding solar power or storage for reducing curtailment[1]. The 81% scenario increases wind up to 10.9 MW (additional to the already installed 11.1 MW) with 10 MW of solar PV.

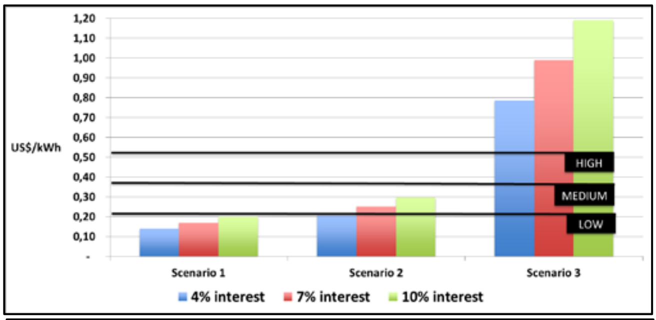
For St. Eustatius and Saba the results for scenarios 1 and 2 are similar. Only at a medium fuel price the renewables will contribute to lower kWh costs, especially when the interest rates for financing of the facilities is 7% or less. Wind power is less attractive on these islands compared to Bonaire with very favorable wind conditions. Scenario 3 for Saba, geothermal energy is a real interesting option, however with important technological risks.

[1] The storage capacity in the tables relates to storage for energy shifting, reducing the amount of curtailment and thus increasing the renewable harvest. Storage for ramp rate control has only been addressed via investment mark-ups, as these need to be assessed in more detail from a financial and technical standpoint.

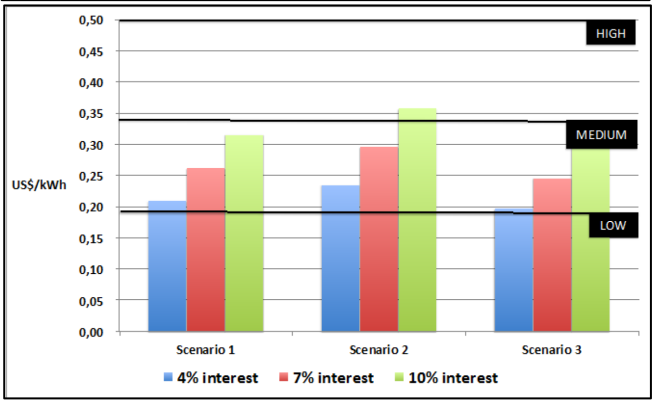
Bonaire Utility:



St. Eustatius:



Saba:



Each scenario will contribute to reducing CO_2 emissions. The table below presents the CO_2 emission reduction and compares the investment costs and the estimated annual costs for each scenario.

Island:		**Investment costs (US$ mln)**	**Annual costs (kUS$; 4%)**	**CO2 reduced (tonnes)**	**Investment per kg of CO2 reduced**	**Annual costs per kg CO2 reduced**
Bonaire utility	Scenario 1	30.75	3,684	17,347	US$ 1.77	US$ 0.21
	Scenario 2	64.17	7,425	31,005	US$ 2.07	US$ 0.24
	Scenario 3	450	48,000	75,087	US$ 5.99	US$ 0.639
Bonaire decentral	Scenario 1	14.5	1,502	8,580	US$ 1.69	US$ 0.175
	Scenario 2	30.7	5,819	15,220	US$ 2.02	US$ 0.382
Statia	Scenario 1	6.52	825	2,736	US$ 2.74	US$ 2.38
	Scenario 2	11.54	1,490	4,433	US$ 4.43	US$ 2.60
	Scenario 3	94.30	11.017	10,056	US$ 9.38	US$ 1.10
Saba:	Scenario 1	3,8	766	1.944	US$ 1.95	US$ 0.39
	Scenario 2	9,5	1.509	3.090	US$ 3.07	US$ 0.49
	Scenario 3	12,8	811	6.266	US$ 2.04	US$ 0.13

Conclusions and recommendations:

At current levels of fuel prices, extension of the share of renewable energy at the CN islands will only result in reducing kWh costs when the investments can be financed at (very) low interest rates. Other scenarios can be developed when world oil prices, and thus the fuel prices, will increase. Feasibility and development studies will be required to ensure that all costs will be taken into account before entering into development and realization.

Energy efficiency has not been addressed but could certainly contribute to reducing electricity demand and thus fuel usage and imports. A practical study on energy consumption in the main economic sectors (households; commercial; industrial; tourism; offices; retail) should be implemented.

From the above, we identified the following recommendations:

1. Initiate integral feasibility studies for the realization of wind power on Saba and St. Eustatius. As solar power is now being implemented, the most feasible option to further realize sustainable electricity generation is through wind power. Main issue will be to identify suitable locations (wind speed; visibility and noise aspects; resistance among inhabitants; cost assessment for site preparation, grid connection and infrastructure development) and associated cost elements;
2. Prepare and implement a feasibility study for OTEC on Bonaire. Bonaire seems to have a relatively attractive coastline and access to deep sea. Bonaire can realize a larger scale installation than the other islands and may combine electricity generation with the provision of cooling and fresh water production.
3. Prepare and conduct an exploration study for geothermal energy for Saba, to be executed by a regionally operating geothermal company, related to other projects developed in the Caribbean. Although Saba has a very small electricity demand, geothermal power generation could be a feasible option, depending on the development costs and financing options. Providing electricity for St. Maarten should be part of the study as this could reduce the electricity generation costs for both islands considerably;
4. Investigate how a financial scheme, with a sufficiently attractive feed-in tariff together with a cost per kW installed to cover for additional balancing costs by WEB or CGB, could be developed for the stimulation of decentralized renewable energy generation at CN.

Samenvatting

Caribisch Nederland (CN), de eilanden Bonaire, St. Eustatius en Saba, beschikken alle drie over een klein elektriciteitsnet waarin dieselgeneratoren met dure brandstof voor de elektriciteitsproductie zorgen. De kosten voor elektriciteit zijn dan ook hoog op deze eilanden met tarieven van $ 0,35 tot $ 0,38, ondanks subsidies van het Ministerie van Economische Zaken.

Deze eilanden hebben wel gunstige omstandigheden voor de productie van duurzame elektriciteit: veel zoninstraling en een goed windklimaat. Alle eilanden hebben al ervaring met duurzame elektriciteitsopwekking: Bonaire beschikt over 11,1 MW aan windturbines en een kleine zonne-energie-installatie van 0,25 MW. Daarmee realiseert Bonaire ca. 40% aan hernieuwbare elektriciteit. Op St. Eustatius is recent een zonnepark van 1,89kWp in gebruik genomen welke in ca. 23% van de elektriciteitsvraag op het eiland gaat voorzien. Om opname in het net mogelijk te maken beschikken Bonaire en St. Eustatius over elektriciteitsopslag. Zowel St. Eustatius als Saba zijn bezig om te komen tot (additionele) grootschalige zonne-energie.

Elektriciteitsopwekking	Bonaire	St. Eustatius	Saba
Dieselgeneratoren	14,4 MW	3,3 MW	2,3 MW
Windvermogen	11,1 MW	-	-
Zonvermogen in bedrijf	0,2 MW	1,9 MW	-
Elektriciteitsopslag	0,1 MWh	0,6 MWh	-
Zonvermogen gepland	-	2,0 MW	2,0 MW
Elektriciteitsvraag	103.400 MWh	13.700 MWh	9.376 MWh

Duurzame energie technologieën:

Er zijn diverse duurzame energie technologieën beschikbaar om het aandeel duurzaam op de CN eilanden verder te verhogen. De volgende technologieën zijn verder onderzocht op hun technische, economische en duurzaamheidseffecten bij de elektriciteitsproductie. De technische en economische eigenschappen van deze technieken zijn hier kort toegelicht:

1. Windenergie: wind turbines worden al veel toegepast in het Caribisch gebied. Bonaire heeft al een relatief groot windpark met zeer goede windomstandigheden. Saba en St. Eustatius hebben iets minder gunstige windcondities en hebben ook problemen om geschikte locaties voor windturbines aan te wijzen. Recente haalbaarheidsstudies wijzen op goede mogelijkheden voor windenergie.

2. Zonne-energie: Zon-PV kan gerealiseerd worden op grotere schaal met zonneparken van 100 kW en groter, tot enige MWs of via kleinschalige, decentrale installaties op huizen, scholen, hotels en andere gebouwen, met capaciteiten van enige kW tot 1 MW voor grote gebruikers. Decentrale zonne-energie wordt nog nauwelijks toegepast op de CN eilanden, omdat het verboden is voor de klanten van elektriciteitsbedrijven om zelf energie op te wekken. Met de nieuwe energiewet voor deze eilanden wordt deze beperking opgeheven.

3. Elektriciteitsopslag: Wind en zon zijn variabele, hernieuwbare energiebronnen. Vanwege de variabele, onzekere energieproductie (variaties per seizoen, per dag, per uur en per minuut), is er elektriciteitsopslag nodig in geval van een grootschalige inzet van zon en wind om de elektriciteitsproductie voortdurend in balans te houden met de vraag.

4. OTEC, Ocean Thermal Energy Conversion, is een nieuwe technologie die het temperatuurverschil tussen het oppervlaktewater van de oceaan (27 – 29 graden Celsius) en de watertemperatuur op ca. 1.000 meter diepte (ca. 5 graden Celsius) gebruikt om elektriciteit op te wekken. Met een 5 tot 8 km lange pijp met een diameter van enige meters wordt koud zeewater opgepompt. Met een grote warmtewisselaar, pompen en turbines kan dan elektriciteit worden geproduceerd. OTEC kan ook zoet water leveren en koud water voor koeling. OTEC kan in principe op alle drie de eilanden worden ingezet.

5. Geothermische energie: eerder onderzoek heeft aangetoond dat er een redelijke kans van 21% is dat op Saba geothermische energie kan worden ontwikkeld voor elektriciteitsopwekking. Het potentieel zou groot kunnen zijn, maar Saba heeft slechts een kleine energievraag. Studies hebben laten zien dat een koppeling met St. Maarten, waarvoor een lange, onderzeese elektriciteitskabel nodig is met eveneens hoge kosten, in aanzienlijk lagere opwekkingskosten kan resulteren. De risico's bij de ontwikkeling van geothermie zijn echter hoog. Op verschillende andere Caribische eilanden vinden ontwikkelingen op dit gebied plaats die nauwlettend gevolgd dienen te worden.

6. Andere duurzame energiebronnen zoals biomassa en biobrandstoffen, energie uit afval, golf en getijde-energie e.a. zijn niet beschikbaar op de eilanden. Ook wordt niet verwacht dat die de komende 15 jaar beschikbaar zullen zijn voor elektriciteitsproductie op de CN eilanden.

Energiebesparing kan ook bijdragen aan vermindering van de energielasten voor burgers en bedrijven op deze eilanden. Helaas is geen informatie beschikbaar over het elektriciteitsverbruik in verschillende sectoren of in huishoudens, over de penetratiegraad van energie verbruikende apparaten of over de kwaliteit van huizen en andere gebouwen.

Parameters voor Wind energie:	**Bonaire**	**Statia /Saba**
Capaciteitsfactor	40%	35%/27%
Elektriciteitsproductie in MWh per MW per jaar	3.500	3.066/2.365
Levensduur	15 jaar	15 jaar
Investeringskosten per kW	2.400 $/kW	2.700 $/kW
Vaste O&M kosten per kW	54 $/kW-jaar	81 $/kW-jaar
Variabele O&M kosten per kWh	0,02 $/kWh	0,02 $/kWh
Parameters voor Zonne-energie:		
Capaciteitsfactor	18 – 20%	18-20%
Elektriciteitsproductie in MWh per MW per jaar	1.577 – 1.752	1.577 – 1.752
Levensduur	25 jaar	25 jaar
Investeringskosten per kW	US$ 1,800 – 2,000 kW	US$ 1,800 – 2,000 kW
Vaste O&M kosten per kW	US$ 15/kW-yr	US$ 34/kW-jaar
Parameters for OTEC:		
Capaciteitsfactor	95%	95%
Elektriciteitsproductie in MWh per MW per jaar	8,3	8,3
Levensduur	20 jaar	20 jaar
Investeringskosten per kW	30.000 $/kW	41.000$/kW
Vaste O&M kosten per kW	800 $/kW-yr	1,100 $/kw
Parameters for Geothermal energy (Saba only):		
Capaciteitsfactor		95%
Elektriciteitsproductie in MWh per MW per jaar		8,670 MWh
Levensduur		20 – 30 jaar
Investeringskosten per kW		US$ 8.500 /kW
Vaste O&M kosten per kW		US$ 200/kW-jaar

De hierboven weergegeven kosten voor hernieuwbare energie-investeringen zijn exclusief de kosten die verband houden met opslagcapaciteit voor het verminderen van de outputbeperking bij te hoge productie of de compensatie voor te snelle outputdalingen/stijgingen, de aanleg/verbetering van infrastructuur, netaansluiting of –versterking, projectmanagement, administratieve procedures en milieueisen. Een toeslag is toegepast om deze kosten in de uiteindelijke berekeningen en scenario-analyses mee te nemen.

Duurzame energiescenario's voor de CN eilanden:

Op basis van bovenstaande informatie over de elektriciteitssectoren van de eilanden en de beschikbare energietechnologieën, zijn drie scenario's uitgewerkt voor ieder van de drie eilanden:

- 60% duurzame elektriciteitsopwekking
- 80% duurzame elektriciteitsopwekking
- 100% duurzame elektriciteitsopwekking

Voor Bonaire zijn nog twee extra scenario's doorgerekend waarbij is uitgegaan van uitbreiding van duurzame opwekking via decentrale installaties, dus bijvoorbeeld op daken van huizen en andere gebouwen.

Met behulp van HOMER Energy software is voor ieder aandeel van duurzame opwekking, de optimale combinatie van verschillende energietechnieken en opslag berekend, samen met de gerelateerde informatie over kWh-productie van iedere technologie, brandstofbesparing in de conventionele opwekking met het potentieel voor kWh-kostenreductie en CO2 emissiereductie. Omdat de eilanden al een aandeel duurzame opwekking (gepland) hebben, worden de scenario's vergeleken met de huidige (geplande) situatie, in termen van de benodigde extra capaciteit, investeringen en brandstofbesparingen.

De scenario's voor de drie eilanden zijn hieronder weergegeven:

Bonaire Utility	Zon (MW)	Wind (MW)	OTEC (MW)	Opslag (MWh)	Duurzaam %	Brandstof-gebruik (m3)	Brandstof-besparing (m3)
As is	0.25	11.1	0	0,1	38%	16,717	N/A
Scenario 1	0	+8,1	0	0,1	62%	10.270	6.425
Scenario 2	10	+10,8	0	0,1	81%	5.211	11.483
Scenario 3	0	0	15		100%	0	26,887
Bonaire decentraal	**Zon (MW)**	**Wind (MW)**	**OTEC (MW)**	**Opslag (MWh)**	**Duurzaam %**	**Brandstof-gebruik (m3)**	**Brandstof-besparing (m3)**
Scenario 1	2	+2.7	0	+1	50%	13.524	3.193
Scenario 2	8	+2.7	0	+5	60%	11.019	5.698

St. Eustatius	Zon (MW)	Wind (MW)	OTEC (MW)	Opslag (MWh)	Duurzaam %	Brandstof-gebruik (m3)	Brandstof-besparing (m3)
As is	3.89	0	0	4.6	42%	2.174.690	N/A
Scenario 1	3.89	1.6	0	4.6	69%	1.161.505	1.013.185
Scenario 2	3.89	3.2	0	4.6	86%	532.730	1.641.960
Scenario 3	0	0	2.3	0	100%		3.724.470

Saba	Zon (MW)	Wind (MW)	OTEC (MW)	Opslag (MWh)	Duurzaam %	Brandstof-gebruik (m3)	Brandstof-besparing (m3)
As is	2	0	0	1	31%	1.593	N/A
Scenario 1	2	2	0	1	63%	873	720
Scenario 2	2	3	0	6	81%	448	1.144
Scenario 3	0	0	1,5	0	100%	-	2.321

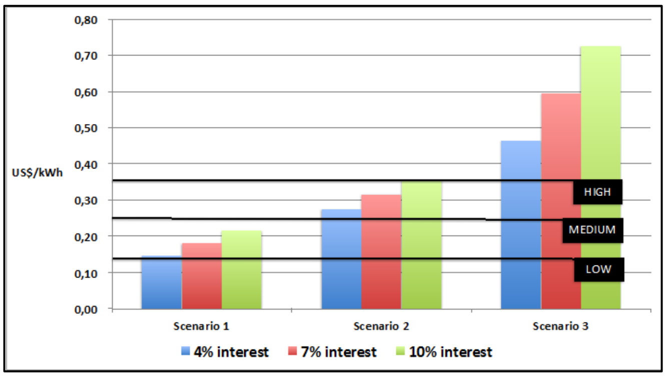
De brandstofbesparingen in Scenario 3 zijn berekend vergeleken met de situatie dat er verder geen duurzame energie wordt opgewekt, dus alsof de gehele elektriciteitsvraag met dieselgeneratoren zou worden opgewekt. OTEC en geothermie hebben in beginsel geen back up nodig. Ook is aangenomen dat alle nu reeds geïnstalleerde duurzame opwekking technisch en economisch afgeschreven zal zijn op het moment dat OTEC en/of geothermie daadwerkelijk gerealiseerd zullen gaan worden.

Voor ieder van de scenario's zijn de kWh-kosten berekend van de extra duurzame elektriciteitsopwekking. Deze zijn vergeleken met de brandstofkosten van conventionele opwekking met dieselgeneratoren als het alternatief. In het geval dat deze kWh-kosten lager zijn dan de brandstofkosten, dan resulteert dit scenario in lagere kWh-kosten in de elektriciteitsvoorziening. De resultaten van deze vergelijking zijn weergegeven in onderstaande staafdiagrammen. De kWh-kosten zijn berekend voor drie verschillende rentetarieven: 4% met financieringshulp of garanties, 10% met commerciële financiering en 7% als een tussenliggend tarief.

De gehanteerd brandstofprijzen zijn direct gerelateerd aan ontwikkelingen op de wereldoliemarkt:

WTI ruwe olieprijs (per barrel) Brandstof:	$ 50	$ 90	$ 130
HFO	$ 0,51	$ 0,91	$ 1,32
LFO	$ 0,73	$ 1,32	& 1,90

De hierboven gegeven brandstofprijzen zijn gebruikt om de kWh-opwekkingskosten door de duurzame energieopwekking te vergelijken met de brandstofkosten van conventionele, met dieselgeneratoren, opgewekte elektriciteit.



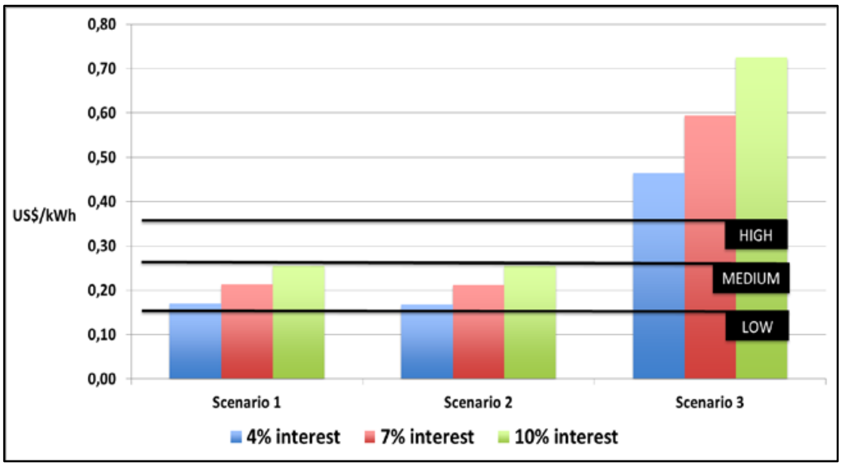
Voor Bonaire komt de uitbreiding van zon- en windenergie tot 50% elektriciteitsopwekking in het decentrale scenario 1, dicht bij de brandstofkosten voor conventionele opwekking. Alle scenario's resulteren in hogere opwekkingskosten wanneer de brandstofprijzen laag zijn. Het decentrale scenario 1 helpt dan om de kWh-kosten op hetzelfde niveau te houden. Het beperkte effect van een toename van hernieuwbare opwekking wordt vooral veroorzaakt doordat Bonaire een betrekkelijk lage brandstofprijs kent. OTEC is nog veel te duur bij de huidige schattingen van de investeringskosten. Verdere ontwikkeling en ervaring met deze techniek is vereist om hier echt gebruik van te kunnen gaan maken. De ontwikkelingen rond deze in principe aantrekkelijke optie dienen gevolgd te worden.

Indien duurzame elektriciteitsopwekking op utiliteitsschaal kan worden ontwikkeld, kan een aandeel duurzaam van 80% worden bereikt door vooral wind toe te passen, die een hogere capaciteitsfactor heeft en mede daardoor lagere kWh-kosten. Met 8,1 MW wind, kan 60% duurzame elektriciteitsopwekking worden bereikt zonder extra zon of opslag voor vermindering van de outputbeperking[2]. In het 80% scenario wordt 10,9 MW wind ingezet (extra t.o.v. de reeds geïnstalleerde 11,1 MW) met 10 MW zon PV.

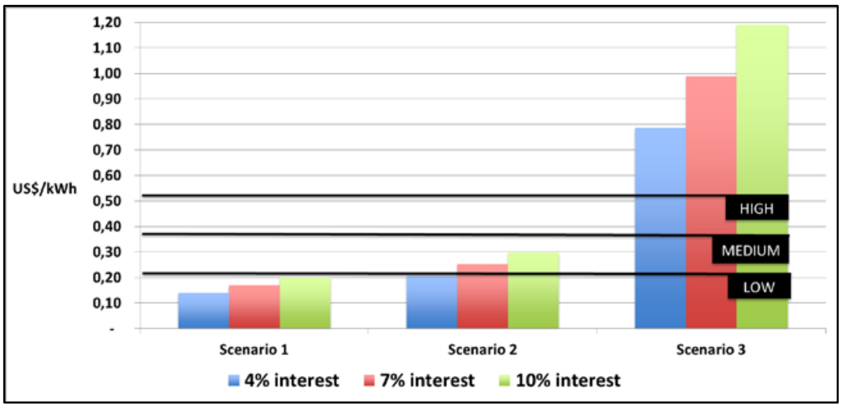
[2] De weergeven opslagcapaciteit is bedoeld voor het opslaan van energie anders verloren was gegaan door een te hoge totale productie, om deze later weer vrij te geven. Opslagcapaciteit voor het compenseren van snelle outputdalingen/stijgingen is meegenomen in de investeringsbedragen middels ophoging aangezien dit nog financieel en technisch dient te worden geadresseerd.

De resultaten van scenario's 1 en 2 voor Saba en St. Eustatius zijn vergelijkbaar. Alleen in het medium-brandstofprijsscenario draagt duurzame opwekking bij aan lagere kWh-kosten, met name als de financieringskosten laag kunnen blijven, bij een rentepercentage van 7% of minder. Wind is minder aantrekkelijk dan op Bonaire met zijn zeer gunstige windklimaat. Scenario 3 voor Saba, geothermische energie blijkt zeer interessant, alhoewel er belangrijke technische risico's zitten in de ontwikkeling er van.

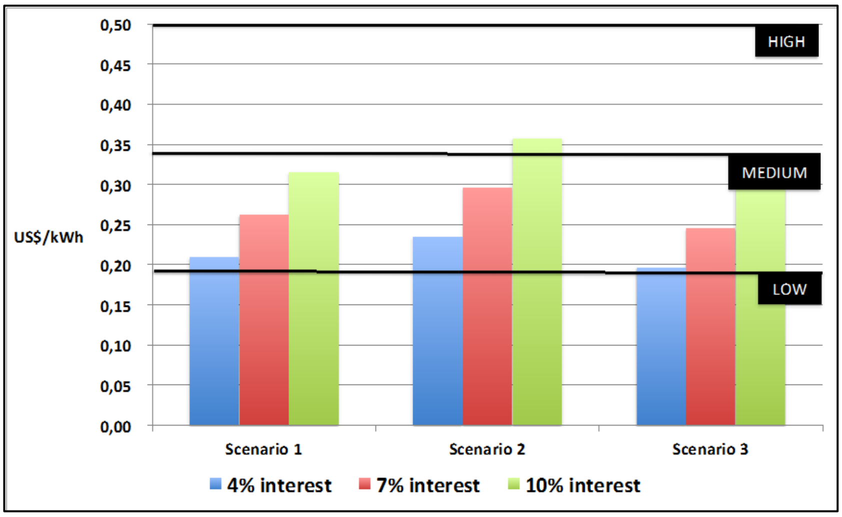
Bonaire Utiliteit:



St. Eustatius:



Saba:



Ieder scenario draagt bij aan vermindering van de CO2-emissies. Onderstaande tabel geeft de CO2 emissiereductie, ook vergeleken met de investeringskosten en de jaarlijkse kosten voor ieder scenario.

Eiland:		Investeringen (US$ mln)	Jaarlijkse kosten (kUS$; 4%)	Vermeden CO2 (tonnes)	Investering per kg vermeden CO2	Jaarlijkse kosten per kg vermeden CO2
Bonaire Utiliteit	Scenario 1	30,753	3.684	17.347	US$ 1,77	US$ 0,21
	Scenario 2	64,170	7.425	31.005	US$ 2,07	US$ 0,24
	Scenario 3	450	48.000	75.087	US$ 5,99	US$ 0,639
Bonaire decentraal	Scenario 1	14,5	1.502	8.580	US$ 1,69	US$ 0,175
	Scenario 2	30,7	5.819	15.220	US$ 2,02	US$ 0,382
Statia	Scenario 1	6,520	825	2.736	US$ 2,74	US$ 2,38
	Scenario 2	11,540	1.490	4.433	US$ 4,43	US$ 2,60
	Scenario 3	94,300	11.017	10.056	US$ 9,38	US$ 1,10
Saba:	Scenario 1	3,8	766	1.944	US$ 1,95	US$ 0,39
	Scenario 2	9,5	1.509	3.090	US$ 3,07	US$ 0,49
	Scenario 3	12,8	811	6.266	US$ 2,04	US$ 0,13

Conclusies en aanbevelingen:

Bij het huidige niveau van de brandstofprijzen draagt uitbreiding van het aandeel duurzame elektriciteitsopwekking alleen bij aan kWh-kosten vermindering indien de investeringen tegen een laag rentetarief kunnen worden gefinancierd. Andere scenario's kunnen worden ontwikkeld als de olieprijzen en dus de brandstofprijzen voor de CN eilanden toenemen. Haalbaarheids- en ontwikkelingsstudies zullen nodig zijn om er zeker van te zijn dat met alle kosten rekening wordt gehouden voordat tot ontwikkeling of realisatie wordt overgegaan.

Energiebesparing is niet verder behandeld maar zou zeker een bijdrage kunnen leveren aan vermindering van de elektriciteitsvraag en dus aan vermindering van brandstofverbruik en –import. Een praktijkstudie naar elektriciteitsverbruik in huishoudens en de belangrijkste sectoren van de economie (handel; industrie; toerisme; kantoren, winkels e.d.) zou uitgevoerd moeten worden om inzicht te krijgen in de meest effectieve maatregelen.

Op basis van het voorgaande komen we tot de volgende aanbevelingen:

1. Voer integrale haalbaarheidsstudies uit naar de realisatie van windenergie op Saba en St. Eustatius. Aangezien zonne-energie al wordt ontwikkeld dient voor verdere uitbreiding van duurzame elektriciteitsopwekking vooral naar wind te worden gekeken als de meest haalbare optie. Belangrijk aspect daarbij is het vinden van geschikte locaties (windsnelheid; geluid; visuele hinder; weerstand bewoners; locatie werkzaamheden; netaansluiting en infrastructuurverbetering) en andere gerelateerde kostenposten;
2. Tref voorbereidingen voor en voer een haalbaarheidsstudie uit voor OTEC op Bonaire. Bonaire lijkt geschikte omstandigheden voor OTEC te hebben, kustlijn en toegang tot de diepzee. Op Bonaire kan een grootschaliger installatie worden gerealiseerd die met koeling en/of zoetwaterproductie kan worden gecombineerd;
3. Tref voorbereidingen voor en laat een exploratiestudie voor geothermische energie op Saba uitvoeren, bij voorkeur uit te voeren door een bedrijf met ervaring in de regio. Alhoewel Saba een kleine elektriciteitsvraag heeft, zou geothermie een haalbare optie kunnen zijn, afhankelijk van de ontwikkelingskosten en financieringsopties. Levering van elektriciteit aan St. Maarten dient onderdeel van deze studie uit te maken, omdat hiermee de opwekkingskosten zouden kunnen worden verlaagd, voor beide eilanden;
4. Onderzoek hoe een financiële regeling voor de CN eilanden voor de stimulering van decentrale duurzame energie kan worden ontwikkeld. Zo'n regeling met een

voldoende aantrekkelijk teruglevertarief, moet ook een opslag kennen om de extra kosten voor elektriciteitsopslag door WEB of CGB te financieren.

Introduction

1.1 Background and objective

The Caribbean region has favorable conditions for the development and implementation of renewable energy. Especially Wind and Solar energy are already widely deployed throughout the region. Bonaire for example now has approx. 40% of wind energy in its electricity supply.

The electricity supply system in the Caribbean region is characterized by:

1. Heavy dominance of fossil fuel based electricity generation using diesel generators with lower efficiencies;
2. High electricity rates as well as for residents as for businesses and industries, hindering economic growth;
3. High expenditures for fuel imports.

The above key characteristics, combined with the abundant availability of renewable energy sources have induced a transition on many Caribbean islands towards more renewable energy deployment especially solar and wind energy.

The Dutch Parliament expressed its opinion that the Dutch Government should prepare an energy plan for the three Dutch Caribbean islands of Bonaire, St. Eustatius and Saba (CN-islands) to become as much as possible fully self-reliant, based on renewable energy for its electricity supply, in an affordable manner.

The objective of this study therefore is to:

1. Provide insight in the affordability and sustainability implications of different opportunities for renewable electricity generation for each island.
2. Answer questions like:
   a. Which investment options are available (more efficient diesel generators; renewable options like biofuel, solar and wind);
   b. Are there other opportunities for cost reduction in electricity generation and distribution?
   c. Which investments are required for load shifting and load balancing?
   d. What can be expected from decentralized solar?
   e. What other policy options are available e.g. in the field of energy efficiency, information dissemination and increase of awareness?
   f. How can 100% renewable electricity generation be realized?

The above objective and additional questions have been addressed in this study.

In view of the above, the Ministry of Economic Affairs has asked to conduct a desk study to examine how the CN-islands could increase the renewable share in electricity generation. How can the CN-islands realize 60%, 80% or even 100% of renewable electricity production within their energy system in an affordable manner? In this respect, affordable means at an equal or lower kWh-price.

1.2 Project approach

This desk study has been implemented through the following approach:

1. Analysis of opportunities offered by different energy technologies at what costs. This analysis has been conducted for all relevant renewable technology options. The results are summarized in Chapter 2 and fully presented in the Annex 1-6;
2. ANNEX 7: Case studies shows examples of islands grids with high penetration of renewables for further reference;

3. Analysis of the current electricity generation of the CN-islands together with development of possible scenarios, mixes of renewable energy technologies to realize the above shares of renewable electricity generation;
4. Interviews with stakeholders on the CN-islands to discuss the island reports and suggestions for energy scenarios;
5. Development of energy scenarios for the CN-islands reaching 60%, 80% and 100% of renewable electricity generation, including an investment and kWh-cost analysis and an assessment of CO_2-emission reduction.

The results of the study are presented in this report. Chapter 2 gives a summary of the most relevant renewable energy technologies. Chapter 3 presents the current electricity generation systems of the CN-islands. Chapter 4 presents the selected scenarios together with the results in terms of fuel use reductions, CO_2 emission reduction, overall investment costs and kWh-costs. Chapter 5 provides conclusions and recommendations.

2 Renewable Energy Technologies

Resources for renewable energy are abundant throughout the Caribbean, and many can be accessed in the short term. Every island nation has extensive wind and solar resources, and several have significant geothermal potential. In the long term, development of biomass energy and biofuels is possible given a concerted economy--wide effort, and ocean energy could be exploited in vast quantities once these technologies mature (Loy & Farrell 2005, p. 9).

The Caribbean region has geographical and geological features that lead to unique opportunities for renewable energy technology implementation. Primarily, the active geological zone of the eastern Lesser Antilles chain offers a geothermal powerhouse.

Throughout the Caribbean, the winter peak in wind coincides with the seasonal low in solar; in both cases the variations are modest compared to many parts of the world (Kammen 2010, p. 2).

Almost all Caribbean islands are considering utility-scale wind power and/or solar PV exploitation, and nations with legacy geothermal exploration either are developing these resources (Guadeloupe; Montserrat) or are on course to do so in the near term. Currently, no utilities are considering utility-scale biomass for electrical power production. Some Caribbean islands developed or are pursuing a waste-to-energy plant.

The following renewable energy technologies have been examined in detail to assess opportunities, costs and sustainability benefits:

- Utility scale wind power;
- Solar energy, especially solar PV;
- Geothermal power generation;
- Ocean thermal energy conversions;
- Tidal and wave energy conversion.

The following technologies have been examined but not in detail as their implementation in CN does not seem realistic:

Biomass and biofuel:

Biomass, including (organic) wastes, is not available at any of the islands in sufficient quantities to allow energy production. This was already mentioned in several other energy studies and policy reports for Bonaire[3]. Biomass could be imported (ethanol; wood pellets) but at the small scale of the islands electricity system this would result in increased costs for electricity generation, and would not result in any additional employment on the islands. Production on the islands would require availability of important land areas and fresh water for irrigation, which could then better be used for food production.

Biofuel production requires the availability of suitable land, in terms of soil type, elevation and slope, in suitable climates (incident radiation, temperature, precipitation/evaporation balances and severe weather), and the geographical nearness of this land to appropriate water and CO2 inputs and possibly nearness to markets or transportation infrastructure. These requirements impose physical and economic limits to algal biofuel production, certainly on the CN-islands. Using the sea for growing plants (algae) would have the additional problem of endangering the coral reefs around the islands, because algae farms are placed on top of or close to them, and because nutrient rich water could contaminate

[3] *KEMA Ecofys Bonaire report*

the sea. Technical and economic developments in these fields need to make significant progress before biofuels can be applied on the CN-islands.

Hydro energy:

Hydro energy is not available on the CN-islands. Economic application of hydro energy requires sufficient rainfall together with storage capacity at sufficient altitudes. Neither is present at these islands. In addition, development and implementation of hydro energy requires larger scale electricity systems than can be found at Bonaire, Saba or St. Eustatius[4]. This is also the case for pumped hydro for storage of electrical energy which might become economically viable for systems larger than 100 MW storage capacities[5].

2.1 Project management and cost overruns

The Dutch Ministry of Economic Affairs witnessed severe cost overruns in many projects on the Caribbean Islands. Some are summarized in the table below.

Realized and ongoing projects	**Cost overrun compared with first detailed cost estimate (%)**
New diesel and wind electricity generating plant Bonaire	54%
Relocation of Saba power plant	169%
New diesel generators for Saba	119%
First St. Eustatius solar park	148%
Projects that will be contracted shortly:	Expected:
Second solar park St. Eustatius	100%
Saba solar park	150%

Table 1: Cost overruns in energy projects in the Caribbean

Therefore the Ministry requested to comment on these cost overruns and to take the reasons for such cost overruns into account when preparing cost assessments for the development and implementation of renewable energy projects on the CN-islands.

Several leading financing organizations have examined the main reasons for extended schedules and cost overruns for larger infrastructure projects in developing countries. Their conclusions are summarized below.

Large infrastructure projects are a particular kind of project characterized by their large size, high complexity, expensive budgets, and extended schedules compared to traditional construction projects. Most of these large projects exceed their estimated budget, fall behind schedule, and fail to meet the original project's objectives. The causes for these problems have been well documented and can be summarized as follows:

- Lack of realism in initial cost estimates;
- Underestimation of length and cost of delays;
- Under-evaluated quantities and price changes;
- Contingencies are set too low;
- Underestimated geological risks;
- Undervaluation of expropriations costs and time;
- Undervaluation of safety and environmental demands;
- High risk as a result of technological innovation;
- Changes in project specifications and design are not sufficiently taken into account.

Causes of poor performance can be analyzed during the planning and execution phase, Haidar and Ellis (2010) identified these causes in each phase being the most relevant:

[4] *OCT report*
[5] *IRENA*

Planning phase causes:

- Incomplete designs;
- Non-realistic planning in terms of cost and time;
- Underestimation of project's complexity;
- Underestimated materials quantities;
- Under-evaluated risks;
- In-efficient governmental procedures and regulations.

Execution phase causes:

- Variations and mistakes due to inadequate planning, incomplete execution requirements, and ambiguous design documents;
- Poor project culture leading to productivity loss;
- Inadequate project organization that is insufficient for the size and complexity of the project;
- Poor communication and team work;
- Poor coordination and integration of work crews; inexperienced personnel in critical positions.

The causes reflect that conventional management practices are not well suited to manage megaprojects. Megaprojects clearly bring together, under various project delivery methods, differing and competing partners, interests, values and work cultures[6].

Reports prepared by KPMG, the World Bank and other financing institutions came to similar conclusions.

The above experiences have been taken into account when assessing the required investment costs for renewable energy facilities on the CN-islands, for which we also identified the following problems:

- No local availability of knowledgeable staff who could be involved in installation and operation and management of a wind park;
- Problematic selection of locations, especially on Saba and St. Eustatius with limited land available for any type of installation. Locations will require more than average preparatory work to make it suitable for installation of energy infrastructure.
- As site location is difficult, it will in most cases not be found at an attractive location for grid connection. Additional grid connection costs must be taken into account as new cables will have to be laid with routing in difficult terrain;
- Difficult and complex administrative procedures with insecure decision-making. No procedures are in place for this type of installations which may result in relatively long term procedures. Especially there may be opposition against the realization of wind turbines.

[6] *Megaprojects management in Ecuador: Challenges and Opportunities, Carlos Diaz c.s. Latin America and Caribbean Engineering and Technology Conference, July 2014*

2.2 Wind energy

The installed capacity of wind energy in the Caribbean is reported at 250MW by GWEC. It consists of wind farms in Aruba, Bonaire, Curaçao, Cuba, Dominica, Guadalupe, Jamaica, Martinique, Granada, St. Kitts and Nevis. Wind energy thus can be regarded as an existing and viable renewable energy source in the Caribbean.

There are many publications on wind power development in the Caribbean. However, most of these studies, articles and reports do not provide practical data on costs and benefits of electricity produced by wind turbines. Shirley & Kammen[7] has been the only source of such information, additional to the documentation for the CN islands at hand. Wind turbine installation costs are estimated at $ 2.400/kW based upon the large 3MW each, 15MW in total wind parks built in Aruba and Curaçao. This is 50% to 70% higher than installation costs in the industrialized countries. It can be expected that smaller wind turbines of 1 MW will be even more expensive.

The ECN report on Saba and St. Eustatius[8] does not address the economic factors of wind energy such as the (normalized) costs per kW. The report does state that the favorable wind location on St. Eustatius is east of the Quill at a distance of 4 km from the nearest grid connection point. There is a substantial cost increase to be expected due to this grid extension. For Saba a location close to the harbor and thus close to the new power plant has been selected, which would most likely limit the grid connection costs.

The KEMA 2011-2025 masterplan for Bonaire[9] estimates the wind costs for Bonaire for smaller wind turbines at $ 2,700/kW (grid related costs excluded). This is considered to be the norm for all CN islands in this study as it is in line with aforementioned Shirley & Kammen study at a reasonable increased cost level for smaller turbines.

Wind speeds vary substantially among the individual islands. Bonaire shows relatively high and constant wind speeds, just like its neighboring islands Curaçao and Aruba. Wind only diminishes during the September/October period due to increased hurricane activity in the Atlantic Ocean. St. Eustatius and Saba have two main wind climate seasons, the hurricane season from July till mid-December and the "trade wind" season between mid-December and July. The following table shows the key parameters for the three individual islands based upon actual wind measurements.

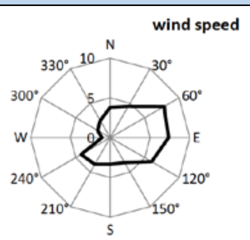
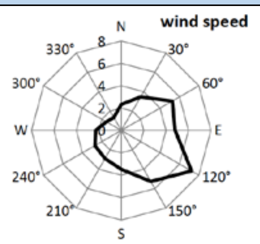
Item	Bonaire	Statia	Saba
Wind directions			
Estimated average wind speed in m/s at 50/60m height	**9.1[10]**	**7.0**	**6.2**

Table 2: Key wind parameters for the CN Islands

[7] *Shirley Kammen Elsevier Energy Policy; Renewable Energy Sector Developments in the Caribbean*
[8] *ECN Site assessment and technology selection for St. Eustatius and Saba (Ref.6)*
[9] *KEMA onderzoeksrapport masterplan 2011-2025 elektriciteit Bonaire (Ref.7)*
[10] *Based on data supplied by WEB*

The 2015 ECN report on wind assessment from a technology point of view, showed average wind speeds at 60m heights of 6,2 m/s for Saba and 7,0 m/s for St. Eustatius. They are based on recent 20 months measurements and resulted in the selection of so-called class III wind turbines[11] for both islands, suitable for these wind speeds. As a reference, the existing wind turbines on Bonaire are class IA compliant, thus suitable for (very) high wind speeds.

However, due to potential hurricane exposure, measures should be taken to mitigate the associated risks. This can be done by an additional insurance policy, which leads to increased costs of about 1% of the investment per year. It is very likely insurance companies will require class II wind turbines, maybe even class I to mitigate their risk.

ECN calculated the energy yield for several types of (class II and III) wind turbines based upon measurements of actual wind speeds and directions. The outcome showed a maximum capacity factor of 35% (rounded) for St. Eustatius and 27% (rounded) for Saba. These values are used in this study for further analysis. It must be said that the report calculated an uncertainty of 14.7% and 12.7% for Saba and St. Eustatius respectively, mainly due to uncorrelated long-term wind speed data.

Shirley & Kammen estimate the fixed maintenance costs at $ 36/kW/year based upon the new Aruba wind park. It is considerably higher than the fixed O&M costs in the U.S. but in the same range as for Europe. For all three islands a 50% add-on is applied due to small-scale cost increases. For Saba and Statia an additional 1% of the investment costs will be added caused by hurricane insurance policies.

No data for variable O&M costs were given but we estimate those at approximately double of these costs in the U.S. as well.

Based upon the above and analysis of all aforementioned sources, wind energy can be regarded as a feasible and favorite renewable source of energy for the CN islands with the following options and parameters. **These figures apply only to new wind energy to be established, not to existing capacity. Additional costs for grid extension, storage, power management systems, et cetera can be substantial and are not included. These costs will be addressed separately.**

Parameters	Benchmark[12]	Bonaire	Statia	Saba
Capacity	1 MW	1 MW	1 MW	1 MW
Capacity factor	25%	40%	35%	27%
Yearly output/ in MWh	2.200	3.500	3.066	2.365
Lifetime	15 years	15 years	15 years	15 years
Capital costs	1,450-2,450 $/kW	2,400 $/kW	2,700 $/kW[13]	2,700 $/kW
Fixed O&M costs	14-64 $/yr	54 $/kW-yr	81 $/kW-yr	81 $/kW-yr
Variable O&M costs	0.01 $/kWh	0.02 $/kWh	0.02 $/kWh	0.02 $/kWh

Table 3: Wind power technical and economic parameters

The costs include additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean.

[11] *https://en.wikipedia.org/wiki/IEC_61400*
[12] *See ANNEX 1 Factsheet Wind Energy for references*
[13] *Substantial additional grid extension costs to be expected*

2.3 Solar Energy

As sunlight is abundant it is estimated that solar is the biggest renewable resource in the Caribbean according to a 2010 study of Nexant[14] amongst many islands including Saba and St. Eustatius. By then however, solar PV was not regarded competitive as compared to wind, geothermal and conventional diesel generation. It must be said that from 2009 onwards, global prices of solar panels dropped substantially, making solar far more competitive than before.

The 2014 Castalia overview of renewables at CREF[15] shows a totally different picture with the French islands Martinique and Guadeloupe leading the way with both >65MW solar PV connected to the grid. An increasing number of islands have either implemented or initiated solar projects. Just recently, the Jamaican Office of Utility Regulation (OUR) announced the outcome of a renewable tender including 33MW of solar energy[16]. Solar PV has established a firm position in the energy production mix of many Caribbean islands.

With regards to the Dutch Caribbean, Curaçao has the most extensive regime on solar, based upon a distributed model with currently approximately 1% (700) of its end-users with grid-tied solar installations with a total capacity of about 10MW. The regime includes permitting, inspections, feed-in and grid-connection tariffs. The energy regulator[17] assumes a payback time of 8 years and adjusts the tariffs every year accordingly. The installation costs are estimated at $1.6-2.0/W ranging from small residential systems to 1MW size. Utility scale solar plants are not (yet) built as the utility company Aqualectra has given more priority to economically more favorable large-scale wind farms.

Curaçao stimulates decentralized solar energy through its Policy Paper on Small Scale Sustainable Electricity Provision of 2011[18]. As part of this policy, Curaçao has set a series of feed-in tariffs for the supply of electricity to the grid by small-scale, decentralized PV-installations. The following table shows this initial incentive scheme.

Tariff group:	Feed-in tariff until 1-1-2015	Fixed tariff per month until 1-1-2015	Feed-in tariff from 1-1-2016	Fixed tariff per month from 1-1-2016
Residential	Net metering[19]	0	$ 0.14/kWh	$ 8.95/kW
Commercial	$ 0.235/kWh	0	$ 0.14/kWh	$ 18.90/kW
Industry standard	$ 0.235/kWh	0	$ 0.14/kWh	$ 18.90/kW
Industry export	$ 0.235/kWh	0	$ 0.14/kWh	$ 8.95/kW
Industry import	$ 0.235/kWh	0	$ 0.14/kWh	$ 18.90/kW
Hospitals	$ 0.235/kWh	0	$ 0.14/kWh	$ 8.95/kW

Table 4: Curaçao scheme for decentralized PV-installations

The system until 2015 resulted in a three-year payback time for residential PV installations causing a very fast increase of these installations. Due to its success, the incentive program resulted in potential increase of the regular tariffs. Therefore the scheme was modified as per January 2015 into a full net billing program with a fixed monthly fee per installed kW. The feed-in tariff is evaluated every year. The table shows the current tariffs as per January 2016.

Aruba's electricity distribution company N.V. Elmar[20] allows end-users to connect solar installations with limited capacity. A grid usage fee per installed kW applies as well as feed-

[14] *Nexant 2010: Caribbean Regional Electricity Generation, Interconnection, and Fuels Supply Strategy (Ref.8)*
[15] *Castalia: Renewable Energy Island Index and Marketplace at 2014 CREF (Ref.9)*
[16] *http://www.our.org.jm/ourweb/media/press-releases (May 2016)*
[17] *www.btnp.org*
[18] *Policy Paper Small-scale Sustainable Electricity provisioning, Government of Curacao, 2011 (Ref. 13)*
[19] *In Dutch: saldering*
[20] *www.elmar.aw*

in tariffs for excess energy. The number of installations is not known. Aruba's electricity production company WebAruba[21] operates a 3.5MW solar power plant at the airport and has recently issued an initiative to implement an additional 5MW ground-mounted solar power plant and roof-top installations on schools and public building of 2.5MW in total.

St. Maarten lags behind with solar energy as no legal, technical and/or financial regulation is in place. It is known however that at least several tens of solar installations have been built and connected to the grid.

The CN islands have embraced solar energy just recently, each at their own pace. Statia utility company STUCO is leading the way and just commissioned a 1.89MW solar power plant in combination with storage and a power management system. Saba is executing a plan to commission a 1MW solar plant and Bonaire has installed a 250kW solar system to gain experience and determine potential next steps. Although not allowed to customers of WEB, a recent reconnaissance flight over Bonaire revealed approximately 300 end-users with grid-tied solar installations.

With regards to solar heating and solar cooling, the results so far are disappointing[22]. Solar Water Heater installations are steadily increasing in the Caribbean, for warm water provisioning for homes and hotels. Barbados is the leading example with over 50.000 solar water heaters installed and can be regarded as a mature market. Other investigated islands show either potential growth or emerging characteristics. The main barriers are lack of incentive programs and regulations like product certifications and installer certifications.

Solar cooling is just beginning to be recognized with regards to its potential value as cooling demand in general matches the PV supply curve. No reliable and useful data is available at this point in time.

Based upon the above and analysis of all aforementioned sources, solar energy can be regarded as a feasible and favorite renewable source of energy for the CN islands. The next table shows the applicable options and parameters. **These figures apply only to new solar energy to be established, not to existing capacity. Additional costs for grid extension, storage, power management systems, et cetera can be substantial and are not included. These costs will be addressed separately.**

Options Parameters	Solar heating Residential	Solar PV Bonaire Large-scale	Solar PV Bonaire Small-scale	Solar PV Saba/Statia Large scale
Capacity	250 liter	1,000 kWp	5kWp	1,000 kWp
Capacity factor	-	18-20%	18-20%	18-20%
Yearly output in MWh	2 – 3 [23]	1,577 – 1,752	7,9 - 8,8	1,577 – 1,752
Lifetime	20-30 years	> 25 years[22]	> 25 years[24]	> 25 years[22]
Capital costs	1,800-2,300 $	1,800-2,000 $/kW	2,000-2.200 $/kW	1,800-2,000 $/kW
Fixed O&M costs[25]	10-25 $/yr	15$/kW-yr	0-40$/kW-yr	34$/kW-yr
Variable O&M costs[26]	-	-	-	-

Table 5: Solar power key technical and economic parameters

The costs include additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean.

[21] *www.webaruba.com*
[22] *UNEP 2014: Solar water heating techscope market readiness assessment" for multiple Caribbean islands (Ref.10)*
[23] *The savings of a solar heating installation in kWh depends substantially on the amount of hot water used.*
[24] *This refers to the lifetime of the solar panels only; the lifetime of the inverters is typically 10 years minimum.*
[25] *Fixed O&M costs for PV include inspection, cleaning, monitoring and insurance in case of large scale.*
[26] *Variable O&M costs are cost depending on the output in kWh like fuel or specific maintenance*

2.4 Energy storage

2.4.1 Key elements of storage in small island electricity grids

Small island electricity grids have a relatively low demand. When intermittent renewables like wind or solar are implemented, it will easily lift the renewable penetration to a substantial level as compared to the daily peak.
It is generally accepted that penetration levels up to 20-25% can be reached without any additional measures to be taken. Above that level, measures will most likely be necessary to address the following issues:

Intermittency causing output variability
The output variability can be categorized as a) short-duration or b) long-duration. Short duration variability – lasting a few seconds to many minutes – is caused by wind speed variability, sometimes involving significant moment-to-moment variations, and rapid fluctuations of solar energy due to clouds, generally called ramping. Storage can be used to address short-duration. In this case high-power, limited-energy storage capacity is needed, depending on the expected amount of ramping.

Time-related mismatch between generation and demand
Storage is also well suited to address intra-day and possibly day-to-day variability. A significant portion of wind generation output occurs at night when demand is low. With storage that "off-peak" energy from wind generation can be stored and used during the day. With high solar penetration, peak power which otherwise would be curtailed, can be stored to be available to serve demand as the solar generation is falling off during late afternoon. Both examples prevent curtailing wind- or solar energy at high penetration levels. In these cases limited-power, high-energy storage capacity is needed.

2.4.2 Current installed base

As renewables are being implemented in the Caribbean step by step, the need for storage become apparent also. The U.S. Department of Energy (DoE) has setup a Global Energy Storage Database, which provides up-to-date information on grid-connected energy storage projects. The recorded storage facilities in the Caribbean are listed in table 2[27]:

Nr.	Country	Technology	Rated Power in kW	Status
1	Antigua and Barbuda	Flow Battery	3,000	Operational
2	Aruba	Compressed Air Storage	1,000	Contracted
3	Aruba	Flywheel	5,000	Contracted
4	Bonaire	Nickel based Battery	3,000	Operational
5	British Virgin Islands	Electro-chemical	1000	Under Construction
6	Haiti	Electro-chemical	100	Under Construction
7	Haiti	Lithium-ion Battery	200	Operational
8	Haiti	Lithium-ion Battery	500	Under Construction
9	Martinique	Sodium based Battery	120	Operational
10	Martinique	Lithium-ion Battery	2,472	Operational
11	Puerto Rico	Sodium-ion Battery	250	Operational

Table 6: DoE Global Energy Storage Database Caribbean

Table 6 shows a very limited amount of storage facilities, only 6 out of the 11 installations are recorded as operational. The recently installed and operational 1,400 kW Lithium-ion storage facility in St. Eustatius is not yet recorded in aforementioned list.

[27] http://www.energystorageexchange.org

This overview, although it might not fully represent the current installed storage capacity in the Caribbean, shows that storage is still very limited in the Caribbean and will, given the expected growth of renewables, be subject to increasing implementation. Tender procedures for 5MW storage facilities for both Guadeloupe and Martinique are already being executed.

2.4.3 Model island simulation

To illustrate the potential role and added value of storage systems in small island electricity grids, a fictional island has been modeled and analyzed by IRENA[28], which will be presented in the following paragraphs.

The simulation and analysis are based upon assumptions, which will be different for the individual CN islands today. Specifically the cost levels used do not reflect current pricing levels. It is therefore meant for illustrative purposes only in order to show the potential effects on the business case of adding solar and storage facilities to a fully diesel-operated production system.

The HOMER Pro®[29] modeling system (hereinafter HOMER), which is emerging as the international standard for modeling of smaller and distributed renewable electricity systems, is used. HOMER is an electricity system design tool that chooses an optimal mix of generation resources from a user-defined set of choices and provides as outputs capital and operating expenses. The results shown here are for a typical, or representative, small island electricity system. However, these results may not be applicable to all such systems. Costs, insolation (sunlight) levels, electricity demand, load shape and other variables vary across systems, and their values affect how renewables and storage interact and perform.

For this analysis, a fictional island located was created in the Caribbean, near Puerto Rico. The electricity system on this island serves 1,000 households, each with an average electricity demand of 500 watts, totaling 500 kW residential average demand. The island also has a comparably sized commercial and industrial average demand of 500 kW. The load factor is 0.37, meaning that the total *peak* demand is 2.7 MW. The daily load shape follows typical working hours with a midday peak. For a base case, it is assumed that a single diesel generator serves the island, with a peak rated output of 3.5 MW.

It is assumed that this diesel generator costs $250/kW. Furthermore, it is assumed that diesel fuel is available at a price of $1/liter. The efficiency of this diesel generator rises sharply with load, which is typical of diesel generators. The final critical assumption is that electricity supply always equals or exceeds demand.

To demonstrate the potential roles of storage and renewables, the island is then modeled with several alternative electricity generation scenarios:

- Generator plus storage;
- Generator plus PV;
- Generator plus PV plus storage; and
- PV plus storage (100% renewables).

The results of these scenarios are summarized in Table 4. Note: "Renewables fraction" is defined as the fraction of annual electricity consumption that is provided by renewable sources. Storage is 7.6 kWh capacity lead-acid batteries, $2,000 each. The storage cost estimate includes balance-of-system costs. The levelized cost of electricity assumes a 6% real interest rate and reflects only generation costs.

[28] *IRENA 2012 Energy storage and Renewables for Island Power: a guide for decision makers (Ref.1)*
[29] *http://www.homerenergy.com*

There are several interesting implications of these results. These are best explained by discussing each scenario individually.

Generator + Storage. Adding storage increases the first cost significantly (i.e. an additional $2 million in this example). However, it also allows for a 25% reduction in diesel use. It does so largely by allowing the diesel generator to operate at higher loads (and thus higher efficiencies) and to switch off entirely when loads are low. In this scenario, the generator was able to reduce its run time from 8,760 hours/year (24 hours/day, 365 days/year) to 5,568 hours/year (an average of about 15 hours/day). Note that the levelized cost of electricity for this scenario is quite a bit lower than for the base case because the diesel savings more than outweigh the additional first cost of storage.

Generator + PV. This relatively small PV system did reduce generator run time, but mostly during midday, when demand was high, thus aggravating the inefficient-at-part-load problem with diesel generators. Diesel savings were modest and levelized cost increased. PV as a supplement to a diesel generator without accompanying storage is unlikely to be a financially attractive choice although it may be worth considering as an interim step to become familiar with the PV technology.

Generator + PV + Storage. This scenario has a very high first cost, but it cut diesel consumption by 50% and thus had the lowest levelized electricity cost. This is because the PV and the storage were able to work together such that the generator operated either at high output levels or shut off entirely. This is a technologically complex system, as it would require a sophisticated controller and software to optimize operation of the PV and storage. Nevertheless, as shown in Table 4, it can be cost effective from a long-term financial perspective.

PV + Storage. This system has both the highest first cost and the highest levelized cost. This is because a very large PV system (7 MW) and storage system (12 MW) is required to ensure system reliability. This nicely points out the challenges in going to a 100% renewable system. One needs to oversize the system significantly or allow for the possibility of occasional generation shortfall.

The results summarized above lead to several key findings:

- Diesel generators have very low first costs but high operating costs. Although alternative systems using storage and/or renewables can have lower levelized costs, as discussed above, implementing these systems requires finding the upfront capital to cover the higher first costs.
- Storage should be considered as a supplement to pure diesel systems, even without renewables. As discussed above, storage can allow diesel generators to operate at much higher efficiencies and to switch off entirely when appropriate. The diesel savings can more than outweigh the higher first costs of the storage. It also prepares the system for integrating renewables later.
- Small amounts of renewables added to diesel-based systems are generally not a cost-effective option. This is because some renewables, notably PV, aggravate the low-load inefficiency of diesel generators.
- Combining diesel generators, renewables and storage can be the lowest cost option, based on levelized cost. However, such systems are complex and technologically sophisticated. It is suggested to add new technologies one at a time, rather than all at once.
- Pure renewable systems, particularly based on PV, can be very expensive, and they will need to be oversized to meet electrical needs throughout the year.

Scenario	Generator (kW)	PV (kW)	Storage (kW)	First cost ($1000)	Diesel use (mill. liters/yr)	Levelised elec. cost (¢/kWh)	Re-newables fraction
Gen Only	3,500	0	0	875	4.0	53.9	0
Gen+Strg	3,500	0	1,000	2,875	3.0	42.6	0
Gen+PV	3,500	500	0	3,375	3.9	55.0	0.10
Gen+PV+Strg	3,500	2,000	2,000	14,875	2.0	42.4	0.28
PV+Strg	0	7,000	12,000	59,000	0.0	68.4	1.00

Table 7: Results of adding storage to island electricity grids

2.4.4 Energy storage cost estimates

The next table shows cost estimates from IRENA for most relevant storage technologies[4]. It also includes some of the aforementioned key metrics as lifetime in years and amount of cycles. The price bandwidths are relatively high, especially for Lithium-ion batteries. It must be emphasized that these costs do not include BoS costs, which can be substantial and double the costs (or more).

	Lead-acid batteries	Li-Ion batteries	NaS batteries	Flow batteries	Fly-wheels	Pumped hydro	Large-scale CAES
Applicable grid system size [kW/MW]	≤10 MW	≤10 MW	≥100 MW	25 kW–10 MW	100 kW–200 MW	Mostly ≥200 MW	≥500 MW
Lifetime [years]	3–10	10–15	15	Cell stack: 5–15; Electro-lyte: 20+	20	25+	20+
Lifetime [cycles]	500–800	2,000–3,000	4,000–40,000	Cell stack: 1,500–15,000	>100,000	>50,000	>10,000
Roundtrip efficiency [%]	70%–90%	85%–95%	80%–90%	70%–85%	85%–95%	75%–85%	45%–60%
Capital cost per discharge power [$/kW]	$300–$800	$400–$1,000	$1,000–$2,000	$1,200–$2,000	$2,000–$4,000	$1,000–$4,000	$800–$1,000
Capital cost per capacity [$/kWh$_{cap}$]	$150–$500	$500–$1,500	$125–$250	$350–$800	$1,500–$3,000	$100–$250	$50–$150
Levelised cost of storage [$/kWh$_{life}$]	$0.25–$0.35	$0.30–$0.45	$0.05–$0.15	$0.15–$0.25	N/A	$0.05–$0.15	$0.10–$0.20
Annual operating costs [$/kW-yr]	$30	$25	$15	$30	$15	$5	$5

Table 8: Technical and cost data for energy storage technologies

As can be seen in figure 1, coming from the 2014 IRENA pricing schedules[30], particularly prices of Lithium-ion batteries have decreased and are expected to decrease further the next couple of years.

[30] *IRENA 2015 Battery storage for renewables - market status and technology outlook (Ref.2)*

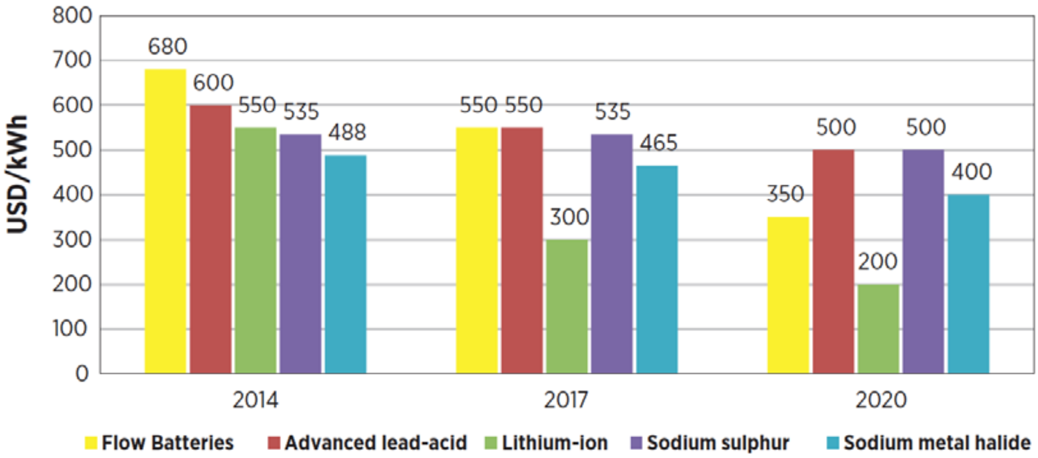


Figure 1: Technical and cost data for energy storage technologies

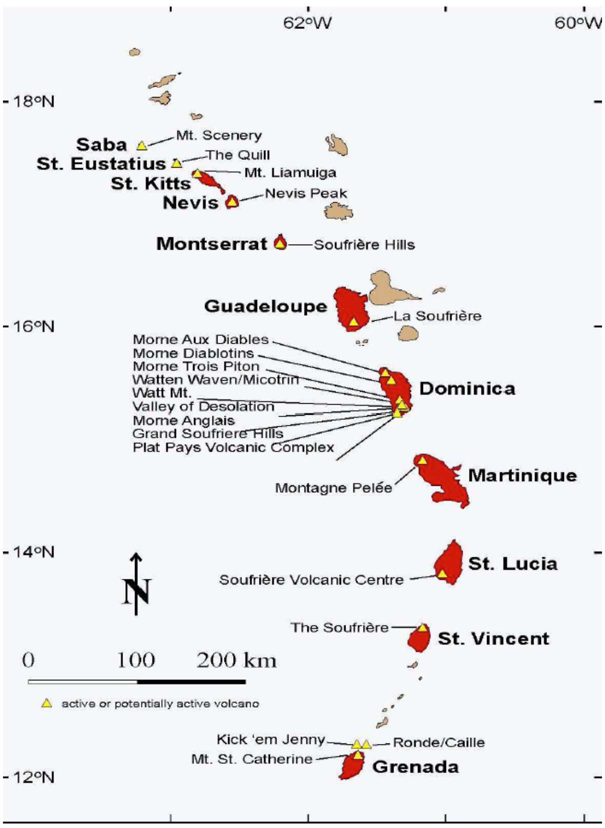
Price levels of other storage technologies have decreased (far) less as compared to Lithium-ion. Flow batteries are expected to show lower price levels in the near future. Bottom-line, price levels are volatile and need to be monitored closely, being one of the (key) factors when selecting a storage technology.

Based upon the above and analysis of all aforementioned sources, energy storage can be regarded as a feasible and favorite technology for supporting renewable penetration. Price levels however are volatile with a downward trend and need to be monitored closely.

The marketdriven position of large-scale Li-Ion batteries and its (predicted) price decreases, indicate a basic price level of $500/kWh with a mark-up for ancillary equipment, transport and implementation.

2.5 Geothermal Energy

The Lesser Antilles island arc extends 850 km along the eastern edge of the Caribbean Plate. Volcanos above a subduction zone have largely built the islands of the arc, as the Atlantic Plate is being subducted under the Caribbean Plate.
According to the Seismic Research Unit of the University of the West Indies there are 19 potentially "active" volcanoes in the Lesser Antilles, six of which have erupted in the past 400 years. Eleven volcanoes have either:
– had severe earthquake swarms
– had associated surface hydrothermal activity
– have deposits dated within the past 10,000 years
– have experienced all of the above



At the World Geothermal Congress 2015, Huttrer and Lafleur presented a geothermal update for Eastern Caribbean Nations[31].

[31] *Country update for Eastern Caribbean Nations, 2015 World Geothermal Conference (Ref.2)*

Since 2010, geothermal exploration and negotiations for the rights to explore have increased in the region. Following the drilling of three successful slim holes in Nevis, the Nevis Island Administration signed a contract and a power purchase agreement with West Indies Power Holdings (WIPH). Also in 2010, the government of Dominica and Icelandic Drilling, Inc. initiated the drilling of three exploratory slim holes in the Wotton Waven district while in St. Lucia, the government signed a Memorandum of Agreement with UNEC Corporation for exploration and development in the Sulphur Springs region.

2.5.1 Saba

Saba is a small island comprising a central volcano with at least 15 andesitic domes on its flanks and a prominent NE-SW trending fracture system that bisects the island. There is a record of volcanic eruption(s) less than 1000 years ago and there are numerous hot springs along the shoreline and just offshore. The islands volcanic carapace is highly fractured with some hot spring temperatures having risen within the last 45 years. (Huttrer 1999). West Indies Power signed agreements with the Government of Saba in 2008 and conducted some surface geo-scientific studies. To date, the results have not been made public, but plans were announced to drill exploratory wells and to construct a power plant. Activities came to a stop when transition from Netherlands Antilles to a special municipality was initiated.

According to the 2012 TNO desk study, Saba is located in a geologically active area. Numerous natural seismic events and hot springs observed on and close to the island imply that Saba is located on a geothermal potential area. The current probability of success (PoS) for geothermal energy is estimated at 21%, based on expert judgment. In order to increase the PoS, a geological exploration and analysis needs to be done, which would approximately cost 0.2-0.4 mln euros. A positive outcome of this next phase will increase the PoS to about 70%. The TNO cost estimate for a 2 MW geothermal power plant is € 10 million, € 5,000/kW. The TNO study includes all costs directly related to the geothermal power plant.

In case a geothermal power plant would be operated for Saba only, the TNO report calculates the (levelized) costs at 0.23-0.30 euro / kWh.

A combination with St. Eustatius would result in even higher costs per kWh due to the required sub-sea power cable, estimated at 27 mln Euros, and is not considered a viable option.

A combination of Saba with St. Maarten could lead to a 31 MW power plant, according to the report. The sea-cable is estimated at 33 mln Euros. Taking advantage of the scale, this would result in far lower (levelized) costs of 0.11-0.15 euro/kWh[32].

TNO prepared the cost estimate for the specific investments directly related to the development and realization of the geothermal power plant: slim exploration well drilling, power plant construction etc. A number of other costs like site preparation, infrastructure development, environmental costs and grid connection costs were not mentioned. As the UK example for Montserrat shows these costs may have a significant impact on overall realization. For the purposes of this study we estimate the realization costs for a 2 MW geothermal power plant to be higher, see next chapter.

[32] *Geothermal potential on Saba, TNO, 2012 (Ref.4)*

2.5.2 St. Eustatius (Statia)

While some heat probably remains beneath The Quill as evidenced by reported occurrences of thermal water in two wells drilled for drinking water, there are no known hot springs or paleo-thermal areas on the island (Huttrer, 1999). Geothermal development interest on Statia has not been evidenced in the past 5 years.

According to the 2012 TNO study, the Quill shows no visible apparent fault zones like on Saba. It is very likely that they are covered by volcanic and marine deposits. The Quill on St. Eustatius is a young volcano and drilled water wells show some increased water temperatures towards the vent of this volcano. This suggests that infiltrated rainwater has been heated. As no detailed analysis of geothermal phenomena or natural seismicity data is available, this does not imply that there is no geothermal potential on St. Eustatius. Therefore, geothermal exploration is essential to further mature a business case. The most obvious area to explore for geothermal resources would be near the Quill.

2.5.3 Economics of geothermal energy

California Energy Commission (CEC) 2007 estimates place the levelized generation costs for a 50 MW geothermal binary plant at US$ 92 per megawatt hour and for a 50 MW dual flash geothermal plant at $88 per megawatt hour, which over the lifetime of the plant can be competitive with a variety of technologies, including natural gas. According to the CEC report, natural gas costs $101 per megawatt hour for a 500 MW combined cycle power plant and $586 per megawatt hour for a 100 MW simple cycle plant[33].

An update of the CEC prepared by KEMA estimates the investment costs for geothermal power plants at an average of US$ 4,046 (high estimate: $ 5,948, low estimate: $2,353[34].

On average the cost for new geothermal projects ranged from 6 to 8 cents per kilowatt-hour according to a 2006 report. It should be noted that the cost for individual geothermal projects can vary significantly based upon a series of factors discussed below, and that costs for all power projects change over time with economic conditions.

The above cost estimates relate to projects realized in the U.S. or Europe where proper infrastructure is in place, equipment is available together with the required experienced staff.

The levelized generation costs for a much smaller geothermal plant of e.g. 2 MW in the Caribbean region, will be considerably higher.

From the UK Montserrat geothermal project, we expect the investment costs to be in the range of US$ 8,500 per kW, which is almost double the specific investment costs for similar plants in the US or Europe.

The levelized kWh costs are expected to be in the range of US$ 0.18 – 0.22 per kWh which can still be competitive with the fuel costs of diesel power plants at Caribbean islands including Saba. A geothermal plant will in fact replace the diesel power plants, as geothermal electricity is a very reliable and adjustable power source, nevertheless diesel generators as backup will be required during maintenance of the geothermal plants and to take over during accidental power interruptions. Lifetime of these diesel generators will be increased significantly as their operational time will be reduced substantially. A 2 MW power plant can produce up to 17 GWh per year.

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[33] *Comparative costs of California Central Station Electricity Generation Technologies, CEC, 2007 (Ref.6)*
[34] *Renewable Energy Cost of Generation Update, CEC by KEMA, 2009 (Ref.7)*

Based upon the above and analysis of all aforementioned sources, geothermal energy could be a feasible renewable source of energy for Saba with the following options and parameters. The table below presents the estimates for capital costs, including additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean.

Parameters	US/Europe	Caribbean
Capacity	100 MW	2 MW
Capacity factor	99%	99%
Yearly output in GWh	867	1.7[35]
Lifetime	20-30 years	20-30 years
Capital costs	3,500-4,000 $/kW	8,500 $/kW
Fixed O&M costs	100 $/kW-yr	200 $/kW-yr
Variable O&M costs	-	-

Table 9: Geothermal energy key technical and economic parameters

2.6 Ocean Thermal Energy Conversion

Today, only one project under implementation is known in the Caribbean region, which is the NEMO facility. NEMO is an ocean thermal energy project off the west coast of Martinique in the Caribbean Sea. A moored barge will be installed housing four turbo-generators. Each will be driven by an ammonia closed Rankine cycle utilizing the circa 20°C temperature difference between the cold seawater at 1.1 km depth and the warm surface waters. The cold water is pumped via a single large diameter riser. Each turbine will produce roughly 4 MW resulting in a total nominal installed capacity of 16 MW with a maximum available capacity of 10.7 MW. The net generated power is exported to the grid via a subsea cable and a substation at an existing conventional fossil fuel power plant. The overall investment costs of the NEMO plant are close to US$ 300 million. The project received a EU grant from the NER 300 program of € 72 million[36].

This project falls within the scope of the partnership agreement signed in January 2013 between DCNS and Akuo Energy to combine their respective skills with a view to marine renewable energy (MRE) developments.
Furthermore, a low-power OTEC plant is planned to be installed on-shore to combine air-conditioning, freshwater production and aquaculture solutions with electricity production by using deep-sea cold water. This NAUTILUS project will complement the NEMO offshore OTEC plant project. As published by Bloomberg[37], this 5.7-megawatt project at Bellefontaine in Martinique will cost about $183 million to build, which equals about $ 32.000 per kW. This facility will also provide fresh water and cooling capacity, which reduces the costs attributable to electricity generation. There is insufficient information available concerning this project to assess the costs directly related to the electricity generation plant.

The Dutch company Bluerise has developed a small pilot scale OTEC project at Curaçao, at Hato airport. This installation will produce fresh water for an agricultural project, cold water for cooling of several buildings of the airport and in the direct neighborhood and

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[35] This is the theoretical output in case of a constant capacity factor throughout the year. Given the demand profiles of Saba and St. Eustatius, the average capacity factor will be lower.
[36] Project NEMO, New Energy for Martinique and Overseas, Akua Energy presentation, 2015, (ref. 6)
[37] http://www.bloomberg.com/news/articles/2014-12-23/akuo-energy-plans-ocean-thermal-power-plant-in-martinique (Ref. 7)

produce electricity. Technical development is completed, the project is supported (not financially) by the Curaçao government. Discussions on guarantees for the supply of cooling water are ongoing. As soon as this will be resolved, the project will be realized[38].

In view of the above cost information, we estimate the investment costs for a 10 MW OTEC facility at US$ 300 million, e.g. US$ 30,000 per kW, with 2.7% of investment costs for the yearly O&M costs.

Based upon the above and all sources analyzed (see last page), OTEC technologies energy cannot be regarded as a feasible renewable source of energy **YET** for the CN islands as it is still in the development phase. The table below presents the estimates for OTEC capital costs.

Parameters	Small-scale		Large-scale
Capacity	2 MW	10 MW	100 MW
Capacity factor	95%	95%	95%
Yearly output in MWh/MW	8,300 [39]	8,300	8,300
Lifetime	20 years	20 years	20 years
Capital costs	41,000 $/kW	30,000$/kW	15,000 $/kW
Fixed O&M costs	1,100 $/kW-yr	800 $/kw	400 $/kW-yr
Variable O&M costs	-		-

Table 10: OTEC key technical and economic parameters

[38] Ocean Ecopark Curacao, Bluerise presentation, (Ref. 8)

[39] This is the theoretical output in case of a constant capacity factor throughout the year. Given the demand profiles of Saba and St. Eustatius, the average capacity factor will be considerably lower.

2.7 Tidal and Wave Energy

No (near) commercial projects are known in the Caribbean.

The 2010 Nexant report on renewables in multiple Caribbean islands[40] did not regard wave energy as a commercially demonstrated technology.

Also, the 2014 study on renewable energies and green policy in the Overseas Countries and Territories (OCT)[41] concluded wave energy not being an optional renewable technology for the Caribbean OCT countries. Wave energy could have future potential but is still very innovative and is not expected to be commercially developed in the near future.

Due to the technology status of wave energy as well as the non-favorable location and related non-existing track record of wave energy in the Caribbean region, this technology is not considered to be part of the future renewable energy production mix of the CN islands.

The Caribbean region also is a non-favorable location for tidal energy. No technical and economic parameters could be identified for the assessment of wave and tidal energy for the CN-islands.

[40] Nexant 2010 - Caribbean Regional Electricity Generation, Interconnection, and Fuel Supply strategy (Ref.3)
[41] OCT 2014 Study on Renewable Energies and Green Policy Final Report (Ref.4)

3 The Electricity Sector of BES Islands; status of renewables

3.1 Bonaire

Bonaire is an island in the Leeward Antilles in the Caribbean Sea. Together with Aruba and Curaçao, it forms the group known as the ABC islands, located less than a hundred miles off the north coast of South America near the western part of Venezuela. Unlike much of the Caribbean region, the ABCs lie outside the hurricane belt and have an arid climate. This helps tourism as visitors to the islands can reliably expect warm, sunny weather. Bonaire is a popular destination for scuba divers, and well known for easy access to its various reefs from the shore.

Bonaire's capital is Kralendijk. The island has a permanent population of 17,408 and an area of 294 km2 (together with nearby uninhabited Klein Bonaire, 6 km2). Bonaire was part of the Netherlands Antilles until the country's dissolution in 2010, when the island became a special municipality within the country of the Netherlands. It is one of the three CN islands located in the Caribbean, the other two being Sint Eustatius and Saba.

Bonaire lies about 50 miles (80 km) off the coast of Venezuela on the continental shelf of South America, and is thus geologically considered a part of the continent. The island is essentially a coral reef that has been geologically pushed up and out of the sea. This also resulted in the natural fringing reef system seen today, in which the coral formations start at the shoreline. The northern end of the island is relatively mountainous, although its highest peak is only 240 m. The southern part of the island is nearly flat and barely rises above sea level. A significant portion of this southern region is covered with seawater in process of evaporation for salt production. This area also contains Lac Bay with its large mangrove forest.

Bonaire has a warm, dry (though humid), and windy climate. The average temperature is 27.5°C with a 1.4 °C seasonal variation, and 5.6°C daily variation. Nearly constant winds blow from the east with an average speed of 12 knots (22 km/h). The humidity is very constant, averaging 76. Average annual rainfall is 20.5 inches (520 mm), most of which occurs in October through January. Bonaire lies outside the hurricane belt, though its weather and oceanic conditions are occasionally affected by hurricanes and tropical storms.

3.1.1 General information on the electricity sector

The Water- en Energiebedrijf Bonaire N.V. (hereinafter: WEB) existed already since 1978 as a merger of the 'Overzeese Gas- en Elektriciteitsmaatschappij' (OGEM) and the Water Distribution Service ('Dienst Water Distributie' - DWD).

In November 2007, WEB entered into a Power Purchase Agreement (PPA) with Ecopower, which resulted in the development and realization of a new 14.5 MW power plant with wind turbines, diesel engines and storage. ContourGlobal[42], a global power generation company, owns the (renewable) power plant nowadays.

Several privately owned solar installations are operational. Exact numbers are unclear and it is also unknown whether they are off-grid or grid-tied as no formal registration is available. It can be noted that increased interest exists in installing solar installations for residential or commercial use, most likely due to the new electricity legislation at hand. An example is one of the main hotels in Bonaire, the Plaza Beach resort, where currently a solar installation of 4000 solar panels is being built.

3.1.2 Electricity demand

The total amount of electricity WEB sells per year is approximately 100 GWh. The average increase during the period 2012-2015 has been about 4% and will remain so according to WEB's forecast for the next years (see next picture).

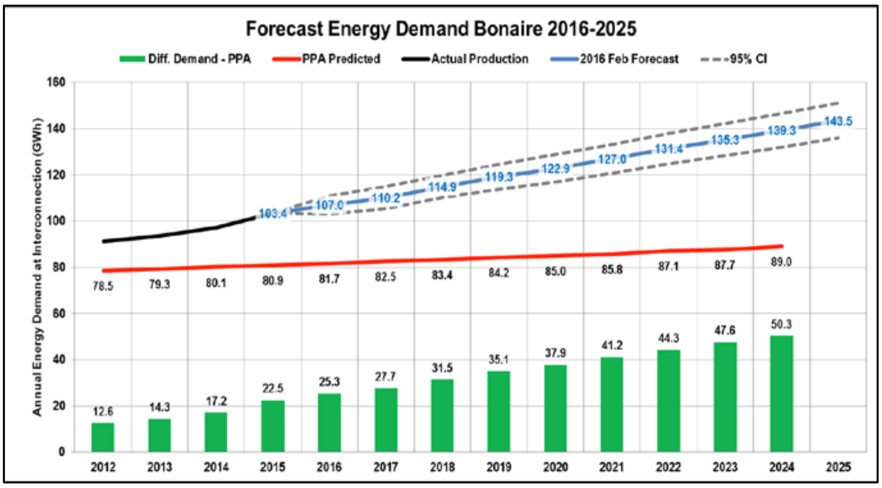

Figure 2: Predicted, realized and forecasted energy demand Bonaire

The PPA contains the exclusive right to supply electricity up to the predicted peak load and predicted demand. WEB forecasts growth (in excess) of predicted peak load or predicted demand 2 years in advance. As can be seen in previous figure, both actuals and future forecasts (black and blue line) show substantial and increasing excess of peak demand as compared to the predicted peak load (red line) according to the PPA. It is clear additional capacity needs to be installed to keep up to demand.

The PPA includes a right of first refusal to supply this excess demand either under the existing PPA or amendment, based upon mutually agreed terms and conditions. This means ContourGlobal will have the (initial) opportunity to establish a commercial offer for the supply of the excess demand, which WEB needs to evaluate and discuss. The PPA

[42] *http://www.contourglobal.com*

also states: "when this is not possible, parties will come to a mutually acceptable (temporary) solution". This give WEB the opportunity to seek for alternative solutions either via setting up own production facilities, or contracting other IPP's[43], as long as this is done in consultation with ContourGlobal.

The demand profile on Bonaire shows a regular pattern for small island grids in the Caribbean with daily peaks at mid-afternoon and early evening. In case of Bonaire, the afternoon peak is slightly higher than the evening peak due to business activities during the day. The profile is relatively flat, as merely no industrial activities exist.

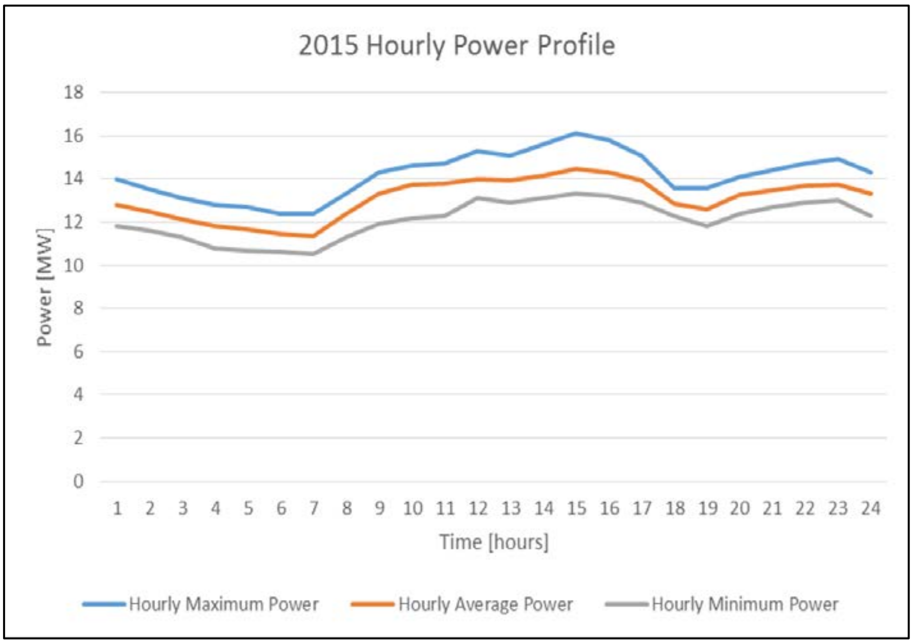

Figure 3: Daily load profiles Bonaire

The peak demand varies throughout the year up to a maximum of approximately 16 MW during September (blue line), as this is the warmest period of the year. In January and February, peak demand is at the lowest point at about 13.5 MW. This is very similar to the pattern of other islands in this part of the Caribbean and related to a period of strongly reduced winds.

3.1.3 The production facilities

In 2005 WEB lost approximately 35% of its base-load power generation capacity due to a fire in its main power plant, after which the new power plant mentioned in Section 3.1.1 was realized.

This now operational plant consists of a 11.1 MW wind farm with 12 Enercon wind turbines of 900kW each at Morotin and 1 additional 300kW wind turbine at Sorobon, working together with four MAN diesel generators of 14.5 MW in total at the BOPEC premises. An energy storage installation of 3MW / 100kWh serves as power supply allowing sufficient time for an additional diesel generator to be started and brought on line in case of wind energy ramping. The conventional diesel power plant uses heavy fuel oil (HFO 3% sulfur).The PPA provides to switch over to biodiesel as soon as this becomes commercially available. A shift to biodiesel could make the Bonaire electricity production system 100% sustainable.

The next figure gives a schematic overview of the current electricity production system.

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[43] *Independent Power Producers*

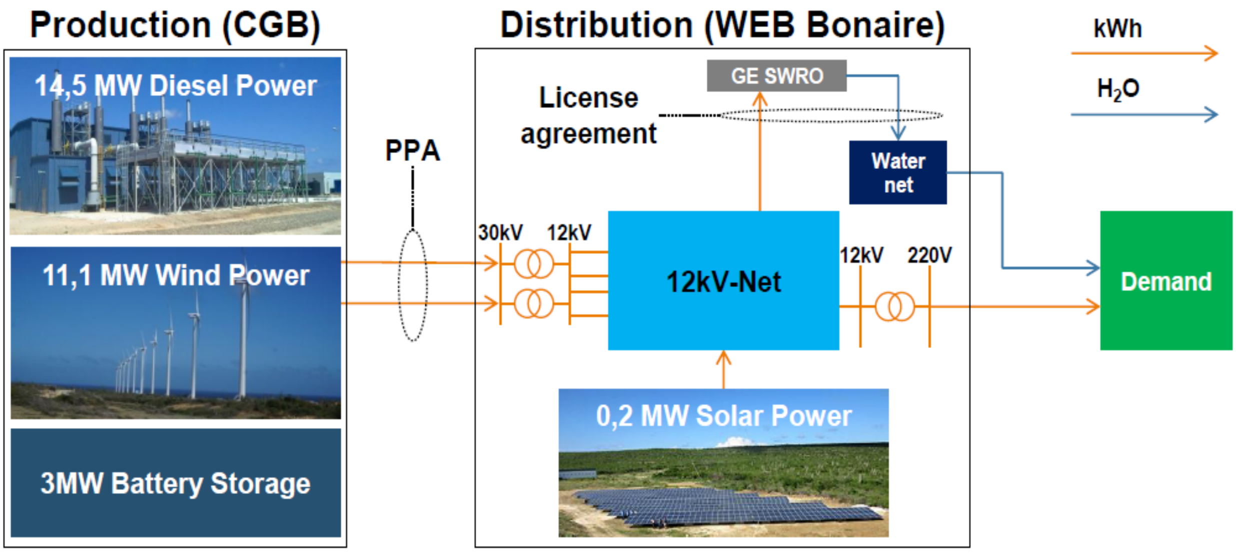

Figure 4: Electricity production system of Bonaire

In the period 2011 – 2014 the share of wind power was 31 to 42%, which in fact is a bit lower than agreed in the PPA: 44% renewable electricity with a possible deviation of 2%.

In February 2015, a 200kW pilot installation of 792 solar panels on the Barcadera site was commissioned and placed under the auspices of the Dutch company WEB Solar Power Solutions. With this installation WEB researches the efficiency and the impact solar panels on the electricity grid. The regular analyses of measurement provide WEB insights in the potential and future possibilities of (large-scale) energy supply by solar panels.

As demand is growing steadily for years and production capacity was running short, WEB could no longer wait with taking measures. Just recently, temporary capacity was installed by means of containerized Aggreko diesel engines in the Hato area. These units run on gasoil and unfortunately do not contribute to sustainability.

It was explicitly mentioned that this temporary solution for increased capacity needs has been addressed in collaboration with ContourGlobal, awaiting long-term solutions. Bonaire should continue its path towards renewable production and address the capacity shortage accordingly on short notice.

3.1.4 Fuel costs and consumption

The next table presents the estimated overall kWh-production and associated overall fuel consumption. No detailed information on the efficiency of the diesel is known as the diesels are operated by ContourGlobal and only overall PPA costs are available. The fuel consumption is estimated based upon diesel size, age and reference fuel consumption.

Fuel and kWh-production:	Year 2015
Total electricity delivered to WEB in MWh	103,400
Total production by diesels in MWh	64,108
Total fuel consumption in liters	16,694,000
Fuel consumption in liter per kWh	0.26

Table 11: KWh production and fuel consumption Bonaire

The above data have been used to calculate fuel savings in volume and costs in the different scenarios for Bonaire.

3.1.5 Efficiency of electricity distribution

The efficiency of electricity distribution is commonly measured in terms of Non Revenue Electricity (NRE), which is the difference between the electricity sold to customers and the electricity fed into the network, in the case for Bonaire, purchased from ContourGlobal. It comprises of both technical losses, for instance due to ohmic and other losses of the cables, and administrative losses, for instance due to billing errors or fraud.

The NRE level of Bonaire is reported by WEB at 12.88% in 2014. Based upon analysis and assistance of Stedin, the target for 2016 is set by WEB at a reduced level of 10.5%, to be reduced further down to 8.5% in 2020.
An overall NRE level of 8-9% can be considered reasonable. The regional average is above 10% as stated by the Carilec[44] Benchmark studies although islands/utilities vary substantially in size and landscape.

3.1.6 Efficiency of electricity consumption

The efficiency of electricity consumption is determined by, on the one hand, the amount of electrical appliances that are used by households and companies, and, on the other hand, the efficiency of these appliances themselves.

A first general approach is to analyze the electricity demand. The average usage per customer however cannot be determined as these figures are not (yet) available. The main topics to reduce electricity demand are:

- Lighting: change conventional lighting bulbs for LED;
- Electric boilers: add solar water heaters;
- Appliances: stimulate procurement of energy efficient appliances;
- Air-conditioning in housing: Add PV-systems;
- Air-conditioning in commercial buildings: consider SWAC in case of local large cooling demands.

With regards to the efficiency of the appliances themselves, they come mainly from the U.S., as the electric supply is 50Hz/127V. It is assumed that there are no active efficiency-driven regulations in place in order to stimulate energy-efficient appliances.

The main questions to be addressed are:

- What are the main drivers for consumption of electricity by end-users?
- Can a rough percentile breakdown be made of the average end-user consumption per appliance (airco, fridge, lighting, electric boiler, etc.);
- Are figures available on the number of households having an electric boiler?

[44] *Caribbean Electric Utility Services Corporation: www.carilec.org*

- Do efficiency-driven regulations exist or are these being developed, like mandatory or duty-related energy labels per appliance?
- In case air-conditioning is widely applied, are building codes available or being developed to reduce cooling demand?

3.1.7 Renewable energy status

The overall status and planned increase of renewables in Bonaire is thus as follows:

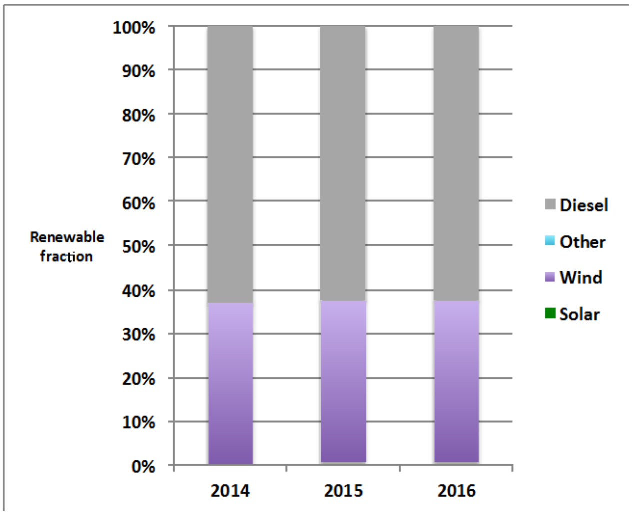

Figure 5: Existing and planned renewable fraction Bonaire

3.1.8 Potential scenarios for additional renewables at Bonaire

There are several options for the further development of renewable electricity generation at Bonaire. The current PPA does not allow WEB to invest in generation capacity unconditionally: Contour Global has a Right of First Refusal in the PPA.

There are also opportunities besides utility scale investments by WEB or Contour Global to further increase the share of renewable electricity generation. Additional capacity is necessary as the electricity demand at Bonaire is growing and there is a serious risk that the electricity demand cannot be guaranteed by the facilities of Contour Global.

We distinguished the following opportunities for increased renewable electricity generation:

1. Enhance decentralized solar and/or wind power with a small-scale renewable energy scheme, similar to the approach taken at Curaçao. Depending on how this scheme will be developed it may result in sufficient solar capacity being installed to fully cover the expected increase in electricity demand, which could result in renewable electricity generation shares of 50% and 60%. These scenarios will require additional electricity storage capacity to enable balancing of production and demand;
2. Identify possible locations for utility scale solar and wind power together with energy storage and PMS at suitable locations at Bonaire, to be realized by CGB, WEB or other partners. This could increase renewable electricity generation to 60% or even 80%.
3. Study opportunities for OTEC to reach 100% sustainable electricity generation to be realized after the closure of the PPA in 2025. The development and implementation of innovative systems like OTEC will require quite some time as a suitable location should be identified, a combination with SWAC will improve the feasibility but requires large cooling demand close to the facility and the trajectory of the cold sea

water pipe will be complicated and time consuming, also in view of environmental studies and licensing procedures.

In Chapter 4, we have analyzed these scenarios and assessed costs and benefits of different combinations of solar and wind power combined with energy storage.

3.2 St. Eustatius

St. Eustatius, locally called Statia, is an island located in the northern Leeward Islands portion of the West Indies, close to St. Maarten. St. Eustatius is immediately to the northwest of Saint Kitts, and to the southeast of Saba. The regional capital is Oranjestad.

The island has an area of 21 square kilometers and is saddle-shaped, with the 602 meter-high dormant volcano Quill ("kuil") to the southeast and the smaller pair of mountains to the northwest. The bulk of the island's population lives in the saddle between the two elevated areas, which forms the center of the island.

St. Eustatius has a population of 3877 as per Jan 1st 2015[45]. The population is relatively stable the last years after a long period of growth. The government is the main employer on St. Eustatius. The main private employer is Statia Terminals, an oil terminal of the American company NuStar. Tourism is also important, in particular the diving tourism.

The size of the economy, measured by the gross domestic product (GDP), of St. Eustatius amounted to well over $ 101 million in 2012[46]. That brings the GDP per capita to approximately $ 26,300, which is, just like all other Dutch Caribbean islands, one of the highest in the Caribbean region.

3.2.1 General information on the electricity sector

On 10-10-2010 St. Eustatius became a special municipality of the Netherlands. Till that time electricity was produced and distributed by GEBE N.V.

As a consequence of the new status, St. Eustatius took over the assets of GEBE N.V. and established its own electricity company: St. Eustatius Utility Company N.V. (STUCO) which formally started on Jan 1st 2014. Due to loss of economies of scale in purchasing fuel and

[45] *www.statline.cbs.nl*
[46] *http://www.cbs.nl/en-GB/menu/themas/macro-economie/publicaties/artikelen/archief/2015/omvang-economie-op-saba-en-sint-eustatius-voor-2012-definitief-bepaald-2012.htm*

the costs of producing and transporting electricity, the costs of electricity increased. In order to keep the electricity rates affordable, the Dutch Ministry of Economic Affairs (MEA) decided to subsidize STUCO. At the same time MEA allocated grants for investments in renewable energy in order to contribute to profitability without aforementioned subsidies.

STUCO is the sole electricity company in St. Eustatius, responsible for production, distribution and supply of electricity (and drinking water) to end-users. Statia Terminal Facilities (now: NuStar) is the only company with own (private) electricity production facilities. The STUCO and the NuStar grids are interconnected and according to STUCO, NuStar can be requested at all times to supply 500 kW, and excess power of another 500 kW if available.

It is known that a couple of privately owned, grid tied solar installations are operational but there is no formal registration.

3.2.2 Electricity demand

The total amount of electricity STUCO produces per year is about 14 GWh. After a long period of substantial growth of the total demand as of 1994 due to the start and expansion of NuStar, the total demand has shown a relatively flat pattern the last 3 years.

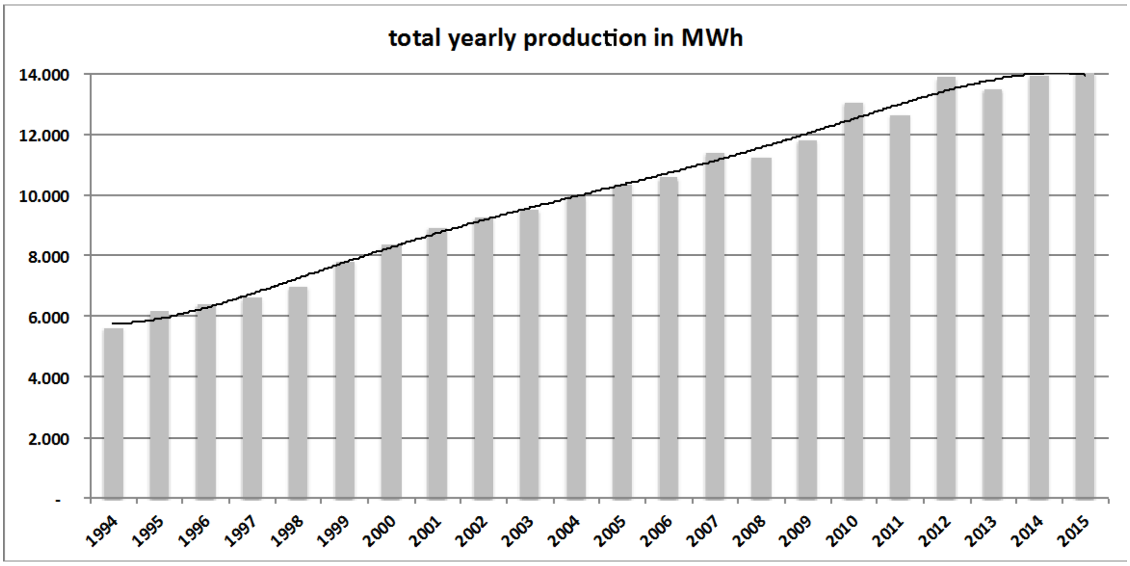

Figure 6: Total yearly demand in MWh 1994-2015 St. Eustatius

The population of St. Eustatius is, after a long period of growth, fluctuating at -3/+3% per year. The electricity demand is therefore expected to grow at a moderate 1% per year the next coming years.

The demand profile on St. Eustatius shows a regular pattern for small island grids in the Caribbean with daily peaks at mid afternoon and early evening. In case of St. Eustatius, the evening peak is slightly higher than the afternoon peak due to relatively small business activities during the day as compared to other islands with bigger economies.

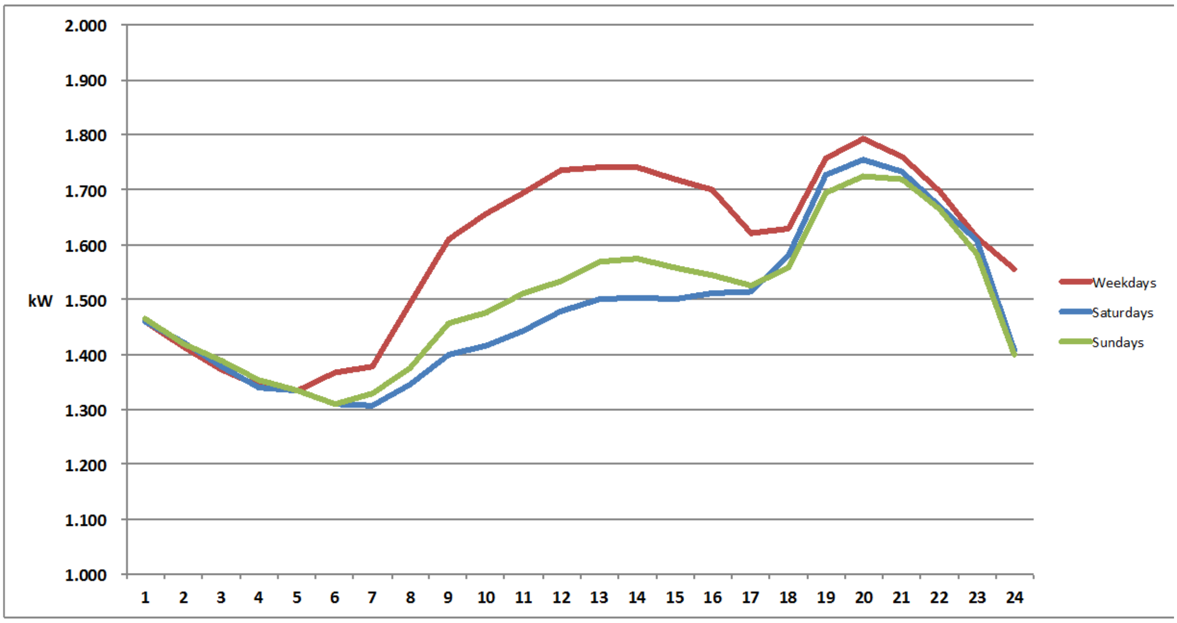

Figure 7: Daily load profiles St. Eustatius

The peak demand varies throughout the year up to a maximum of approximately 2.3 MW during September, as this is the warmest period of the year. From December on to March, demand is at the lowest point down to approximately 1.8 MW in January and February. This is very similar to the pattern of other islands in the region and related to the climate pattern and hurricane season.

3.2.3 The production facilities

In 2014 a project was initiated to establish a first step in renewable production expansion, to a large extent to be financed by the aforementioned MEA grants. March 24th 2016, the new-built solar plant of 1.89 MW, as can be seen in the picture on the front page, was commissioned on the north side of the island, near the airport.

This solar plant is equipped with a Li-Ion battery system to address fast fluctuation of solar power and to store excess energy when the solar power is too high to be fed into the network. It will be released during the evening and/or night. The conventional diesel generators produce all electricity to meet total demand at anytime. A power management system (software) keeps the whole installation and all its components in balance[47]. The installation can be regarded as state-of-the-art and unprecedented in general and for small island states in particular.

The production plant with the conventional generators consists of two buildings (blue and grey) as can be seen in the picture.

[47] *An illustrative explanation and video are available at http://www.sma.de/en/newsroom/current-news/news-details/news/15828-sustainable-power-supply-for-caribbean-island-st-eustatius-with-the-sma-fuel-save-solution.html*

Figure 8: STUCO production plant

The production plant contains 9 Caterpillar diesel engines with different sizes. Engine #7, #8 and #9 are the main engines with a total running capacity of 3,3 MW in total. The key data of these three engines are listed in the next table.

Unit	Engine and generator type	Date of commissioning	Nameplate Capacity	Running Capacity
7	3512B + SR4B	December 2006	1,015 kW	900 kW
8	3516B + SR4B	December 2008	1,450 kW	1,200 kW
9	3516BHD + SR4B	November 2013	1,325 kW	1,200 kW
Total installed capacity:			3,790 kW	3,300 kW

Table 12: Key data main diesel engines St. Eustatius

The other diesel generators (#1-6) are older and smaller. They are still available out of contingency point of view. Their total running capacity is in total approximately 2.4 MW.

3.2.4 Fuel costs and consumption

The next table presents the estimated overall kWh-production and associated overall fuel consumption.

Fuel and kWh-production:	Year 2015
Total net production in MWh	14,000
Total fuel consumption in liters	3,725,000
Fuel consumption in liter per kWh	0.27

Table 13: KWh production and fuel consumption St. Eustatius

It must be said that these figures are based upon operations with diesel generators only. The recent commissioning of the solar park changed the dispatch scheme and the average load of the various diesel generators thus affecting the fuel efficiency.

3.2.5 Efficiency of electricity distribution

The efficiency of electricity distribution is commonly measured in terms of Non Revenue Electricity (NRE), which is the difference between the electricity sold to customers and the electricity fed into the network. It comprises of both technical losses, for instance due to ohmic and other losses of the cables, and administrative losses, for instance due to billing errors or fraud.

The NRE level of St. Eustatius is at a historical level of 12-13%[48], mainly due to 19km of aged overhead lines. Linked to the solar park implementation, an additional 5km of high tension underground cabling will be installed and 3 km of overhead lines removed. This will reduce the NRE to 9-10%. Additionally, it is planned to put another 9-10km of cabling underground, reducing the NRE further to an expected 8-9%. No funding has been found yet for this additional step.

As these NRE reductions are due to lower technical losses, it will result in reduced production equal to the reduced NRE. A reduction of NRE from 12% to 8% will result into a reduced electricity production of 4% as well. At the same time it will not change to the amount of electricity sold, creating additional operational margins.

No figures are known on administrative losses, this needs to be discussed with STUCO.

An overall NRE level of 8% can be considered very reasonable. The regional average is above 10% as stated by the Carilec[49] Benchmark studies although islands/utilities vary substantially in size and landscape.

3.2.6 Efficiency of electricity consumption

The efficiency of electricity consumption is determined by, on the one hand, the amount of electrical appliances that are used by households and companies, and, on the other hand, the efficiency of these appliances themselves.

A first general approach is to analyze the electricity demand. The average usage per customer however cannot be determined as these figures are not (yet) available. The main topics to reduce electricity demand are:

- Lighting: change conventional lighting bulbs for LED;
- Electric boilers: add solar water heaters;
- Appliances: stimulate procurement of energy efficient appliances;
- Air-conditioning in housing: Add PV-systems;

With regards to the efficiency of the appliances themselves, they come mainly from the U.S., as the electric supply is 60Hz/127V. It is assumed that there are no active efficiency-driven regulations in place in order to stimulate energy-efficient appliances.

The main questions to be addressed are:

- What are the main drivers for consumption of electricity by end-users?
- Can a rough percentile breakdown be made of the average end-user consumption per appliance (airco, fridge, lighting, electric boiler, etc.)?
- Are figures available on the number of households having an electric boiler?
- Do efficiency-driven regulations exist or are these being developed, like mandatory or duty-related energy labels per appliance?
- In case air-conditioning is widely applied, are building codes available of being developed to reduce cooling demand?

[48] *Annual report STUCO 2014*
[49] *Caribbean Electric Utility Services Corporation: www.carilec.org*

3.2.7 Renewable energy

On March 24th, St. Eustatius power company STUCO celebrated the commissioning of its solar park that will provide over 20 percent of the island power needs. At times St. Eustatius will have more than 100 percent renewable energy penetration on the grid.

STUCO has initiated the second phase as of April 2016. This second phase should double the amount of solar production and will be commissioned in 2017. No plans are made yet for renewable expansion after phase 2.

The overall status and planned increase of renewables in St. Eustatius is thus as follows:

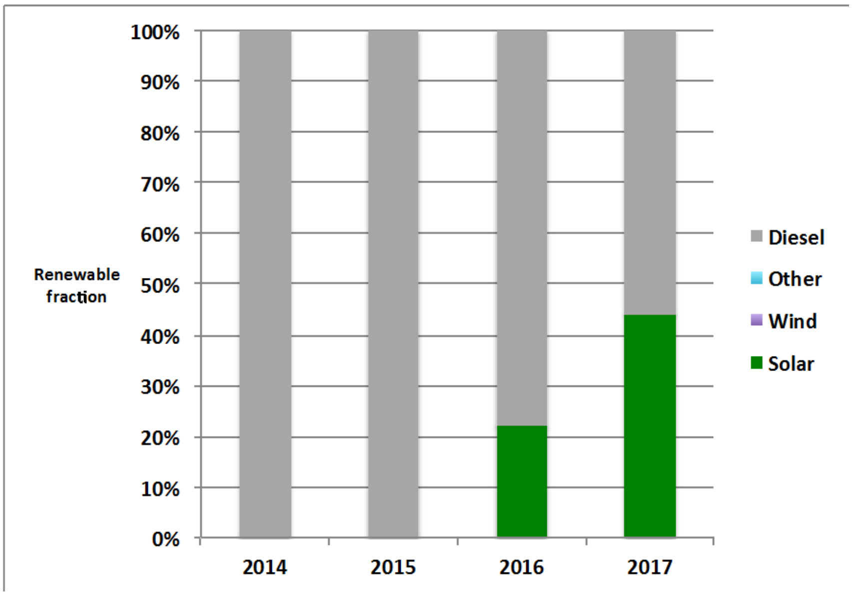

Figure 9: Existing and planned renewable fraction St. Eustatius

3.2.8 Potential scenarios for additional renewables at St. Eustatius

There are several options for the further development of renewable electricity generation at St. Eustatius. The development of the two solar parks will already realize an important increase of renewable electricity generation up to 40-45% of electricity demand.

We distinguished the following opportunities for increased renewable electricity generation, as requested in the assignment:

1. Increase of solar and wind power capacities to reach 60% of renewable electricity. This implies doubling of the renewable energy share in power generation.
2. Further increase of solar and wind power, combined with adequate energy storage capacity, to reach 80% of renewable generation capacity;
3. Study opportunities for OTEC to reach 100% sustainable electricity generation. The development and implementation of innovative systems like OTEC will require quite some time as a suitable location should be identified, and the trajectory of the cold sea water pipe will be complicated and time consuming, also in view of environmental studies and licensing procedures.

In Chapter 4, we have analyzed these scenarios and assessed costs and benefits of different combinations of solar and wind power combined with energy storage.

3.3 Saba

Saba is an island located in the northern Leeward Islands portion of the West Indies, close to St. Maarten.

Saba has a land area of 13 square kilometers. It consists largely of the potentially active volcano Mount Scenery, at 887 meters the highest point of the entire Kingdom of the Netherlands. Its major settlements are The Bottom (the capital), Windwardside, Hell's Gate and St. Johns.

As of January 2013, the population of Saba was 1,991 inhabitants and it relatively stable. The tourism industry now contributes more to the island's economy than any other sector. There are about 25,000 visitors each year. Saba is especially known for its ecotourism, having exceptional scuba diving, climbing and hiking. Saba has a number of inns, hotels, rental cottages and restaurants.

Saba's houses have a cottage look with red roofs. The lifestyle is slow and old-fashioned with little nightlife, even with the emergence of an ecotourism industry in the last few decades. Sabans are proud of their history of environmental conservation, calling Saba “The Unspoiled Queen.”

The size of the economy, measured by the gross domestic product (gdp), of Saba amounted to well over $ 42 million in 2012[50]. That brings the gdp per capita to approximately $ 21,400, which is, just like all other Dutch Caribbean islands, one of the highest in the Caribbean region.

3.3.1 General information on the electricity sector

On 10-10-2010 Saba became a special municipality of the Netherlands. Till that time electricity was produced and distributed by GEBE N.V., the electricity company for St. Maarten, Saba and St. Eustatius.

[50] http://www.cbs.nl/en-GB/menu/themas/macro-economie/publicaties/artikelen/archief/2015/omvang-economie-op-saba-en-sint-eustatius-voor-2012-definitief-bepaald-2012.htm

As a consequence of the new status, Saba took over the assets of GEBE N.V. and established its own electricity company: Saba Electric Company N.V. (SEC), which formally started on Jan 1st 2014. Due to loss of economies of scale in purchasing fuel and the costs of producing and transporting electricity, the costs of electricity increased. In order to keep the electricity rates affordable, the Dutch Ministry of Economic Affairs (MEA) decided to subsidize SEC. At the same time MEA allocated grants for investments in renewable energy in order to contribute to profitability without aforementioned subsidies.

SEC is the sole electricity company in Saba, responsible for production, distribution and supply of electricity to end-users.

As far as known, only one small, privately owned, grid tied solar installation is operational. An important factor is the typical red-shingled roofs that Saba houses share, giving the island a unique uniform cottage style. There is a strong feeling amongst inhabitants to preserve this style as much as possible.

3.3.2 Electricity demand

The total amount of electricity SEC sells per year is 8.5-9.0 GWh. The average increase during the period 2011-2015 has been 2%, mainly due to increased usage of air-conditioning.

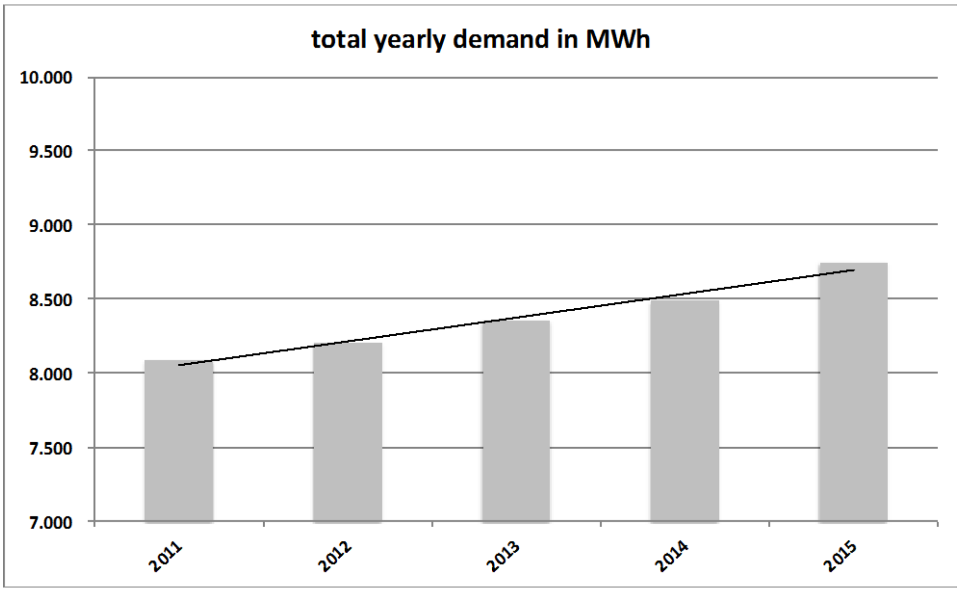

Figure 10: Total yearly demand in MWh 2011-2015 Saba

The population of Saba varies through the years. After a period of increase since the new status of special municipality in 2010, the last two years a decrease in population occurred, leaving Saba with a very small net population growth of nearly 2% since 2010. The electricity demand is therefore expected to grow with 1-2% per year.

The demand profile on SABA shows a regular pattern for small island grids in the Caribbean with daily peaks at mid afternoon and early evening. In case of SABA, the evening peak is lower than the afternoon peak due to decreasing temperatures in the evening given the microclimate.

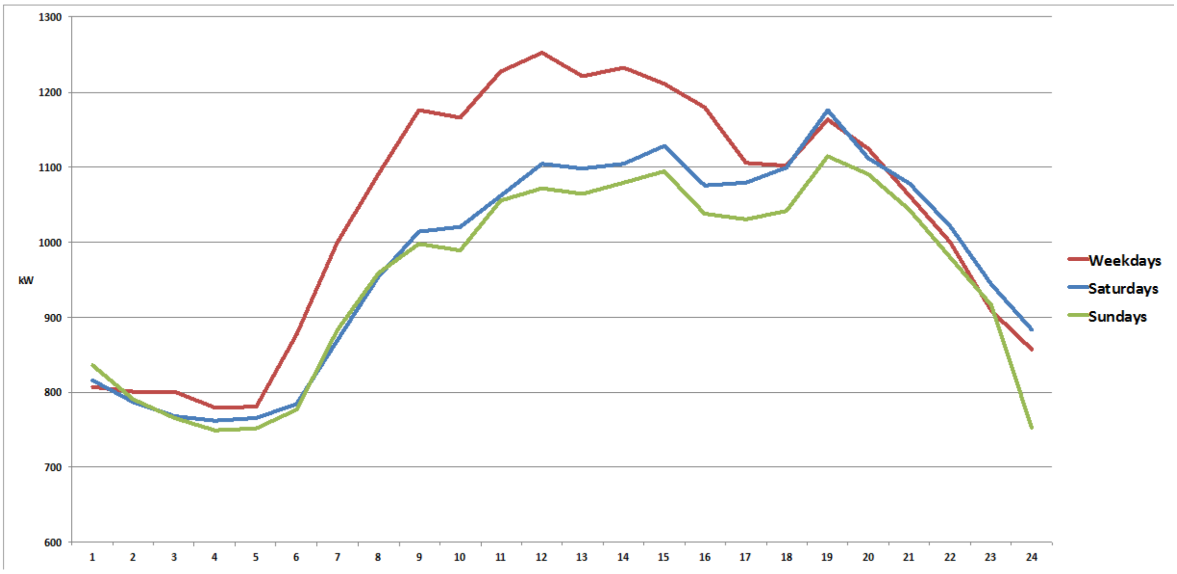

Figure 11: Daily load profiles Saba

The peak demand varies slightly throughout the year and shows a maximum of approximately 1.3 MW during September, as this is the warmest period of the year. This is very similar to the pattern of other islands in the region and related to the climate pattern and hurricane season.

3.3.3 The production facilities

In 2014, SEC commenced with the relocation of the one and only power plant at the harbor site. The old location was 15 meter from the shore and 4 meter above sea level and was, given the exact location, not hurricane proof. Besides that, most of the seven caterpillar diesel engines had passed their end-of-life[51].

Financially supported by MEA, the new power plant was commissioned in 2015. A formal handover still needs to take place. The new location is very nearby the old one, somewhat uphill so no major changes were needed for the transmission network. The new diesel power plant is equipped with two new diesel engines from the ABC[52], being the first of its kind in the Caribbean, to act as main production units. These new diesel generators would be 16% more fuel-efficient[53] which needs to be proved the next coming period. Three of the seven old caterpillar diesel engines were also moved to the new building whereas the other four old units are being sold. A 55kW PV solar system is installed on the roof of the new power plant.

[51] *Arcadis report on relocation power plant Saba, October 21th 2013.*
[52] *Anglo Belgian Corporation, www.abcdiesel.be*
[53] *ECN-Liandon, "Grid integration analysis of solar PV at Saba", 16 juli 2015*

Figure 12: SEC new power plant

The key data of the 5 engines in the new power plant are listed in the next table.

No.	Unit	Date of commissioning	Nameplate Capacity
1	ABC #1	2015	1,310 kW
2	ABC #2	2015	980 kW
3	Caterpillar 3512	2010	1,015 kW
4	Caterpillar 3512	2008	1,015 kW
5	Caterpillar 3412	2009	600 kW

Table 15: Key data main engines

The two new ABC diesels have enough capacity to meet demand at all times, with enough spare capacity for growth. In case of (un-) planned maintenance of one of these new diesels, one or more of the older three CAT diesels can assist in production capacity needed, increasing the reliability of the total production site.

3.3.4 Fossil fuel consumption and costs

The next table presents the overall kWh-production and consumption for 2015. As the new power plant with ABC diesels is operational since the beginning of 2016, the fuel efficiency will increase substantially. Initial analysis of SEC indicates an improvement of about 15% down to approximately 0,25 liter per kWh.

Fuel and kWh-production:	Year 2015
Total net production in kWh	9,376,000
Total fuel consumption in liters	2,695,000
Fuel consumption in liter per kWh	0.287

Table 14: kWh production and fuel consumption Saba

The solar park is expected to be constructed end of 2016, beginning of 2017[54]. This will influence the dispatch and the average load of diesel generators thus affecting the fuel efficiency.

[54] *SEC Budget 2015 – 2018 revised*

3.3.5 Efficiency of electricity distribution

The efficiency of electricity distribution is commonly measured in terms of Non Revenue Electricity (NRE), which is the difference between the electricity sold to customers and the electricity fed into the network. It comprises of both technical losses, for instance due to ohmic and other losses of the cables, and administrative losses, for instance due to billing errors or fraud.

The NRE level of Saba is calculated at 7.2% in 2015. This relatively low figure is due to the characteristics of the medium/high voltage network, which is mainly underground, and the fairly small distances in the 127 low voltage distribution network, which contributes substantially to the overall losses.

An overall NRE level of 7.2% can be considered very reasonable. The regional average is above 10% as stated by the Carilec[55] Benchmark studies although islands/utilities vary substantially in size and landscape.

3.3.6 Efficiency of electricity consumption

The efficiency of electricity consumption is determined by, on the one hand, the amount of electrical appliances that are used by households and companies, and, on the other hand, the efficiency of these appliances themselves.

A first general approach is to analyze the electricity demand. The average usage per customer in 2015 per customer segment is as follows:

Segment	Number of customers	Average usage per month in kWh
Households	1,038	272
Commercial	228	1,880
Industry	N/A	N/A

Table 15 Average demand per customer segment Saba

These average usage figures can be considered to be low according to the Carilec[5] Benchmark studies, which show a residential usage of approximately 385 kWh per month and a commercial usage of approximately 2,925 kWh per month, averaged over 13 Caribbean islands. This may be caused by less penetration of air-conditioning on Saba as most of the houses and offices are at an elevated altitude (300 meters).

With regards to the efficiency of the appliances themselves, they come mainly from the U.S, as the electric supply is 60Hz/127V. It is assumed that there are no active efficiency-driven regulations in place in order to stimulate energy-efficient appliances. Energy efficiency policies could contribute to reducing the electricity demand (or preventing it to increase). A more detailed study into the main electricity consumption drivers is required to assess the energy savings potential.

The main questions to be addressed are:

- What are the main drivers for consumption of electricity by end-users?
- Can a rough percentile breakdown be made of the average end-user consumption per appliance (airco, fridge, lighting, boiler, etc.)
- Do efficiency-driven regulations exist or are these being developed, like mandatory or duty-related energy labels per appliance?

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[55] *Caribbean Electric Utility Services Corporation: www.carilec.org*

3.3.7 Renewable energy status

SEC has planned for an initial 1MW solar park in agreement with and to be financially supported by MEA as a first step towards an intended 2MW solar capacity. During 2014 and 2015, initial project activities have been executed amongst which a grid stability study, location and soil analysis and more. It is expected that the ground breaking of the initial will take place in 2016. The 1 MW solar plant would reduce the fuel demand with 16%calculated with reference to the new diesel power plant. The intended 2MW would then add up to 32%, potentially supported by energy storage.

The overall status and planned increase of renewables in Saba is thus as follows:

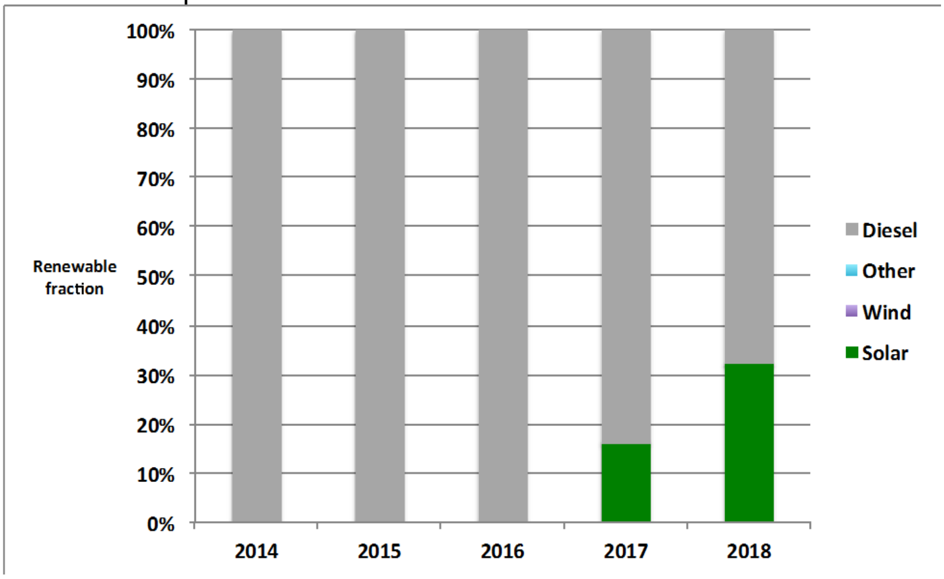


Figure 13: Existing and planned renewable fraction Saba

3.3.8 Potential scenarios for additional renewables at Saba

There are several options for the further development of renewable electricity generation at Saba. The development of the solar park will already realize an important increase of renewable electricity generation up to approx. 16% of electricity demand.

We distinguished the following opportunities for increased renewable electricity generation, as requested in the assignment:

1. Increase of solar and wind power capacities to reach 60% of renewable electricity. This implies doubling of the renewable energy share in power generation.
2. Further increase of solar and wind power, combined with adequate energy storage capacity, to reach 80% of renewable generation capacity;
3. Study opportunities for geothermal energy to reach 100% sustainable electricity generation.

In Chapter 4, we have analyzed these scenarios and assessed costs and benefits of different combinations of solar and wind power combined with energy storage.

4 Renewable Energy Scenarios

4.1 Introduction

For all three CN islands we have assessed the most economic and technically feasible scenarios to reach 60% and 80% renewable electricity generation. These scenarios are all based on the conventional and readily available technologies solar PV and wind power in combination with energy storage.

Starting point for these scenarios is the current established position of each individual CN island in terms of renewable electricity generation, as described in chapter 3 in every detail. The “as is” scenario’s consist therefore of both operational renewables as well as planned (as agreed with MEA) renewable expansions. These “as is” scenarios are shown in the following table:

Power generation:	Bonaire	St. Eustatius	Saba
Diesel generators	14.4 MW	3.3 MW	2.3 MW
Operational wind power	11.1 MW	-	-
Operational solar power	0.3 MW	1.9 MW	-
Operational energy storage	0.1 MWh	0.6 MWh	-
Planned renewables	-	2.0 MW solar	2.0 MW solar

Table 16: Composition of CN islands electricity generation mix

The 60% and 80% scenarios have been calculated using the electricity demand of 2015. Electricity demand forecasts or expected demand for 2020 or 2025 could have been used also. However, there are quite some uncertainties in electricity demand development. For reason of comparison it will not make any difference which electricity demand would be applied. The outcomes provide insight in the most effective mix of energy technologies taking a specific electricity demand. In case of a higher demand the required capacities of solar and wind power will have to be increased slightly but proportionally.

The scenario analyses have been prepared user HOMER Pro®, widely used simulation software for the integration of variable renewable energy sources like solar and wind power, combined with storage, in small island electricity grids. The results of the HOMER analyses have been used as input to assess the expected investment and kWh-costs of the renewable electricity production as well as the related CO2 emission reductions of each scenario.

The kWh costs have been calculated for different discount rates:

1. 4% based on financing with government support and/or guarantees from the national government;
2. 7% based on partly commercial financing, and
3. 10% based on fully commercial financing of the investments.

Due to the financial viability of the CN island governments and the CN utility companies, we expect that financing will only be possible with some form of support by the Government.

The outcomes of the scenarios cannot be considered as results of a feasibility study. Only a full feasibility study will take the overall costs of each scenario into account, addressing specific issues like siting, civil and infrastructure works, grid connections et cetera, in even more detail. These costs have now been included by means of general estimates, based on experiences in different projects. Also storage capacities have been determined based upon energy shifting, reducing the amount of curtailment and thus increasing the renewable harvest. Storage for ramp rate control has only been addressed via investment markups, as these need to be assessed in more detail from a financial and technical standpoint.

When comparing different renewable scenarios with conventional electricity production by means of conventional fuel-based diesel generators, one should consider multiple fuel price scenarios. Fuel prices are time-related to the crude oil prices which for the Caribbean are set by the U.S. WTI crude oil index[56]. The prices for the different fuels, HFO for Bonaire and LFO for St. Eustatius and Saba, were estimated based upon information provided and gathered, for three different crude oil price levels, US$ 50, US$90 and US$ 130. The applied price levels are shown in the following table:

WTI crude oil price (per bbl)	US$ 50	US$ 90	US$ 130
HFO	US$ 0.51	US$ 0.91	US$ 1.32
LFO	US$ 0.73	US$ 1.32	US& 1.90

Table 17: Fuel price levels at three crude oil scenarios

4.2 Bonaire

Based on the above-mentioned scenarios for fuel price developments and technical and economic data on solar and wind power and energy storage, an analysis is made for Bonaire.

The first analysis was done with HOMER to determine the technically feasible solutions and its characteristics in terms of renewable production. This was done for each combination of different solar capacities (0-10MW in steps of 2MW) and different wind capacities (0-12.8 MW in steps of 3x0.9MW wind turbines = 2.7MW). These capacities are ADDITIONAL to the existing wind capacities of 11.1MW. The existing situation is referred to as “as is” with 38% renewable fraction based on 11.1MW wind and 0.25MW solar.

Each of the combinations were examined with storage capacities ranging from 0-10MWh, potentially needed to decrease the amount of curtailment by charging batteries in case of overproduction and discharging later during the day when renewable production allows. Adding storage might increase the renewable fraction but also induces higher cost levels thus investments.

For Bonaire two different approaches have been used to increase renewable electricity generation:

1. Utility scale development of renewable energy, focusing on solar and wind power with storage. As CGB has a right of first refusal, utility scale projects have to be realized in close cooperation with or agreed by CGB;
2. Decentralized implementation of primarily solar energy for which a scheme will be developed to stimulate households and companies to invest in their own renewable electricity generation.

Bonaire utility scale scenarios

The results for Bonaire are shown in the next figure. It shows per scenario (combination of solar and wind power) the estimated investment levels as well as the new renewable fraction, for increasing storage capacity.

[56] *WTI is the NYMEX crude oil i.dex: http://www.nasdaq.com/markets/crude-oil.aspx*

The baselines represent the total avoided fuel expenses for a period of 10 years at a fuel price level associated with a WTI crude oil price of $50, $90 and $130. The $50 scenario is regarded “low”, the $90 scenario is regarded “medium”, and the $130 scenario is regarded “high”.

If a scenario is above a certain baseline, the investments will be higher than the (undiscounted) avoided costs of fuel for a period of 10 year given a stable either $50, $90 or $130 oil price. In practice, renewable installations will have a longer lifetime than 10 years so the actual fuel saving over the total lifetime will be higher.

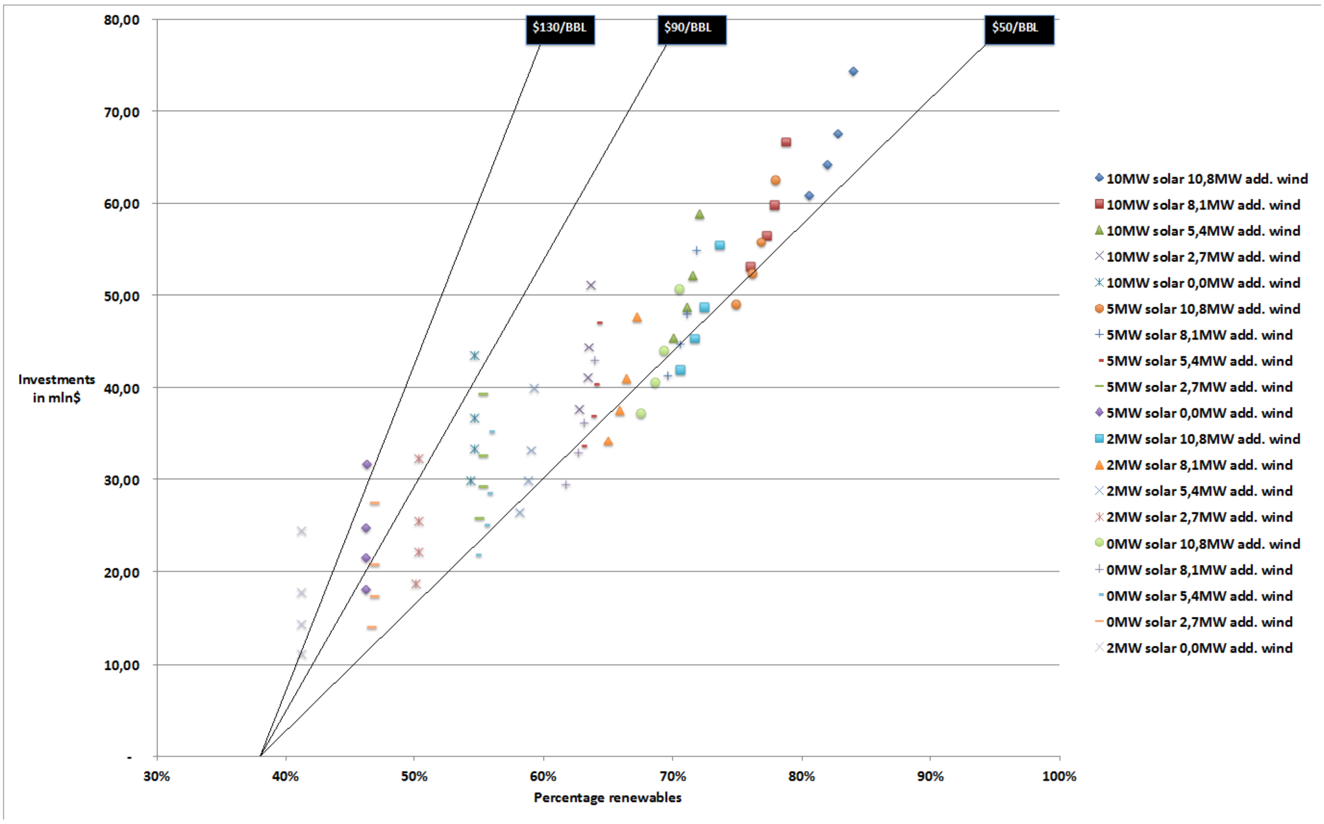


Figure 14: Investment levels for renewable options at Bonaire

The key conclusions that can be drawn from the figure for Bonaire are the following:

- High renewable levels of 60% or 80% can be reached by a combination of solar, wind and storage but a considerable amount of capacities need to be added;
- Investment levels are mostly in between the WTI oil price of $50/bbl and $90/bbl,;
- Wind contributes better than solar to the existing production mix to reach 60% but to reach 80% solar is recommendable in terms of overall investment costs, mainly due to combined production pattern, saving additionally needed storage.

The table below presents the combinations of solar, wind and storage that reach 60% or 80% of renewable electricity generation. 100% renewable electricity can only be realized using OTEC, as a solar and wind combination would require an immense amount of storage to reach 100%.

PV MW	Wind MW	Storage MWh	Invest $mln	Renew. %	Production MWh	Demand MWh	Excess MWh	PV MWh	Wind MWh
5	5,4	0	33.52	63%	104,821	103,400	1,421	8,689	18,740
2	5,4	5	29.81	59%	103,991	103,400	541	3,475	18,740
0	8,1	0	29.44	62%	106,808	103,400	3,408		28,110
10	10,8	0	60.79	81%	114,100	103,400	10,700	17,378	37,480
10	8,1	10	59.81	78%	107,476	103,400	3,898	17,378	28,110
5	10,8	10	55.73	77%	109,261	103,400	5,676	8,689	37,480

Table 18: 60% and 80% renewable option for Bonaire

60% renewable electricity can be reached by adding 8.1 MW of wind power (9 wind turbines of 0,9MW each) to the current power station which has 11.1 MW of wind already. No solar or additional storage for energy shifting is required[57]. Due to the variability of wind power and having regular over-production of wind electricity (more wind electricity generation than demand), not all wind power can be absorbed in the grid, resulting in a rather high level of excess kWh of approx. 12% of wind electricity produced.

80% of renewable electricity generation can be reached by adding 10.8 MW of wind power (12 wind turbines of 0,9MW each) and 10 MW of solar power. This situation also results in significant excess kWh, approx. 20% of renewable electricity generation.

For these three scenarios costs and CO2 emission reductions have been calculated. It must be said that many other combinations of solar and wind capacities can be examined, the scenarios give a firm indication but integral feasibility studies need to be executed to substantiate the financial investments.

Affordability and sustainability:

Based on the above data on investments, renewable kWh production and resulting fuel savings, we have assessed the kWh-costs for these scenarios, together with a 100% renewable electricity generation scenario based on OTEC. When the calculated kWh costs are lower than the fuel costs for conventional power generation, these investments will result in reduced cost levels for the overall production of electricity.

The next tables show the yearly fuel amount savings and the fuel cost savings for the preferred renewable scenarios for all three oil price scenarios low, medium and high.

BONAIRE	Solar (MW)	Wind (MW)	OTEC (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	0.2	11.1	0	0.1	38%	16,694	N/A
Scenario 1	0	19,2	0	0.1	62%	10,270	6,425
Scenario 2	10,2	21,9	0	0.1	81%	5,211	11,483
Scenario 3	0	0	15	0	100%	0	26,926

Table 19: Fuel savings for the renewable energy scenarios Bonaire

The fuel cost savings for scenario 3 gives the conventional fuel consumption without any renewables, e.g. without any wind power as an OTEC will replace all other electricity generation capacity and will be realized at the long run, when installed solar and wind power will have reached its technical and economic lifetime. Therefore the fuel savings in scenario 3 are higher than the fuel consumption in the “as is” situation.

[57] The storage capacity relates to storage for energy shifting, reducing the amount of curtailment and thus increasing the renewable harvest. Storage for ramp rate control has only been addressed via investment mark-ups, as these need to be assessed in more detail from a financial and technical standpoint.

BONAIRE	Investment costs (kUS$)	Fuel savings (m3)	Fuel cost savings at three oil price levels (kUS$)		
			LOW	MEDIUM	HIGH
Scenario 1	29,436	6,425	3,277	5,846	8,481
Scenario 2	60,790	11,483	5,857	10,450	15,158
Scenario 3	450,000	29,926	13,733	24,503	35,543

Table 20: Fuel savings and cost savings for the renewable energy scenarios Bonaire

The kWh-costs realized with the (additional) solar and wind power (and the OTEC facility) are presented below, together with the fuel costs of kWh-production for the three oil price scenarios of US$ 50, 90 and 130 per barrel.

BONAIRE	Depr. (kUS$)	O&M costs (kUS$)	Financial costs in kUS$ at three interest rates:			Total annual costs (kUS$)			kWh-costs (US$)		
			4%	7%	10%	4%	7%	10%	4%	7%	10%
Scenario 1	1,936	437	1,177	2,061	2,944	3,551	4,434	5,317	0.16	0.20	0.25
Scenario 2	3,709	733	2,432	4,255	6,079	6,874	8,698	10,522	0.16	0.20	0.24
Scenario 3	22,500	12,000	18,000	31,500	45,000	52,500	66,000	79,500	0.51	0.64	0.77

Table 21: Renewable energy kWh-costs

When comparing the kWh-costs of the (additional) renewable power with the fuel costs of diesel power, it's clear that at the current oil prices of approximately US$ 50 per barrel (low), none of the scenarios will result in a kWh cost reduction, as Bonaire has relatively low fuel costs compared to the other CN islands. This is even the case when a very low interest rate of 4% is taken into account.

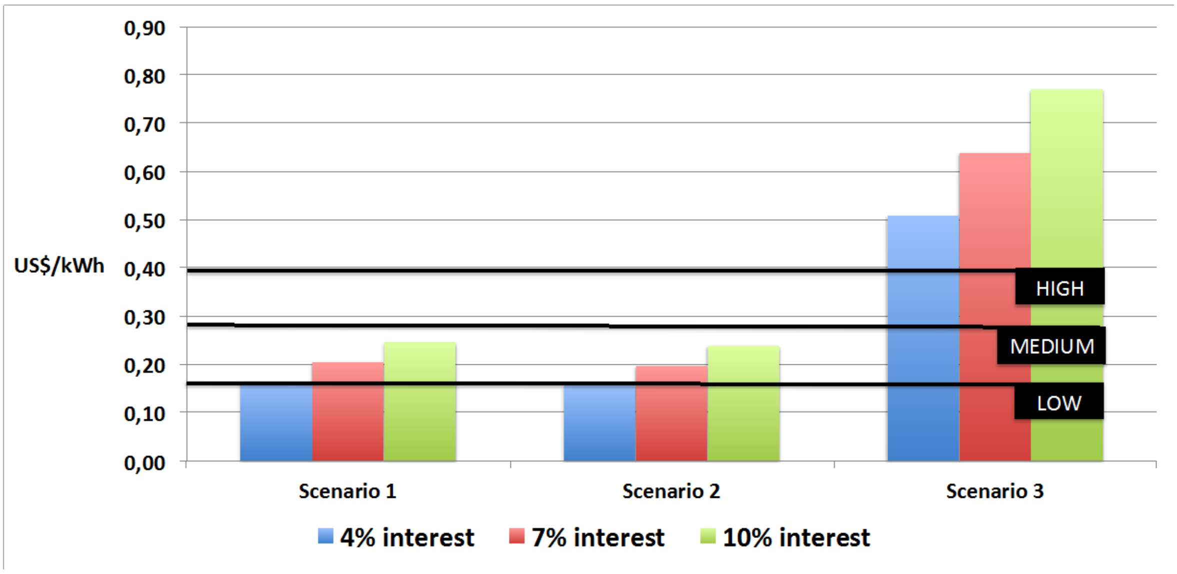


Figure 15: Renewable kWh versus conventional fuel costs Bonaire

As can be seen the above figure, it will not be possible, or at very high costs, to reach 100% renewable electricity generation only with solar and wind power. The variability of these renewable energy sources makes it more and more difficult to really absorb all electricity generated in the grid. With increasing capacities, the amount of needed storage increases more than proportionally thus investments. Only in case storage cost will be considerably lower in the future, solar and wind can be increased further.

100% renewable electricity generation thus requires other renewable energy options. For Bonaire OTEC could be an interesting and possibly feasible option. The costs of OTEC systems however are still very high as shown in ANNEX 5: Factsheet OTEC. With current information on investment costs of US$ 30,000/kW for onshore OTEC facilities, these are not (yet) economically attractive. The combination of cooling, using cold seawater, and fresh water production will improve its feasibility. Further research and specific location studies will be necessary, especially as deep seawater is abundant in the CN-islands.

At an oil price level of US$ 90 (medium) almost all scenarios will clearly contribute to reduce costs of power generation. This is primarily caused by the relatively high share of wind power in these scenario. Wind power has by far the lowest kWh production costs due to the very attractive capacity factor of wind at Bonaire in combination with the investment level.

The fuel savings directly result in reducing CO2 emissions. The expected CO2 emission reduction is presented in Table 22. The costs of CO2 emission reduction are considerably higher than in the Netherlands for similar investments

BONAIRE	Investment costs (kUS$)	Annual costs (kUS$)	Fuel savings (m3)	CO2-emission reduction (tonnes)	Investment per kg of CO2 reduced	Annual costs per kg CO2
Scenario 1	29,436	3,551	6,425	17,347	$1.70	$0.20
Scenario 2	60,790	6,874	11,483	31,005	$1.96	$0.22
Scenario 3	450,000	52,500	26,926	72,701	$6.19	$0.72

Table 22: CO2 emission reduction estimates

Bonaire decentral scenario:

A second scenario to increase the renewable fraction rapidly is to stimulate households and companies to invest in their own decentralized renewable electricity generation. This could potentially compensate the increase in demand, saving WEB additional investments and prolonged discussions with ContourGlobal on a structured approach on generation extensions.

Bonaire decentraal	Zon (MW)	Wind (MW)	OTEC (MW)	Opslag (MWh)	Duurzaam %	Brandstof-gebruik (m3)	Brandstof-besparing (m3)
Scenario 1	2	+2.7	0	+1	50%	13,524	3,193
Scenario 2	8	+2.7	0	+5	60%	11,019	5,698

Table 23: Bonaire decentral scenarios

Small-scale, decentralized investments in renewable energy systems can be stimulated through a regulation together with a financial scheme setting a sufficiently attractive feed-in tariff for the electricity generated. Households and companies can thus invest in small solar PV systems or wind turbines, depending on availability of suitable sites, especially for wind turbines. The scheme will have to provide sufficient certainty for the investors, also on the long term. It will also have to take volatility in fuel prices into account.

Such a scheme will result in investments by other parties on the islands, probably especially on Bonaire, and thus reduce investments required by WEB or CGB. Depending on the success of such a scheme, additional storage capacity will be required to ensure balancing electricity generation and demand. The scheme will thus have to be setup in such a way that funds are created to add this storage when solar PV is increasing.

Most of the investments and costs will be carried by a large number of households and companies. Therefore it is not possible to analyze the annual costs and the kWh-costs in the same detail as for the other scenarios. The expected kWh-costs are presented in Figure 16.

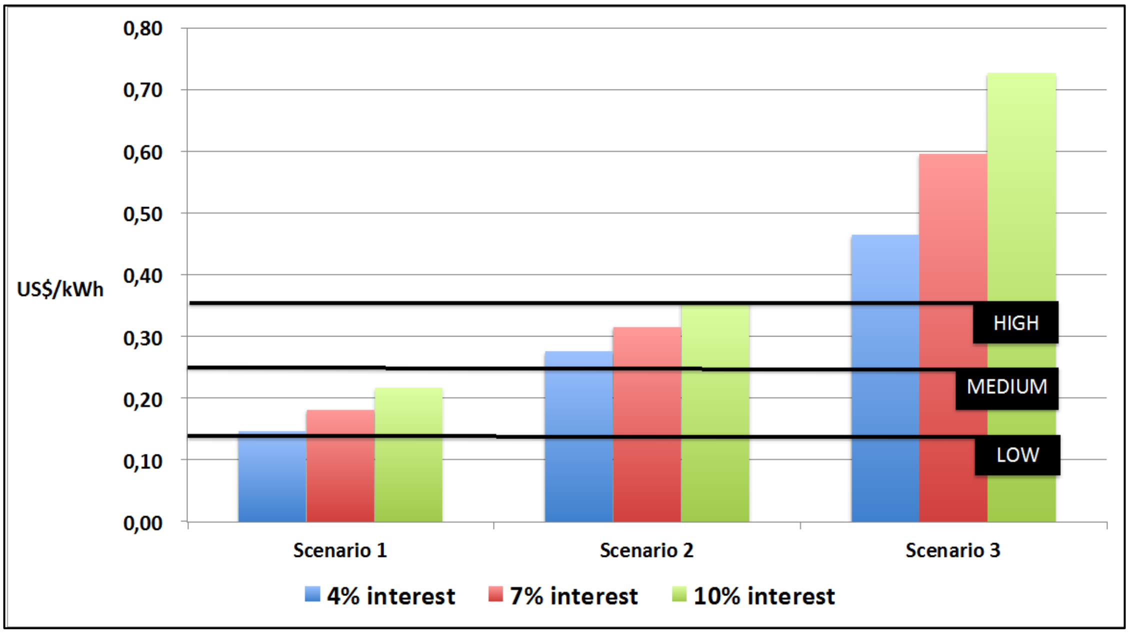


Figure 16: KWh-costs estimates for Bonaire decentral

The table below presents the expected CO_2-emission reduction and the costs per kg of CO_2-emission reduced.

Island:		Investment costs (US$ mln)	Annual costs (kUS$; 4%)	CO2 reduced (tonnes)	Investment per kg of CO2 reduced	Annual costs per kg CO2 reduced
Bonaire decentral	Scenario 1	14.5	1,502	8,580	US$ 1.69	US$ 0.175
	Scenario 2	30.7	5,819	15,220	US$ 2.02	US$ 0.382

Table 24: Bonaire decentral CO2 emission reduction estimates

The utililty and decentral scenarios for Bonaire can also be combined: with an effective financial scheme, decentralized solar PV deployment can be stimulated in combination with utility scale wind and solar power development. A more detailed financial analysis including the effects on cash flows for WEB and CGB and a feasibility study for wind power and storage is required.

4.3 St. Eustatius

Based on the above-mentioned scenarios for fuel price developments and technical and economic data on solar and wind power and energy storage, an analysis is made for St. Eustatius.

The first analysis was done with HOMER to determine the technically feasible solutions and its characteristics in terms of renewable production. This was done by adding solar capacity of 2MW and wind capacity of 0-4MW (in steps of 0,8MW) to the “as is” situation, consisting of 1,89MW installed and 2MW planned solar power, 3,89MW in total. Each of the combinations have been examined with storage capacities ranging from 0-10MWh. Increasing storage increases the renewable fraction but also has higher investment and O&M costs.

The results for St. Eustatius are shown in the next figure. It shows per scenario (combination of solar and wind power) the investment level as well as the (new) renewable fraction, for increasing storage capacity.

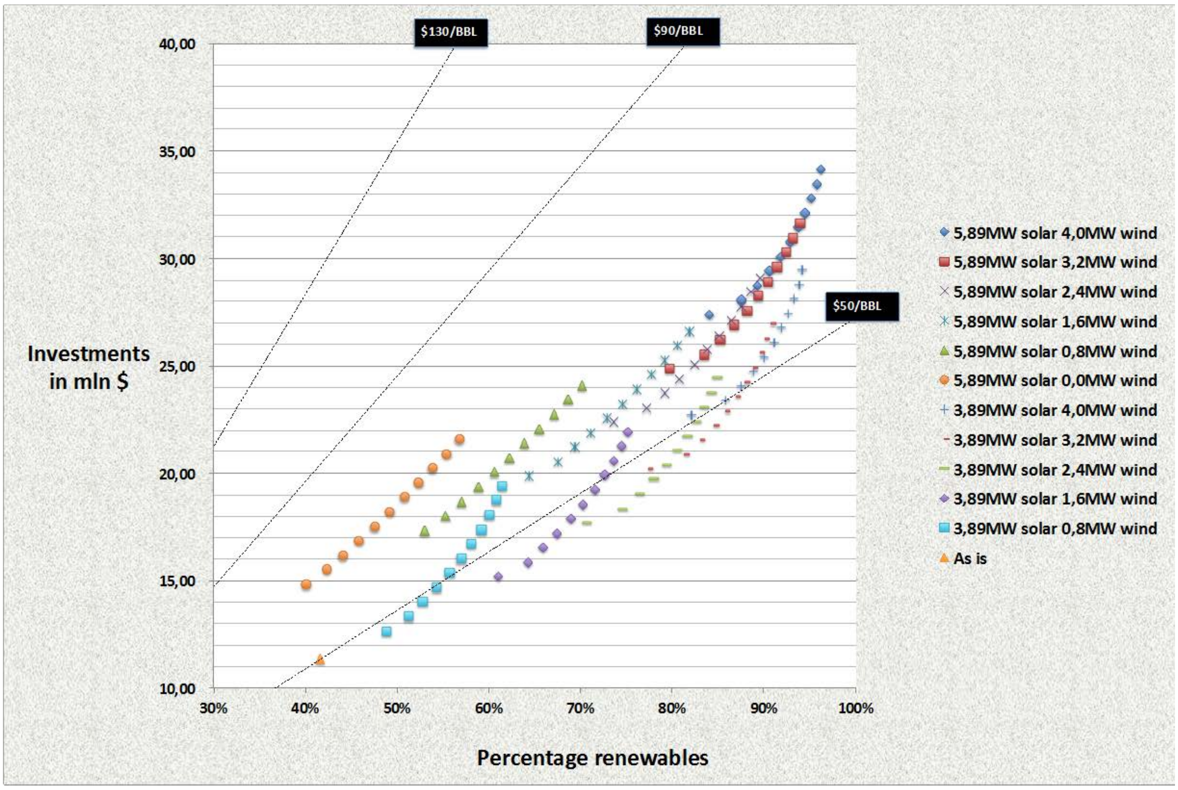


Figure 17: Investment levels for renewable options at St. Eustatius

The baselines represent the total avoided fuel expenses for a period of 10 years at a fuel price level associated with a WTI crude oil price of $50, $90 and $130. The $50 scenario is regarded "low", the $90 scenario is regarded "medium", and the $130 scenario is regarded "high".

If a scenario is left of a certain baseline, the investments will be higher than the (undiscounted) avoided costs of fuel for a period of 10 year given a stable either $50, $90 or $130 oil price.

The key conclusions that can be drawn from the figure are the following:

- High levels of more than 90% renewable fractions can be reached by a combination of solar, wind and storage but investment levels increase substantially;
- Investment levels are mostly between the $50/bbl and $90/bbl oil price scenarios, some of them stay below the low oil price scenario;
- Wind contributes better than solar to the existing production mix ("as is") in terms of lower total investment costs, mainly due to a higher capacity factor based on assumed wind speeds and related avoided additional storage costs.

The next table shows the combinations of solar and wind power and storage that reach 60% of net renewable electricity production. The economical best option seems to be the combination of 1.89 MW solar with 2,4 MW wind and 1 MWh storage capacity. Investments for this combination are US$ 15.54 million. This combination has excess kWh-production of 695,147 kWh, approx. 7.5% of renewable electricity generation.

PV MW	Wind MW	Storage MWh	Invest $mln	Renew. %	Production kWh	Demand kWh	Excess kWh	PV kWh	Wind kWh
3,89	1.6	0	15.16	61%	16,753,960	13,999,910	2,754,053	6,760,221	4,548,285
3,89	0.8	8	18.05	60%	14,621,610	13,999,910	461,981	6,760,221	2,274,142
3,89	0.8	4	15.35	56%	15,227,870	13,999,910	1,132,232	6,760,221	2,274,142

Table 25: 60% renewable options for St Eustatius

However, Statia will have 3.89 MW of solar power generation capacity installed in 2016/2017, as wind energy was still premature and needs to be assessed in more detail[58]. Taking this into account, the best option for St. Eustatius to reach 60% of renewable electricity generation will be to add 1.6 MW of wind power. This scenario will require total investments of approx. 15.16 million US$ and will have a rather high percentage of excess kWh production of 2,754,053 kWh, almost 16% of renewable electricity generated. This is primarily caused by the relatively high share of solar power within the small electricity grid of St. Eustatius.

The above comments on the 60% of renewable electricity are confirmed in the variants providing 80% of renewable electricity, as summarized in the next table. The best option is again the one with no solar power additions, but even more wind capacity,, the 3.89 MW solar, 3,2 MW wind and 1 MWh storage scenario. This variant has excess kWh-production of 4,423,480 kWh, approx. 24% of renewable electricity generation, and has the lowest (relative) investment costs of US$ 20.86 million.

PV MW	Wind MW	Storage MWh	Invest $mln	Renew. %	Production kWh	Demand kWh	Excess Wh	PV kWh	Wind kWh
3,89	4	0	22.69	82%	20,633,580	13,999,910	6,633,679	6,760,221	11,370,690
3,89	3.2	1	20.86	81%	18,463,620	13,999,910	4,423,480	6,760,221	9,096,569
3,89	2.4	4	20.37	79%	16,467,160	13,999,910	2,359,567	6,760,221	6,822,411

Table 26: 80% renewable options for St. Eustatius

It must be said that many other combinations of solar and wind capacities can be examined. Whereas solar is very predictable and proven on St. Eustatius, wind energy is lagging behind and need proper attention as recent studies show promising results. These tables mainly show that levels of 60-80 can be reached in a certain combination of solar, wind and storage. The exact combination needs to be determined via a feasibility study with a sufficient wind data assessment to substantiate the financial investments.

As can be seen in Figure 16, it will not be possible, or at very high costs, to reach 100% renewable electricity generation only with solar and wind power. The variability of these renewable energy sources makes it more and more difficult to really absorb all electricity generated in the grid. With increasing capacities, the amount of needed storage increases more than proportionally thus investments. Only in case storage cost will be considerably lower in the future, solar and wind can be increased further.

100% renewable electricity generation thus requires other renewable energy options. For St. Eustatius OTEC could be an interesting and possibly feasible option. Costs of OTEC systems however are still high as shown in ANNEX 5: Factsheet OTEC. With current information on investment costs of US$ 41,000/kW for onshore OTEC facilities, these are not (yet) economically attractive. The combination of cooling, using cold seawater, and fresh

[58] *See paragraph 2.2*

water production will improve its feasibility. Further research and specific location studies will be necessary, especially as deep seawater is abundant in the CN-islands.

Affordability and sustainability

Based on the above data on investments, renewable kWh production and resulting fuel savings, we have assessed the kWh-costs for the different scenarios with reference to the as-is situation. When these kWh costs are lower than the fuel costs for conventional power generation, these investments will result in reduced cost levels for the overall production of electricity.

The next tables show for the preferred renewable scenarios the fuel savings and the fuel cost savings, for all three oil price scenarios low, medium and high. The preferred 60% and 80% scenarios have been adjusted for the “as is” scenario which will include an estimated 4,6MWh of storage after establishing the current expansion under implementation. Also only the ADDITIONAL investments on top of the “as is” 3.89MW solar /4.6MWh storage installation is taken into account. The investment costs shown in Table 28 are therefore lower than those indicated in Tables 25 and 26.

St. Eustatius	Solar (MW)	Wind (MW)	OTEC (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	3.89	0	0	4.6	42%	2,174	N/A
Scenario 1	3.89	1.6	0	4.6	69%	1,161	1,013
Scenario 2	3.89	3.2	0	4.6	86%	532	1,642
Scenario 3	0	0	1.8	0	100%	-	3,724

Table 27: Fuel savings for the renewable energy scenarios for St. Eustatius

Again, as for Bonaire, the fuel savings in scenario 3 are higher than the fuel usage in the “as is” situation, as the OTEC will replace all other renewable electricity generation options, also the already installed/planned 3.89 MW. OTEC is expected to become available after the lifetime of this solar power capacity has expired.

St. Eustatius	Additional Investment (US$)	Fuel savings (m3)	Fuel cost savings at three oil price levels (US$)		
			LOW	MEDIUM	HIGH
Scenario 1	6,520,000	1,013	741,265	1,334,277	1,927,289
Scenario 2	11,540,000	1,642	1,201,288	2,162,319	3,123,350
Scenario 3	94,300,000	3,724	2,724,891	4,904,804	7,084,717

Table 28: Fuel cost savings for the renewable energy scenarios for St. Eustatius

The kWh-costs realized with the additional solar and wind power (and an OTEC facility) are presented below, together with the fuel costs of kWh-production for the three oil price scenarios of US$ 50, 90 and 130 per barrel.

St. Eustatius	Additional investment (US$)	Depr. (kUS$)	O&M costs (kUS$)	Financial costs in kUS$ at three interest rates:			Total annual costs (kUS$)			kWh-costs (US$)		
				4%	7%	10%	4%	7%	10%	4%	7%	10%
Scenario 1	6,520,000	435	130	261	456	652	825	1,021	1,216	0.22	0.27	0.32
Scenario 2	11,540,000	769	259	462	808	1,154	1,490	1,836	2,183	0.24	0.30	0.35
Scenario 3	94,300,000	4,715	2,530	3,772	6,601	9,430	11,017	13,846	16,675	0.79	0.99	1.19

Table 29: Renewable energy kWh-cost estimates

When comparing the kWh-costs of the additional renewable power with the fuel costs of diesel power, it’s clear that at the current oil prices of approximately US$ 50 per barrel (low), the scenarios 1 and 2 will not result in a kWh cost reduction although when financed at 4% interest rates, it comes close.

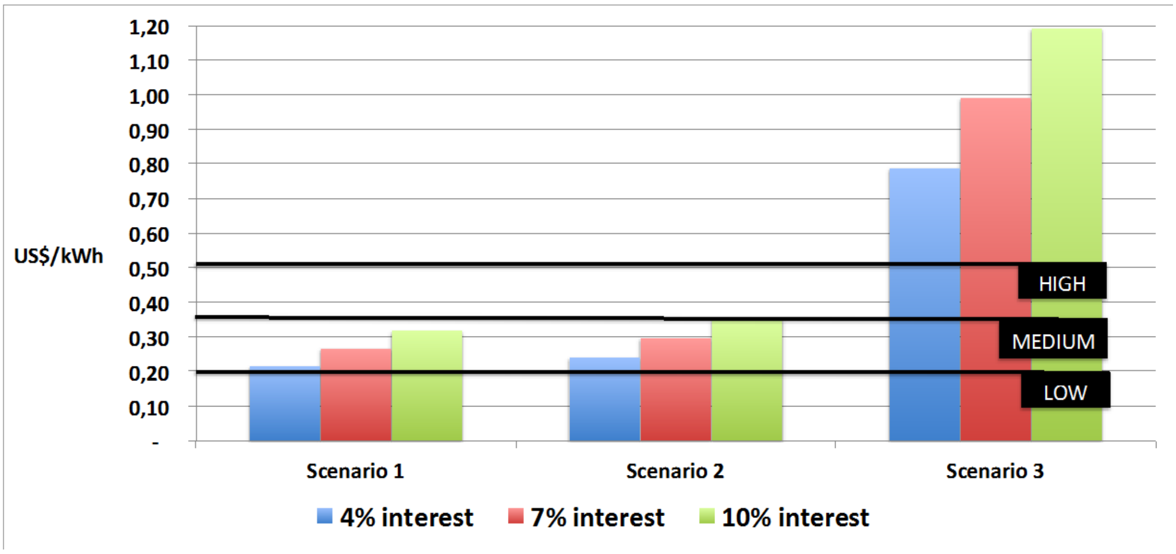


Figure 18: Renewable kWh versus conventional fuel costs St. Eustatius

At an oil price level of US$ 90 (medium) several solar and wind scenarios have kWh cost estimates equal or lower than the kWh-costs of diesel generations. OTEC kWh costs are significantly higher than the fuel costs of conventional power generation in all scenarios. OTEC will also fully replace the diesel generators resulting in additional savings. Together with additional benefits like fresh water production OTEC could certainly become an interesting option in the future.

The fuel savings directly result in reducing CO2 emissions. The expected CO2 emission reduction is presented in the table below
.

St. Eustatius	Additional investment costs (US$)	Annual costs (kUS$; 4%)	Fuel savings (m3)	CO2-emission reduction (tonnes)	Investment per kg of CO2 reduced	Annual costs per kg CO2
Scenario 1	6,520,000	825	1,013	2,736	$2.38	$0.30
Scenario 2	11,540,000	1,490	1,642	4,433	$2.60	$0.34
Scenario 3	94,300,000	11,017	3,724	10,056	$9.38	$1.10

Table 30: CO2-emission reduction estimates

4.4 Saba

Based on the above-mentioned data for oil price developments and technical and economic data on solar and wind power and energy storage, an analysis is made for Saba.

The first analysis was done with HOMER to determine the technically feasible solutions and its characteristics in terms of renewable production. This was done by adding solar capacity of 2MW and wind capacity of 0-4MW (in steps of 0,8MW) to the “as is” situation, consisting of 2MW planned solar power. Each of the combinations were examined with storage capacities ranging from 0-10MWh, potentially needed to decrease the amount of curtailment by charging in case of overproduction and discharging later during the day. Adding storage might increase the renewable fraction but also induces higher cost levels thus investments.

The results for Saba are shown in the next figure. It shows per scenario (combination of solar and wind power) the investment level as well as the renewable fraction, for increasing storage capacity. The baselines represent the same yearly expenses for a period of 10 years at a fuel price level associated with a WTI barrel price of $50, $90 and $130.

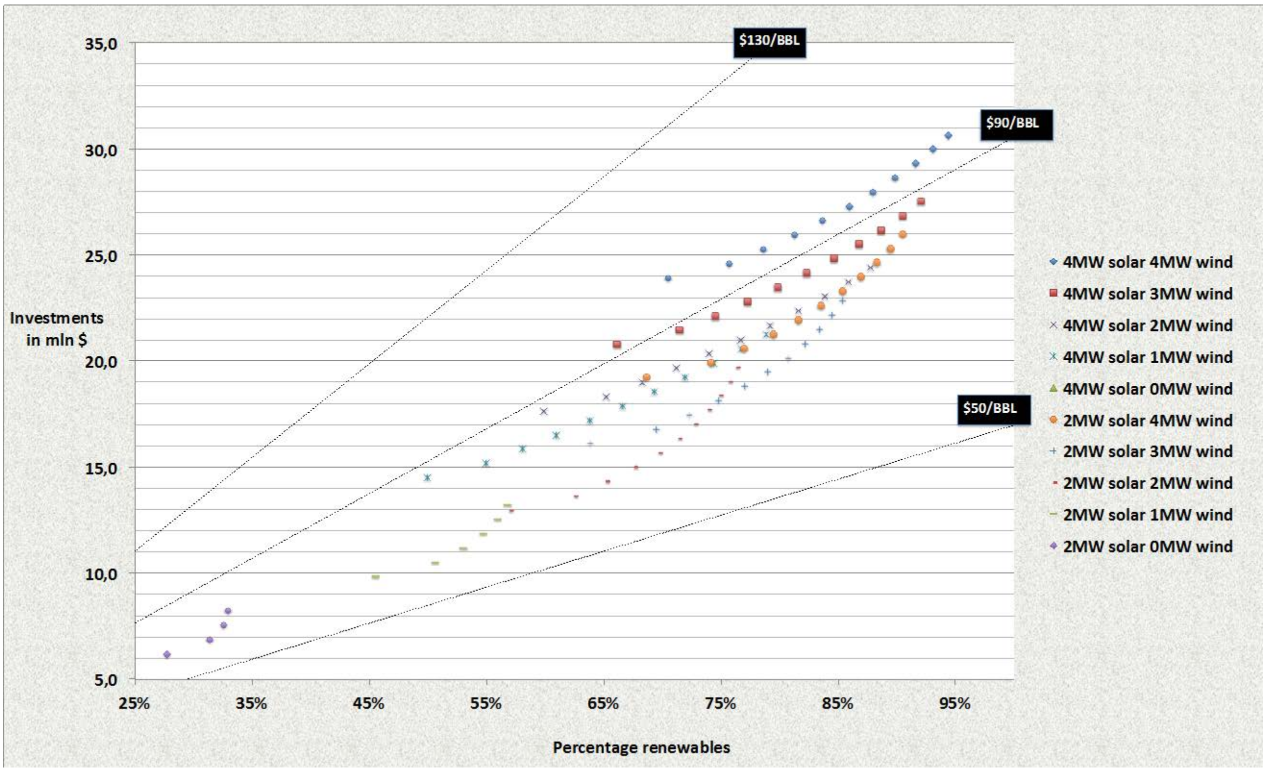


Figure 19: Investment levels for renewable options at Saba

The key conclusions that can be drawn from the figure are the following:

- High levels of more than 90% renewable fractions can be reached by a combination of solar, wind and storage but investment levels increase substantially;
- Investment levels are above the oil price level of $50/bbl (low), some of them also above the $90/bbl (medium);
- Adding wind to the planned solar capacity contributes better than increasing solar capacity further in terms of lower total investment costs, mainly due to a higher capacity factor based on assumed wind speeds and related avoided additional storage costs.

Table 29 shows the combinations of solar and wind power and storage that reach 60% of renewable electricity in the grid. The economical best option is the combination of 2 MW solar with 2 MW wind and 1 MWh storage capacity. Investments for this combination are US$ 13.6 million. This combination has the least excess kWh-production although still more than 17% of the additional renewable electricity cannot be absorbed.

PV MW	Wind MW	Storage kWh	Invest $mln	Renew. %	Production kWh	Demand kWh	Excess kWh	PV kWh	Wind kWh
4	1	3000	16.51	61%	12,336,720	9,375,777	2,857,916	6,289,289	4,786,630
2	3	0	16.09	64%	13,706,910	9,375,777	4,331,146	3,144,645	7,179,954
2	2	1000	13.63	63%	11,442,800	9,375,777	2,025,041	3,144,645	4,786,630

Table 31: 60% renewable options for Saba

The above comments on the 60% of renewable electricity are confirmed in the variants providing 80% of renewable electricity, as summarized in the next table .The best option is the one with no additional solar power and more even wind, the 2 MW solar, 3 MW wind and 6 MWh storage capacity. This variant has the least kWh-losses and reaches 81% of renewable electricity generation at the lowest investment costs of US$ 20.1 million. Approximately 21% of the generated renewable electricity cannot be absorbed in the grid but the share of excess kWh is even higher in all other combinations.

PV MW	Wind MW	Storage kWh	Invest $mln	Renew. %	Production kWh	Demand kWh	Excess kWh	PV kWh	Wind kWh
4	3	4000	23.46	80%	15,351,440	9,375,777	5,849,384	6,289,289	7,179,954
4	2	7000	22.35	82%	12,797,850	9,375,777	3,215,625	6,289,289	4,786,630
2	4	4000	21.93	82%	14,439,370	9,375,777	4,949,391	3,144,645	9,573,260
2	3	6000	20.14	81%	12,125,560	9,375,777	2,597,154	3,144,645	7,179,954

Table 32: 80% renewable options for Saba

It must be said that many other combinations of solar and wind capacities can be examined. Whereas solar is very predictable at Saba, wind energy is lagging behind and need proper attention as recent studies show promising results. These tables mainly show that levels of 60-80 can be reached in a certain combination of solar, wind and storage. For wind turbines the location with highest wind speeds should be selected, which may result in higher grid connection costs. These costs are included in the above investment cost assessments. The exact combination needs to be determined via a feasibility study with a sufficient wind data assessment to substantiate the financial investments.

As can be seen in Figure 15, it will not be possible, or at very high costs, to reach 100% renewable electricity generation only with solar and wind power. The variability of these renewable energy sources makes it more and more difficult to really absorb all electricity generated in the grid. With increasing capacities, the amount of needed storage increases more than proportionally thus investments. Only in case storage cost will be considerably lower in the future, solar and wind can be increased further.

100% renewable electricity generation thus requires other renewable energy options. For Saba geothermal energy seems to be a very interesting and possibly feasible option. At this stage, TNO assesses the possibility of realizing successfully a small geothermal power plant at 21% on the basis of currently available information. Further research is required to identify the main risks and opportunities. A stepwise approach can be taken to further examine whether the chance of success can improve before larger costs for preparatory studies have to be made.

Affordability and sustainability

Based on the above data on investments, renewable kWh production and resulting fuel savings, we have assessed the kWh-costs for the different scenarios. When these kWh costs are lower than the fuel costs for conventional power generation, these investments will result in reduced cost levels for the overall production of electricity.

The next tables show for the preferred renewable scenarios the fuel savings and the fuel cost savings, for all three oil price scenarios low, medium and high.

The preferred 60% and 80% scenarios have been adjusted for the “as is” scenario. Only the ADDITIONAL investments on top of the “as is” 2MW solar / 1MWh storage installation is taken into account. Therefore the investment costs in Table 34 are considerably lower than indicated in tables 31 and 32.

Saba	Solar (MW)	Wind (MW)	GEO (MW)	Storage (MWh)	Renewable %	Fuel usage (m3)	Fuel savings (m3)
As is	2	0	0	1	31%	1,593	N/A
Scenario 1	2	2	0	1	63%	873	720
Scenario 2	2	3	0	6	81%	448	1,144
Scenario 3	0	0	1,5	0	100%	-	2,321

Table 33: Fuel savings for the renewable energy scenarios for Saba

The fuel savings in scenario 3 are higher than the fuel usage in the “as is” situation, as the geothermal facility will replace all other renewable electricity generation options, also the already installed 2 MW of solar power. Geothermal energy is expected to become available after the lifetime of this solar power has expired.

Saba	Investment costs (US$)	Fuel savings (m3)	Fuel cost savings at three oil price levels (US$)		
			Low	Medium	High
Scenario 1	3,820.000	720	526,724	948,102	1,369.,81
Scenario 2	9,515.000	1,144	837,328	1,507,190	2,177.,52
Scenario 3	12,750.000	2,321	1,697,883	3,056,190	4,414.,96

Table 34: Fuel cost savings for the renewable energy scenarios for Saba

The kWh-costs realized with the additional solar and wind power and of a geothermal facility are presented below, for the three interest rates of 4%, 7% and 10%.

Saba	Investment (mln US$)	Depr. (kUS$)	O&M (kUS$)	Financial costs in kUS$ at three interest rates:			Total annual costs (kUS$)			kWh-costs (US$)		
				4%	7%	10%	4%	7%	10%	4%	7%	10%
Scenario 1	3.8	452	162	153	267	382	766	881	996	0.26	0.30	0.34
Scenario 2	9.5	886	243	381	666	952	1,509	1,795	2,080	0.32	0.38	0.44
Scenario 3	12.8	1	300	510	893	1,275	811	1,193	1,576	0.09	0.13	0.17

Table 35: Renewable energy kWh-costs

When comparing the kWh-costs of the additional renewable power with the alternative of fuel costs based on diesel generators, it’s clear that at the current oil prices of approximately US$ 50 per barrel (low), scenarios 1 and 2 will not result in a kWh cost reduction. This is also the case when a low interest rate of 4% is taken into account, as can be seen in the next figure. Scenario 3 (geothermal) however is very promising from a financial perspective and needs proper attention.

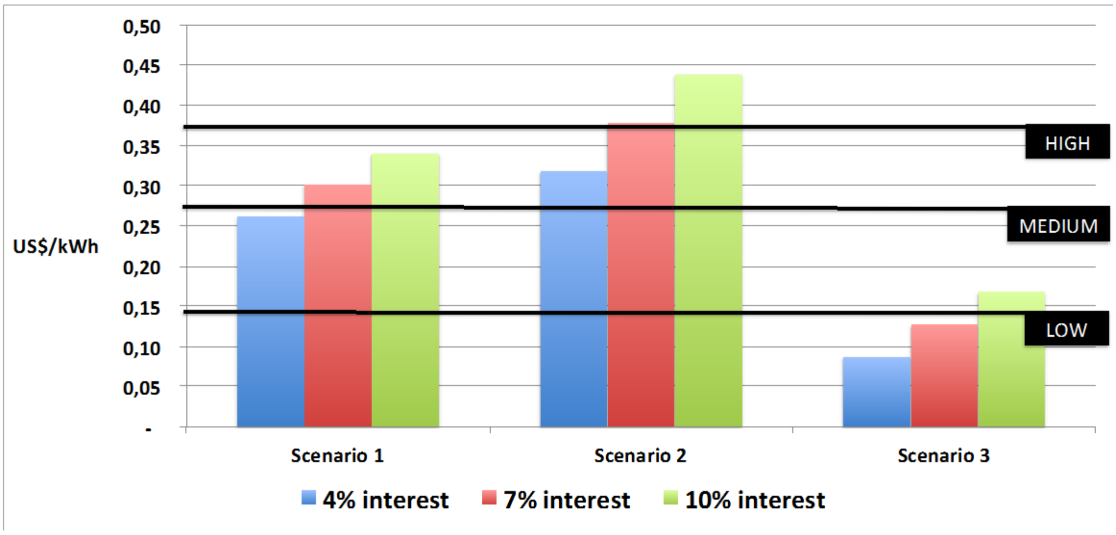


Figure 20: Renewable kWh versus convention fuel costs Saba

At an oil price level of US$ 90 (medium) all three scenarios can contribute to reduced costs of power generation, depending on the applicable interest rate.

The fuel savings will directly contribute to reducing CO2 emissions. The expected CO2 emission reduction is presented in Table 34, together with the costs of CO2 emission reduction.

Saba	Investment costs (US$ mln)	Annual costs (kUS$; 4%)	Fuel savings (m3)	CO2-emission reduction (tonnes)	Investment per kg of CO2 reduced	Annual costs per kg CO2 reduced
Scenario 1	3.8	766	720	1,944	US$ 1.95	US$ 0.39
Scenario 2	9.5	1,509	1,144	3,090	US$ 3.07	US$ 0.49
Scenario 3	1.,8	811	2,321	6,266	US$ 2.04	US$ 0.13

Table 36: CO2-emission reduction estimates for Saba

5 Conclusions and recommendations

5.1 Main Findings

Overall objective of this study was to investigate, on the basis of available data and information, whether it would be possible, technically and economically, to realize a fully sustainable electricity supply in the Caribbean Netherlands (CN): Bonaire, St. Eustatius and Saba.

With the aim to provide an objective and reliable answer, different opportunities and scenarios have been analyzed on their sustainability and affordability, e.g. on their effect on kWh-generation costs. The overall conclusions can be summarized as follows:

1. Conventional electricity generation on the CN-islands is very expensive due to the small-scale electricity systems and therefore inefficient diesel powered generation. Fuel costs are already high and will increase substantially if oil prices start rising to historical high levels. An increase of the share of renewable electricity generation will reduce the vulnerability of the islands to fuel price increases and will reduce kWh-generation costs if financed with low interest rates;
2. None of the currently available renewable energy options can make the CN-islands fully sustainable without increasing current kWh-generation costs, except for the option of geothermal energy on Saba. There are however, still important technological risks related to the development and implementation of geothermal electricity generation, which need to be assessed carefully;
3. 100% sustainable electricity generation can only be achieved using technologies like OTEC or geothermal energy sources. Both are available at the CN-islands and provide reliable and manageable electricity generation. They do require further studies before they could be applied commercially on the CN islands, probably in about 10 years or more;
4. At an oil price of US$ 90, solar and wind energy can significantly contribute to the sustainability of the electricity generation on the CN-islands, up to approx. 80% of electricity supply. The affordability of the different options will depend heavily on the financing modalities: support or guarantees from the (national) government with a relatively low interest rate of 4% or less, would enable kWh-cost reductions, reducing future needs for subsidizing the utility companies of the CN-islands;
5. The investment costs for the scenarios based on solar and wind power are much higher than would be expected in the Netherlands. This is caused by significant higher costs for infrastructure preparation, grid connection, non-availability of required expertise on the islands, environmental costs and project management costs. These additional costs have been taken into account in scenarios in this study;
6. The costs of CO_2 emission reduction on the CN-islands are considerably higher compared to similar costs in the Netherlands. The availability of solar and wind power is generally better than in the Netherlands, however, the total investment costs are much higher too.
7. The development and realization of wind power is a challenge, especially on Saba and St. Eustatius as only recent studies with wind speed measurement over a longer period of time showed promising results. This is the main reason why a solar as a proven and predictable technology has been developed on St. Eustatius and additional solar parks on both St. Eustatius and Saba are being established. The development and implementation of wind power is most likely the next step from an economical point of view.

8. OTEC is a potential renewable energy source in the future, abundantly available at the islands, as it needs deep waters with high surface temperatures. Investment costs however, are still very high, although interesting projects are being developed in the region (Martinique) and need to be followed closely. A combination of OTEC with SWAC and fresh water production will improve its economic feasibility;
9. There are no other renewable energy options available at the islands:
    a. Biomass or biofuel is simply not available, Saba and St. Eustatius do not have any land available, and if so, it would be used for agricultural purposes. For Bonaire biomass production from the sea might be a future option if it can be combined with durable coral reef management. Research and development results should be waited for.
    b. Waste: There are no significant quantities of waste available on the islands to allow development of a waste-to-energy facility, incineration or digestion of organic wastes.

Bonaire:

Bonaire's electricity company WEB has established a PPA with ContourGlobal. ContourGlobal operates the power plant, including 11.1 MW of wind power, producing practically all electricity for Bonaire. As demand has been and will remain to be growing rapidly, additional production capacity, preferable renewable production capacity is needed

Through the PPA ContourGlobal has a Right of First Refusal for the development of additional generation capacity. Although (or maybe because) the PPA can be interpreted multiple ways, it has slowed down execution of structural expansion and led to installing costly temporary containerized Aggreko diesels.

Development of solar and wind power could therefore partly be realized through decentralized efforts: fostering households and companies to invest in their own small-scale solar or wind power generation. This can be stimulated through an appropriate scheme, setting feed-in tariffs that are sufficiently attractive for the target groups and still enabling WEB and/or ContourGlobal to take adequate measures for supply and demand balancing and management.

It is expected that with an adequate incentive scheme the share of renewable electricity generation at Bonaire could increase to 50% and maybe even 60%.

Further developments could be realized together with CGB through larger scale implementation of solar and wind power combined with electricity storage and PMS. This may result in renewable electricity generation shares up to 60% and 80%.

100% renewable electricity supply can only be achieved with OTEC, the only available other potential renewable energy source. The variability of solar and wind power does not allow to make the electricity supply fully sustainable as it will need an increasing amount of storage with high associated costs. OTEC is abundantly available and Bonaire seems to have favorable circumstances for OTEC development. Current costs are extremely high but may decrease over time to competitive levels.

St. Eustatius:

St. Eustatius is already progressing to more renewable electricity generation in the very near future. A 1.89 MW solar park has just become operational and tenders have just been published for a second solar park with a capacity of an estimated 2MW and an estimated 4MWh of storage, which is expected to be commissioned during the first half of 2017.
As previously mentioned, this will bring the renewable fraction above 40%.

A further increase to reach 60% and 80% of renewable electricity generation should most likely be realized through the implementation of wind power and (additional) energy storage. It must be said that many other combinations of solar and wind capacities can be examined, the following scenarios give a firm indication but integral feasibility studies need to be executed to substantiate the financial investments.

1. 69% renewable electricity: add 2 wind turbines, 1.6 MW of wind power;
2. 86% renewable electricity: add 4 wind turbines, 3.2 MW of wind power;
3. 100% of renewable electricity can be achieved by developing and implementing OTEC, a 2.3 MW OTEC will be sufficient although investments will be high up to US$ 94 million for this relatively small-scale installation. Further study will be required.

Saba:
With support of the Ministry of Economic Affairs, also Saba is preparing for a first solar park with a capacity of 1 MW combined with an estimated 0.3 MWh of energy storage, to be expanded to a 2MW solar and 1MWh storage facility afterwards. The first solar park will become operational in 2017 and will bring the share of renewable electricity generation up to 31%.
Solar and wind power can certainly be used to bring the share of renewable electricity generation up to 60% and even 80%, when combined with sufficient storage capacity. It must be said that many other combinations of solar and wind capacities can be examined, the following scenarios give a firm indication but integral feasibility studies need to be executed to substantiate the financial investments.

1. 63% renewable electricity: add 2MW of wind power;
2. 81% renewable electricity: add 3MW of wind power combined with an additional 5MWh of energy storage;
3. 100% renewable electricity: develop and implement a geothermal energy facility of approx. 1.5 MW. Investment costs should be around US$ 13 million. Further experts assessment will be required to determine its potential.

Recommendations:

From the above, we identified the following recommendations:

1. Initiate integral feasibility studies for the realization of wind power on Saba and St. Eustatius. As solar power is now being implemented, the most feasible option to further realize sustainable electricity generation is through wind power. Main issue will be to identify suitable locations (wind speed; visibility and noise aspects; resistance among inhabitants; cost assessment for site preparation, grid connection and infrastructure development) and associated cost elements;
2. Prepare and implement a feasibility study for OTEC on Bonaire. Bonaire seems to have a relative attractive coastline and access to deep sea. Bonaire can realize a larger scale installation than the other islands and may combine electricity generation with the provision of cooling and fresh water production.
3. Prepare and conduct an exploration study for geothermal energy for Saba, to be executed by a regionally operating geothermal company, related to other project developed in the Caribbean. According to the TNO study, the only cost-efficient option is to jointly develop geothermal with St. Maarten and to establish a power power cable between the islands.
4. Investigate how an incentive scheme could be developed for the stimulation of decentralized renewable energy generation at Bonaire in order to stimulate renewable penetration parallel to large-scale developments to be discussed between WEB and ContourGlobal. Lessons can be learned from the Curaçao experience.

ANNEX 1 Factsheet Wind Energy

Wind technology

Wind power technologies transform the kinetic energy of the wind into useful mechanical power. The kinetic energy of the airflow provides the motive force that turns the wind turbine blades that, via a drive shaft, provide the mechanical energy to power the generator in the wind turbine. Wind power technologies come in a variety of sizes and styles and can generally be categorized by whether they are horizontal axis or vertical axis wind turbines (HAWT and VAWT), and by whether they are located onshore or offshore.

The power output of wind turbines is determined by the capacity of the turbine (in kW or MW), the wind speed art the specific location and height of the turbine, and the diameter of the rotors. The maximum energy than can be harnessed by a wind turbine is roughly **proportional to the swept area** of the rotor. Blade design and technology developments are one of the keys to increasing wind turbine capacity and output. By doubling the rotor diameter, the swept area and therefore power output is increased by a factor of four. This is the reason why wind turbines become bigger and bigger as far as progressing design and materials allow (see figure 1)[59].

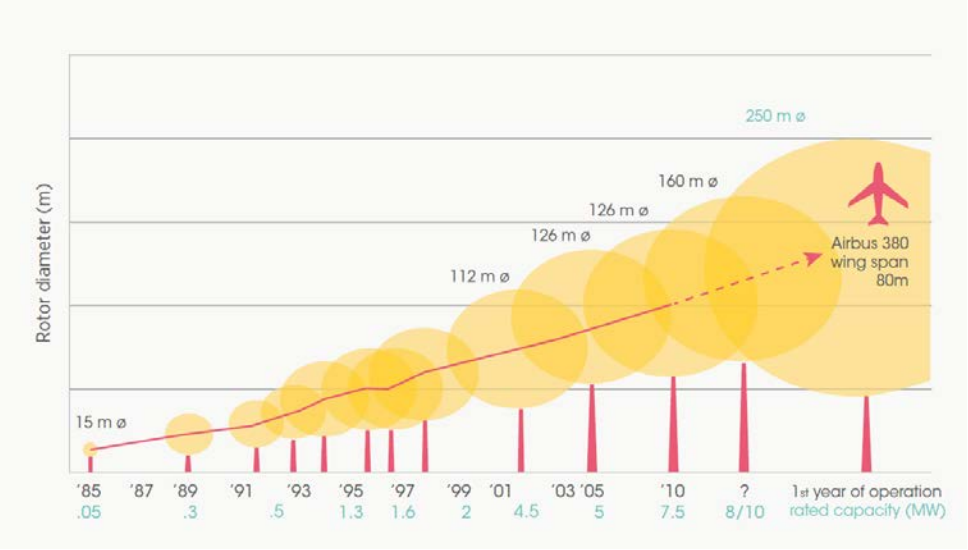


Figure 1: Development of wind turbines

The biggest commercially available wind turbine today is the Vestas V164 of 8MW. This turbine has a tower height of 140-meter, a tip height of 220 meter, and a swept area of 21,000 m^2.

Besides the swept area, the average wind speed at the specific location and height determines the actual output of the wind turbine. The output is proportional to the velocity of the wind **to the third power**. If wind speed doubles, the output increases eight-fold. Obviously, wind turbines are built at locations with high average wind speeds.

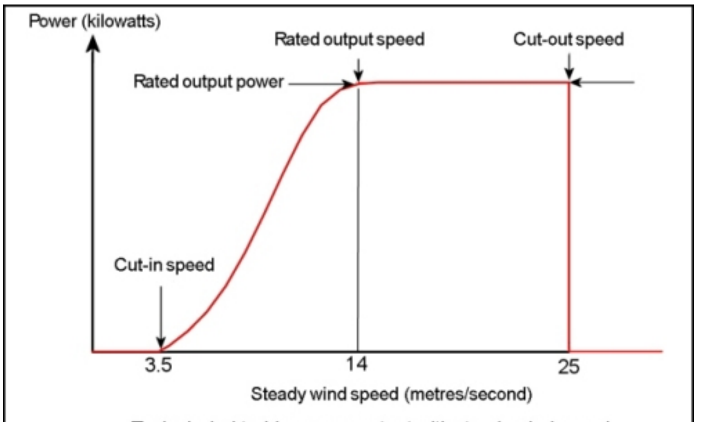
The output of a wind turbine varies with the fluctuating wind speed. At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate

[59] *IRENA 2012 Renewable Technologies Cost Analysis - Wind Power (Ref.1)*

electrical power. The speed at which the turbine first starts to rotate and generate power is called **the cut-in speed.**

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly till the power output reaches the limit that the electrical generator is capable of, **the rated power output.** Typically with large turbines, above this speed, the blade angles are adjusted so as to keep the power at the constant level.

At some point, the **cut-out speed**, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill.

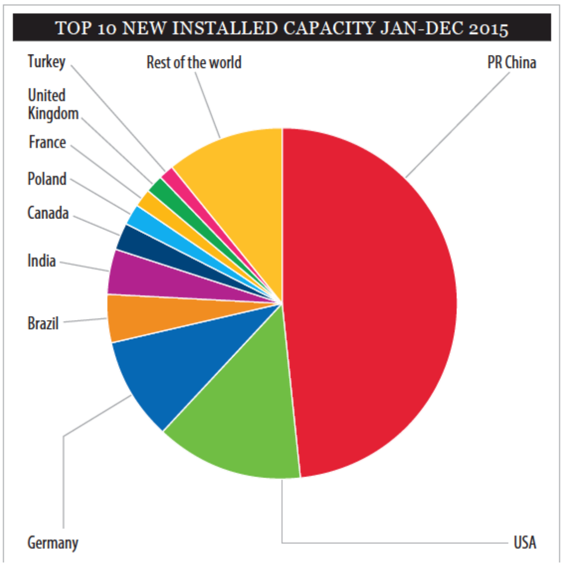


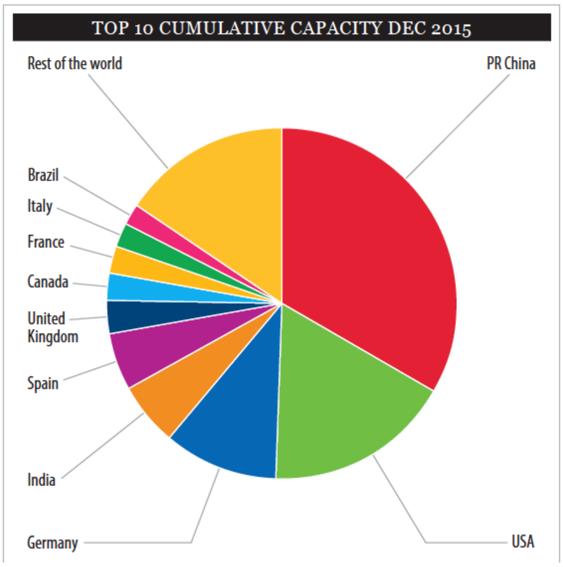
Typical wind turbine power output with steady wind speed.

The average output of a typical wind turbine depends fully on the average wind speeds and is usually expressed in a percentage of the rated output power (**capacity factor**), which could range from 5-50%.

Wind energy developments

Wind energy is rapidly increasing worldwide. According to the recent publication of the Global Wind Energy council (GWEC)[60], the total installed wind energy power at the end of 2015 is 432,419 MW, and showed a growth of 63.013 MW during 2015, which is an increase of approximately 17%. The next figure shows that China was the main contributor to the growth in 2015, expanding its overall share of installed capacity even more.





Like other renewable energy technologies, wind energy is capital intensive, but has no fuel costs. The key parameters governing wind energy economics are the:

- Investment costs (including those associated with project financing);
- Operation and maintenance costs (fixed and variable);
- Capacity factor (based on wind speeds and turbine availability factor);
- Economic lifetime; and
- Cost of capital.

Although capital intensive, wind energy is regarded one of the most cost-effective renewable technologies in terms of the cost per kWh of electricity generated.

Wind energy installation costs

The installed cost of a wind energy project is dominated by the upfront capital cost for the wind turbines (including towers and installation). Wind turbine investment costs have been investigated by different organizations like IRENA, US Department of Energy (DoE) and ECN. The next table shows typical ranges for onshore and offshore wind farms for developed countries[61].

[60] *GWEC 2015 Global Wind Statistics (REF.2)*
[61] *IRENA 2012 Renewable Technologies Cost Analysis - Wind Power (Ref.1)*

	Onshore	Offshore
Capital investment costs (USD/kW)	1 700-2 450	3 300-5 000
Wind turbine cost share (%)[1]	65-84	30-50
Grid connection cost share (%) [2]	9-14	15-30
Construction cost share (%) [3]	4-16	15-25
Other capital cost share (%) [4]	4-10	8-30

Table 1: comparison of capital cost breakdown onshore/offshore wind

The DoE cost estimates, as investigated by Berkely Lab[62], are presented in the next figure and shows pricing in the $900–$1,300/kW range. Data on average global pricing from Vestas largely confirm these pricing points. The costs are exclusive of substations and grid connection costs. Overall wind power project costs (including grid connection a/o) were estimated at $ 1.630/kW.

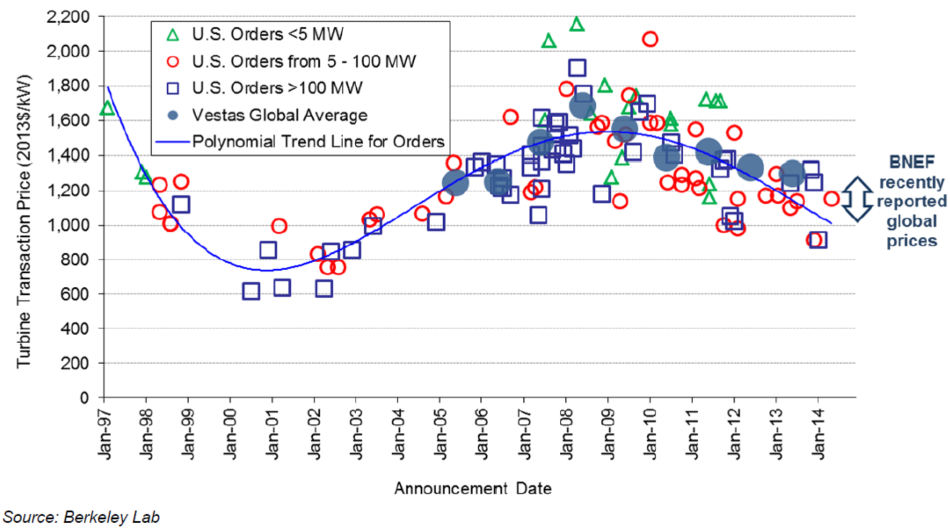


Figure 2: Reported wind turbine transaction costs over time

In its report for SDE+ in 2015[63], ECN estimates the overall wind power project costs at € 1.290/kW, down 5% compared with 2014 and 2015, which corresponds with the DoE figures and trends as presented in figure 2.

Wind energy Operation and Maintenance costs (O&M)

The fixed and variable operations and maintenance (O&M) costs are a significant part of the overall costs of wind power. O&M costs typically account for 20% to 25% of the total LCOE (Levelized Costs of Electricity)[64] of current wind power systems. O&M costs tend to increase over time after the commissioning of the plant, due to an increasing probability of component failures and that when a failure does occur it will tend to be outside the manufacturer's warranty period.

O&M costs appear to be the lowest in the United States at around $ 0.01/kWh ($ 10/MWh), perhaps due to the scale of the market and the long experience with wind power. European countries tend to have higher cost structures for O&M for onshore wind projects, varying per country from $ 0.01/kWh to 0.04/kWh. For offshore projects, it might go up to $ 0.05 to 0.06/kWh.

[62] *DoE 2013 Wind Technologies Market Report (Ref.3)*
[63] *ECN eindadvies basisbedragen SDE+ 2016 (Ref.4)*
[64] *Average cost price over the lifetime, see https://en.wikipedia.org/wiki/Cost_of_electricity_by_source*

In its 2015 report for SDE+ 2016, ECN estimated the O&M costs in the Netherlands at about € 0.01/kWh (or € 20 – 30/kW), which is very much in line with the US cost estimates.

Other fixed costs for insurance, land, taxes, grid connection, road maintenance etc. are estimated by ECN at € 12,4/kW/year. In view of the above, we have estimated the O&M costs for wind turbines on the CN islands at US$ 54 for Bonaire and US$ 81 for Saba and St. Eustatius. These figures include the costs for inspection and cleaning (required under these islands conditions) and 1% insurance for Saba and St. Eustatius.

Wind energy kWh prices

For wind power, the LCOE costs per kWh represents the sum of all costs of a fully operational wind power system over the lifetime of the project with financial flows discounted to a common year. The principal components of the economics of wind power systems include capital costs, operation and maintenance costs and the expected annual energy production.

The LCOE of onshore wind has fallen strongly since the first commercial wind farms were developed. In the United States, the cost of electricity generated from wind fell from about $ 0.30/kWh in 1984 to a low of around $ 0.055/kWh in 2005. A similar trend occurred in Europe, where the LCOE of wind declined by 40% between 1987 and 2006 for wind farms on good coastal sites. There has been a steady decline in the price demanded in the wind auctions since 2009. The 2009 auction saw prices of between $ 0.09 and $ 0.10/kWh, but by 2011 the price range was between $ 0.065 and US 0.070/kWh.

IRENA indicates kWh-costs for onshore wind power projects to be $ 0.06 to $ 0.11/kWh. However, the exact value depends on project specifics (e.g. the wind turbines' capacity factor) and different sources often use different boundaries (i.e. some studies include tax incentives, others don't).

ECN has calculated the overall electricity costs for onshore wind energy in the Netherlands to be in the range of € 0.07 – 0.093/kW, depending on the wind regime. The lowest costs obviously for the best wind regime.

Wind power in the Caribbean

The installed capacity of wind energy in the Caribbean is reported at 250MW by GWEC. It consists of wind farms in Aruba, Bonaire, Curacao, Cuba, Dominica, Guadalupe, Jamaica, Martinique, Granada, St. Kitts and Nevis. No additional capacity has been installed in 2015. Wind energy thus can be regarded as an existing and viable renewable energy source in the Caribbean.

There are many publications on wind power development in the Caribbean. However, most of these studies, articles and reports do not provide practical data on costs and benefits of electricity produced by wind turbines. Shirley & Kammen[65] has been the only source of such information, additional to the documentation for the CN-islands at hand. Wind turbine installation costs are estimated at $ 2,400/kW based upon the large 3MW each, 15MW in total wind parks built in Aruba and Curacao. This is 50% to 70% higher than installation costs in the industrialized countries. It can be expected that smaller wind turbines of 1 MW will be even more expensive.

The ECN report on Saba and St. Eustatius[66] does not address the economic factors of wind energy such as the (normalized) costs per kW. The report does state that the favorable wind location on St. Eustatius is east of the Quill at a distance of 4 km from the nearest grid connection point. There is a substantial cost increase to be expected due to this grid extension. For Saba a location close to the harbor and thus close to the new power plant has been selected, which would most likely limit the grid connection costs.

The KEMA 2011-2025 masterplan for Bonaire[67] estimates the wind costs for Bonaire for smaller wind turbines at $ 2,700/kW (grid related costs excluded). This is considered to be the norm for all CN-islands in this study as it is in line with aforementioned Shirley & Kammen study at a reasonable increased cost level for smaller turbines.

Wind speeds vary substantially among the individual CN-islands. Bonaire shows relatively high and constant wind speeds, just like its neighboring islands Curacao and Aruba. Wind only diminishes during the September/October period due to increased hurricane activity in the Atlantic Ocean. St. Eustatius and Saba have two main wind climate seasons, the hurricane season from July till mid-December and the “trade wind“ season between mid-December and July. The following table shows the key parameters for the three individual islands based upon actual wind measurements.

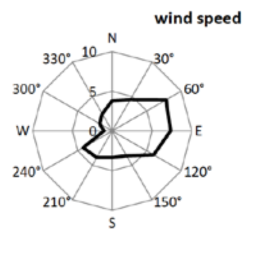
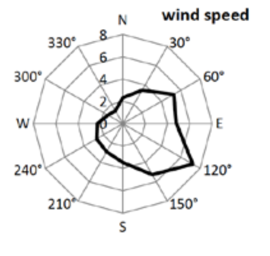
Item	Bonaire	Statia	Saba
Wind directions			
Estimated average wind speed in m/s at 50/60m height	**9.1**[68]	**7.0**	**6.2**

Table 2: Key wind parameters for the CN-Islands

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[65] Shirley Kammen Elsevier Energy Policy; Renewable Energy Sector Developments in the Caribbean (Ref.5)
[66] ECN Site assessment and technology selection for St. Eustatius and Saba (Ref.6)
[67] KEMA onderzoeksrapport masterplan 2011-2025 elektriciteit Bonaire (Ref.7)
[68] Based on data supplied by WEB

The 2015 ECN report on wind assessment from a technology point of view, showed average wind speeds at 60m heights of 6.2 m/s for Saba and 7.0 m/s for St. Eustatius. They are based on recent 20 months wind speeds measurements and resulted in the selection of class III wind turbines[69] for both islands, suitable for these wind speeds. As a reference, the existing wind turbines on Bonaire are class IA compliant, thus suitable for (very) high wind speeds.

However, due to potential hurricane exposure, measures should be taken to mitigate the associated risks. This can be done by an additional insurance policy, which leads to increased costs of about 1% of the investment per year. It is very likely insurance companies will require class II wind turbines[70] to mitigate their risk, maybe even class I to mitigate their risk.

ECN calculated the energy yield for several types of (class II and III) wind turbines based upon the limited measurements of actual wind speeds and directions. The outcome showed a maximum capacity factor of 35% (rounded) for St. Eustatius and 27% (rounded) for Saba. These values are used in this study for further analysis. It must be said that the report calculated an uncertainty of 14.7% and 12.7% for Saba and St. Eustatius respectively, mainly due to uncorrelated long-term wind speed data.

Shirley & Kammen estimate the fixed maintenance costs at $ 36/kW/year based upon the new Aruba wind park. It is considerably higher than the fixed O&M costs in the U.S. but in the same range as for Europe. For all three islands a 50% add-on is applied due to small-scale cost increases. For Saba and Statia an additional 1% of the investment costs will be added caused by hurricane insurance policies.

Mazars[71] conducted an in depth investigation into the investment costs for the Bonaire power generation facility of ContourGlobal (Ecopower at time of commissioning). This research provided a detailed overview of all direct and indirect investment costs. The costs related to the wind park are shown below.

Ecopower windpark investment:	**Costs:**
11 windturbines (900 kW) including PMS	US$ 18,720,000
1 Sorobon wind turbine (existing)	US$ 1,078,000
Cable laying and civil works	US$ 2,034,000
Cabling windpark	US$ 596,000
Site investigation and excavation works	US$ 452,000
Testing and commissioning	US$ 149,000
Other civil works and construction	US$ 400,000
Financing costs (50%)	US$ 2,320,000
Development and project management (50%	US$ 1,370,000
Insurance, due diligence a/o (50%)	US$ 900,000
Total investment costs:	**US$ 28,019,000**
Capacity:	11,1 MW
Investment costs per kW installed:	**US$ 2,524**

Table 3: Costs for the Bonaire wind park

Part of the civil and construction works can most probably be attributed to the conventional power plant at this location. The above costs comply well with the Kammen estimates.
No data for variable O&M costs were given but we estimate those at approximately double of these costs in the US as well.

[69] *https://en.wikipedia.org/wiki/IEC_61400*
[70] *The factual hurricane wind speeds could even lead to class I wind turbines*
[71] *Bevindingen onderzoek WEB-Bonaire (project WEB-Ecopower), Mazars, Nov 2015 (Kamerstukken II, 34 300 XIII nr. 169)*

Environmental impacts

The environmental impact of wind energy has several aspects. The obvious visual disruption of landscapes is unavoidable due to the size of wind turbines and their placement in specific areas.

Noise intrusions are also widely reported, with variability depending on topography, wind speed & direction, and time of day. This needs to be carefully addressed.

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely document and studied. A recent National Wind Coordinating Committee (NWCC) review of peer-reviewed research found evidence of bird and bat deaths from collisions with wind turbines and due to changes in air pressure caused by the spinning turbines, as well as from habitat disruption. The NWCC concluded[72] that these impacts are relatively low and do not pose a threat to species populations.

[72] *NWCC 2010. Wind turbine interactions with birds, bats, and their habitats: A summary of research results and priority questions (Ref.8)*

Wind power fluctuates over time, mainly under the influence of meteorological fluctuations. For large individual wind turbines, the variation in the power output on seconds scale is very small, due to the averaging of the wind field across the rotor and the filtering effect of the turbine inertia[73]. In case of a wind farm, consisting of multiple wind turbines, the variation in the aggregated power output is small for time-scales of even tens of seconds, due to the averaging of the output of individual turbines across the wind farm. The variations within an hour are much more significant and need to be taken into account.

Regular spinning reserves of the operational diesel generators can address these (minutes to hours) fluctuations of wind power. For the CN-islands however, smaller wind turbines (< 1MW) will be applicable. Unfortunately, for these kinds of turbines no data on power fluctuations on a second or minute scale is available. Although short-term wind output variations seem to be limited to minutes instead of seconds as well, this needs to be investigated for the individual islands, locations and wind turbines at hand.

Bottom-line, wind energy is intermittent energy. Due to the variability of wind energy, backup power must be available at all time to ensure balancing of electricity production with consumption. Back-up power should be provided two different purposes.

The first purpose is to provide energy when wind energy is not available during period of less wind or even no wind at all. As no wind periods do occur, the back up should be capable of providing full wind power for a certain period of time.

The second purpose is to provide power in case of wind ramping due to short-term wind effects. As said, for the applicable wind turbines, the time scale of the fluctuations in output needs to be confirmed.

Backup energy and power can be provided through diesel generators with sufficient flexibility or energy storage devices (batteries; small hydro pumping).

Additionally, a power management system (PMS) is needed to control the total electrical system. The PMS is basically a control system with software, real-time connected to all mayor components like the diesel generators, the wind turbines, and storage devices. It continuously balances the demand and the supply of electricity by sending commands to all connected units based upon many variables. A proper functioning communication system is key.

When increasing the penetration of wind and/or solar capacity, at a certain point the power output will exceed the demand during the day. This will open the way to shut down the diesel generators completely in order to harvest as much wind power as possible with minimum storage capacity required. As the diesel generators supply the frequency (control) of the network, this needs to be taken over. One of the main options being developed by the marketplace is the so-called grid-forming inverters (GFI)[74], which will take over the frequency control function. However, these electronic devices lack inertia and additional grid stability measures need to be taken to guarantee a stable frequency and voltage.

All aforementioned measures (storage, power management, GFI's, grid stability measures,...) induce additional costs and need to be included in the business case.

Summary

[73] *EWEA Large-scale Integration of wind Energy in the European Power Supply (Ref.9)*
[74] *IEA-PVPS 2012 "PV Hybrid Mini-Grids: Applicable Control Methods for Various Situations"*

Based upon the above and analysis of all aforementioned sources, wind energy can be regarded as a feasible and favorite renewable source of energy for the CN-islands with the following options and parameters. **These figures apply only to new wind energy to be established, not to existing capacity. Additional costs for grid extension, storage, power management systems, et cetera can be substantial and are not included. These costs have been addressed separately.**

Parameters	IRENA/DoE/ECN	Bonaire	Statia	Saba
Capacity	1 MW	1 MW	1 MW	1 MW
Capacity factor	25%	40%	35%	27%
Yearly output/ in MWh	2,200	3,500	3,066	2,365
Lifetime	15 years	15 years	15 years	15 years
Capital costs	1,450-2,450 $/kW	2,400 $/kW	2,700 $/kW[75]	2,700 $/kW
Fixed O&M costs	14-64 $/yr	54 $/kW-yr	81 $/kW-yr	81 $/kW-yr
Variable O&M costs	0.01 $/kWh	0.02 $/kWh	0.02 $/kWh	0.02 $/kWh

The costs include additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean:

- No local availability of experts in wind. Specialized staff for installation and O&M needs be brought in.
- Problematic selection of locations, especially on Saba and St. Eustatius with limited land available for any type of installation. Locations will require more than average preparatory work to make it suitable for installation of a wind park.
- As site location is difficult, it will in most cases not be found at an attractive location for grid connection. Additional grid connection costs must be taken into account as new cables will have to be laid with routing in difficult terrain;
- Difficult and complex administrative procedures with insecure decision-making. No procedures are in place for this type of installations which may result in relatively long term procedures, especially as there will be opposition against the realization of wind turbines.

[75] *Substantial additional grid extension costs to be expected*

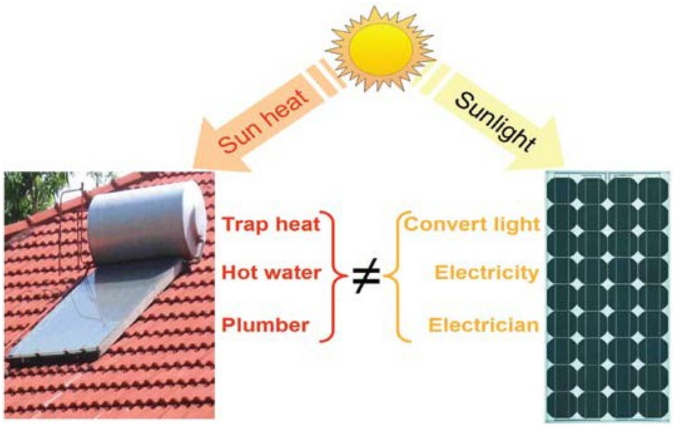
References

1. IRENA 2012 Working paper “Renewable energy technologies: cost analysis series”;
2. GWEC “Global wind statistics 2015”;
3. DoE Energy Efficiency and Renewable Energy “2013 Wind technologies market report”;
4. ECN “SDE Eindadvies basisbedragen 2016”;
5. Elsevier Energy Policy 57; Shirley & Kammen “Renewable energy sector development in the Caribbean: Current trends and lessons from history”;
6. ECN March 2015 report “ANNEX II Site assessment and technology selection for St. Eustatius and Saba, version 3;
7. KEMA “final draft masterplan Bonaire 2011-2025;
8. NWCC 2010 - Wind turbine interactions with birds, bats, and their habitats: A summary of research results and priority questions;
9. EWEA Large-scale Integration of wind Energy in the European Power Supply;
10. Bevindingen onderzoek WEB-Bonaire (project WEB Ecopower), Mazars, November 2015.

ANNEX 2: Factsheet Solar Energy

The Technology

The sun delivers its energy to us in two main forms: heat and light. Therefore there are two main types of solar power systems, namely, Solar Thermal systems that trap heat to warm up water, and solar PV[76] systems that convert sunlight directly into electricity as shown in the picture.



In case of solar thermal systems a fluid is circulated through the solar heat collectors to capture the heat and deliver it to a water storage tank. When users need **hot water**, the solar-heated water in the storage tank pre-feeds the primary water-heating system.
Such a system can be installed to provide **cooling** too. In this case the solar heat collection system transmits the energy to a refrigeration device which cools the air, providing air-conditioning. It is far less efficient to run an airconditioning system on solar PV systems.

In case of PV systems, the solar cells on a solar panel are exposed to sunlight resulting in the generation of direct current ("DC") electricity due to the charaterictics of the semiconducting materials, such as silicon. An inverter then converts the DC into alternating current ("AC") electricity, so that it can feed into one of the building's AC distribution boards. In case of large utility scale installations, large inverters feed the electricity directly into the grid.

The output of any solar energy system obviously depends on the amount of solar energy, also called solar irradiance, which in case of PV, is commonly expressed in kWh/m2 per day. Solar panels are rated accordingly, typically 250-300W so the rating represents the maximum output per day under standard conditions. Specific software using solar data and solar diagrams help determining the expected average output with optimum installation variables like orientation and tilt for the location at hand.

Solar energy is intermittent energy as it depends on the amount of sunlight, which varies in time. Besides the seasonal change in sunrise and sunset, clouding substantially influences solar energy. The electricity output of PV systems can change substantially in seconds as the photovoltaic effect reacts instantaneously to changes in solar irradiation. High penetration of PV systems thus burdens the stability of any electricity grid and requires sufficient fast balancing power.

In case of many distributed PV systems the variations of total solar output power due to clouding effects, averages out, decreasing the total need for stabilizing balancing power. However,

[76] PV stands for PhotoVoltaics: converting solar energy into direct current electricity using semiconducting material that exhibits the photovoltaic effect.

decentralized PV systems at end-user premises will decrease sales of utility companies in case of all-inclusive tariff systems. This will affect the total coverage of the network costs calling for new tariff systems addressing this issue effectively.

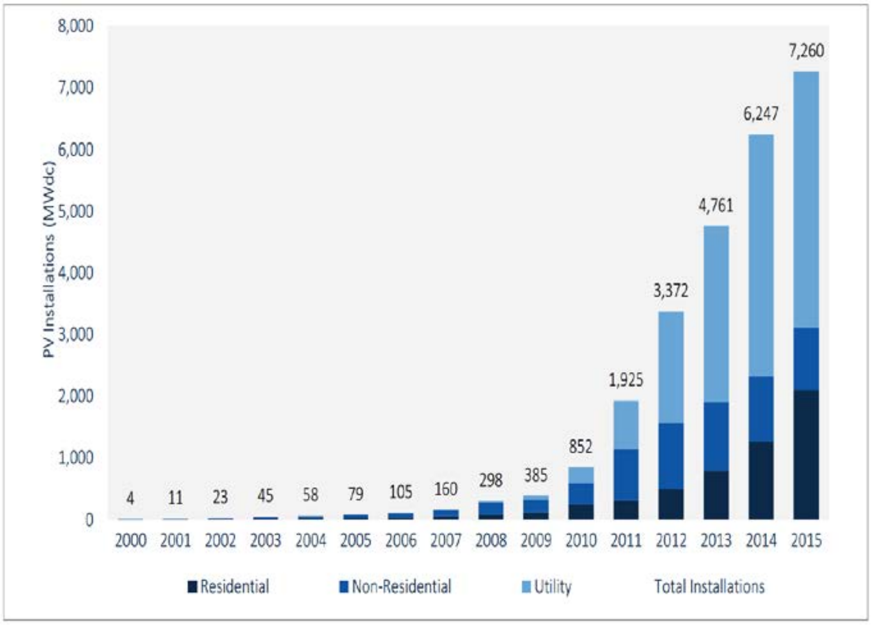
Solar technology has been globally commercialized for many years with costs reduced to a competitive level and technical support readily available everywhere. Especially PV is regarded as a key component to the energy mix of the future as it is a mature technology with decreasing cost levels, lifetime of 25-50 years with a low level of maintenance. It can be integrated with other technologies relatively easily to become part of a hybrid system.

According to the latest report of the International Energy Agency (IEA)[77] renewables are expected to be the largest source of net additions to power capacity over the medium term. China, India and Brazil and other developing countries account for two-thirds of the renewable expansion over the medium term. Solar PV is the second-largest source of new capacity (after on-shore wind) with a third of this deployment.

As the U.S. and Europe have been leading the way with regards to renewables and because they are important economic partners of the Caribbean region, their respective developments of solar energy is briefly touched in the next paragraphs.

United States

2015 was a momentous year for solar power in the United States. Solar PV deployments reached an all-time high of 7,260 MW, up 16% over 2014 and 8.5 times the amount installed five years earlier, according to the latest report of the Solar Energies Industries Association SEIA[78].
It is forecasted that 16 GW of new PV installations will come on-line in 2016, up 120% over 2015. Utility PV is expected to drive the majority of demand, accounting for nearly three-fourths of new installations.

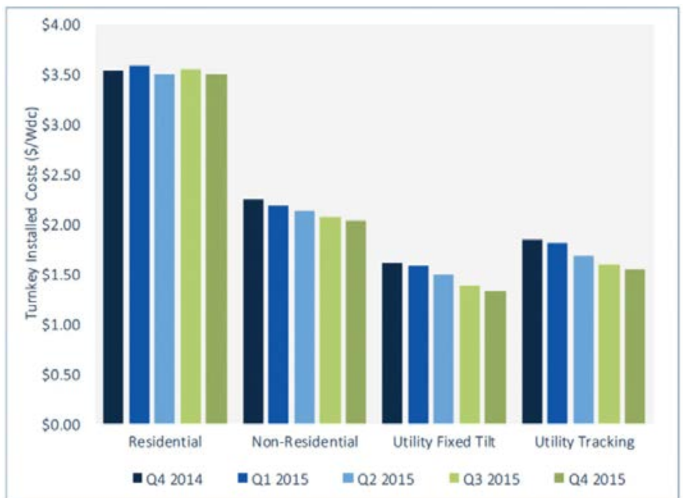


To a large extent, the steady increase of solar power is driven by a 30 percent federal tax credit for solar systems on residential and commercial properties[79]. This tax credit, recently extended to the end of 2016, is a dollar-for-dollar reduction in the income taxes that a person or company would otherwise pay the federal government, based on the amount of investment in solar property. Various additional state incentives exist and may be applicable too.

[77] *IEA Renewable Energy Medium Term Market Report 2015 (Ref.1)*
[78] *SEIA U.S. Solar market insight; 2015 year in review (Ref.2)*
[79] *http://www.seia.org/policy/finance-tax/solar-investment-tax-credit (Ref.3)*

In quite a few states in the U.S., large scale centralized PV is currently an economically competitive resource to meet utilities' peak power needs, replacing aging coal plants alongside combined-cycle natural gas plants. These PV installations are mainly built and contracted based upon a long term Power Purchase Agreement (PPA) with current price levels ranging between $0.035/kWh and $0.060/kWh. These price levels do reflect the receipt of the aforementioned federal and state incentives. Besides that, they are mainly very large-scale installations (>100MW). On top of that, PPA prices depend on the predicted output of the installation, which primarily depends on the location at hand.

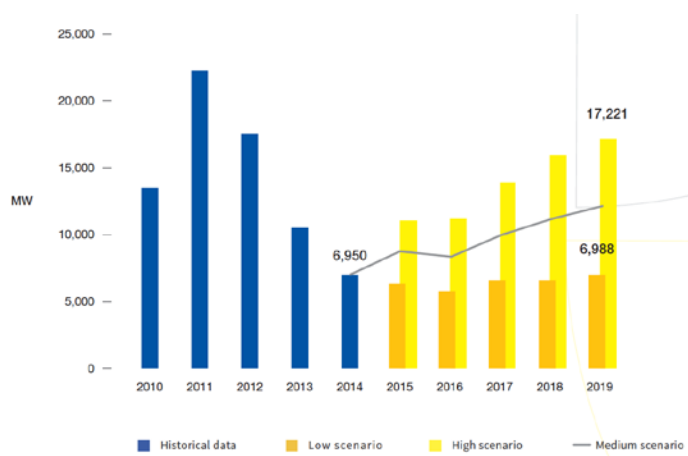
The installation costs of solar systems give a more objective view on the costs of solar, as these costs do not include any incentive program. As can be seen in the picture, residential pricing is stabilizing at $3.50/W due to decreasing hardware costs but increasing soft costs like customer acquisition. As 65% of the cost is so-called soft costs (labor, engineering, et cetera), one should be careful when benchmarking price levels with other regions. Especially the permitting and inspection procedures are considered costly.



For utility scale projects, pricing continues to trend downward, reflecting continued aggressive cost reductions, both in hardware and soft costs. Current average price levels are below $1.50/W. Due to advantages from scale, variations in utility system costs are much smaller than variations in residential solar costs.

Europe

Solar Power Europe new market report[80] shows that Europe experienced a year of growth for the first time since 2010-2011, adding 8.1 GW of solar power to the grid in 2015 - a 15% increase compared to 7 GW in 2014. After a long period of economic recession along with (even retroactive) measures with regards to incentive programs for solar, the PV market seems to revive. The base for European solar demand in 2015 derives from mainly 3 countries - UK, Germany and France. These top 3 markets counted for 75% of the connections, equal to 5.3



[80] *Solar power Europe; Global Market Outlook for solar power 2015-2019 (Ref.4)*

GW. Solar shares are high as compared worldwide, on average 4% of electricity consumption; in the most mature markets, Germany, Greece and Italy, around 8%.

PV in Europe shows a relatively highly distributed pattern due to feed-in tariff incentives in many countries. Feed-in tariffs have been steadily lowered in many European countries the last couple of years. Currently, a transition takes place from incentive based growth to new market-based frameworks. As a result, distributed PV is evolving slowly in the direction of self-consumption[81], creating maximum return on investments.

However, this drives the question of grid financing and incomes at the retail level, which is vital in several countries. For example, Spain implemented a kind of "solar tax" that is almost prohibitive for any investments in self-consumption, while countries such as Belgium are going to oblige PV end-users to contribute to grid costs for their self-consumed electricity, even from existing systems.

The installation costs differ per country due to different markets, price regimes, and incentives. Based upon a recent Fraunhofer/ISE report[82], the hardware costs for rooftop systems up to 100kW in Germany, one of the leading solar countries in Europa, have been stabilized at €1.3 /W in 2015. The total installation costs is estimated between €1.8-2.2 /W in most countries in Europe[83], far less than the installation costs in the U.S. due to substantially less administrative red tape.

O&M costs are very limited in the US and Europe. IRENA estimates these costs at US$ 6,5 per kW. However, under circumstances at the CN islands, more regular inspection and cleaning will be required due to high moisture levels and salt in the air. We therefore estimate the O&M costs for solar PV at the CN islands at US$ 15 /kW. This should be further increased with 1% insurance costs for Saba and Statia due to possible hurricanes. For Saba and Statia overall O&M is thus estimated at US$ 34 /kW.

[81] The self-consumption of solar energy refers to the proportion of energy, which is used directly in the building where a PV system is located (Ref.5)
[82] Fraunhofer Institute for Solar Energy Systems: Photovoltaics report March 2016 (Ref.6)
[83] IRENA: Renewable power generation costs 2014 (Ref.7)

As sunlight is abundant it is estimated that solar is the biggest renewable resource in the Caribbean according to a 2010 study of Nexant[84] amongst many islands including Saba and St. Eustatius. By then however, solar PV was not regarded competitive as compared to wind, geothermal and conventional diesel generation. It must be said that from 2009 onwards, global prices of solar panels dropped substantially, making solar far more competitive than before.

The 2014 Castalia overview of renewables at CREF[85] shows a totally different picture with the French islands Martinique and Guadeloupe leading the way with both >65MW solar PV connected to the grid). An increasing number of islands have either implemented or initiated solar projects. Just recently, the Jamaican Office of Utility Regulation (OUR) announced the outcome of a renewable tender including 33MW of solar energy[86]. Solar PV has established a firm position in the energy production mix of many Caribbean islands.

With regards to the Dutch Caribbean, Curacao has the most extensive regime on solar, based upon a distributed model with currently approximately 1% (700) of its end-users with grid-tied solar installations with a total capacity of about 10MW. The regime includes permitting, inspections, feed-in and grid-connection tariffs. The energy regulator[87] assumes a payback time of 8 years and adjusts the tariffs every year accordingly. The installation costs are estimated at $1.6-2.0/W ranging from small residential systems to 1MW size. Utility scale solar plants are not (yet) built as the utility company Aqualectra has given more priority to economically more favorable large-scale wind farms.

Curacao stimulates decentralized solar energy through its Policy Paper on Small Scale Sustainable Electricity Provision of 2011[88]. As part of this policy, Curacao has set a series of feed-in tariffs for the supply of electricity to the grid by small-scale, decentralized PV-installations. From 1 January 2015 the following rates apply:

Tariff group:	Feed-in tariff until 1-1-2015	Fixed tariff until 1-1-2015 per month	Feed-in tariff from 1-1-2015	Fixed tariff from 1-1-2015 per month
Residential	$ 0.235/kWh	0	$ 0.184/kWh	$ 8.95/kW
Commercial	$ 0.235/kWh	0	$ 0.184/kWh	$ 18.90/kW
Industry standard	$ 0.235/kWh	0	$ 0.184/kWh	$ 18.90/kW
Industry export	$ 0.235/kWh	0	$ 0.184/kWh	$ 8.95/kW
Industry import	$ 0.235/kWh	0	$ 0.184/kWh	$ 18.90/kW
Hospitals	$ 0.235/kWh	0	$ 0.184/kWh	$ 8.95/kW

Table 1: Curacao scheme for decentralized PV-installations

The system until 2015 resulted in a three-year payback time for residential PV installations causing a fast increase of these installations. This again threatened to make the electricity supply system unstable, or requiring investments in balancing power or energy storage systems.

[84] *Nexant 2010: Caribbean Regional Electricity Generation, Interconnection, and Fuels Supply Strategy (Ref.8)*

[85] *Castalia: Renewable Energy Island Index and Marketplace at 2014 CREF (Ref.9)*

[86] *http://www.our.org.jm/ourweb/media/press-releases*

[87] *www.btnp.org*

[88] *Policy Paper Small-scale Sustainable Electricity provisison, Government of Curacao, 2011 (Ref. 13)*

Therefore the scheme was modified in 2014, making it less attractive with now payback times of around 8 years.
Aruba's electricity distribution company N.V. Elmar[89] allows end-users to connect solar installations with limited capacity. A grid usage fee per installed kW applies as well as feed-in tariffs for excess energy. The number of installations is not known. Aruba's electricity production company WebAruba[90] operates a 3.5MW solar power plant at the airport and has recently issued an initiative to implement an additional 5MW ground-mounted solar power plant and roof-top installations on schools and public building of 2.5MW in total.

St. Maarten lags behind with solar energy as no legal, technical and/or financial regulation is in place. It is known however that at least several tens of solar installations have been built and connected to the grid.

The CN-islands have embraced solar energy just recently, each at their own pace. Statia utility company STUCO is leading the way and just commissioned a 1.89MW solar power plant in combination with storage and a power management system. Saba is executing a plan to commission a 1MW solar plant and Bonaire has installed a 250kW solar system to gain experience and determine potential next steps.

With regards to solar heating and solar cooling, the results so far are disappointing[91]. Solar Water Heater installations are steadily increasing in the Caribbean, for warm water provisioning for homes and hotels. Barbados is the leading example with over 50,000 solar water heaters installed and can be regarded as a mature market. Other investigated islands show either potential growth or emerging characteristics. The main barriers are lack of incentive programs and regulations like product certifications and installer certifications.

Solar cooling is just beginning to be recognized with regards to its potential value as cooling demand just perfectly matches the PV supply curve. No reliable and useful data is available at this point in time.

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[89] *www.elmar.aw*
[90] *www.webaruba.com*
[91] *UNEP 2014: Solar water heating techscope market readiness assessment" for multiple Caribbean islands (Ref.10)*

Environmental impact

Land use:
The main environmental impact of solar energy is related to the land needed to install the solar panels. As small islands inherently have limited land available, installing large solar installations may lead to interference with existing or planned land uses and habitat loss.

For this very reason, St Eustatius has chosen to install the existing solar panel at 2 meters height, in order to keep the land available for agricultural activities including animal grazing opportunities.

Recycling of solar panels:
Currently the recycling of solar panels faces a big issue, specifically, as there aren't enough locations to recycle old solar panels. Currently, there aren't yet enough non-operational solar panels to make recycling them economically attractive. Recycling of solar panels is particularly important because the materials used to make the panels are rare or precious metals, all of them being composed of silver, tellurium, or indium. Due to the limitability of recycling the panels, those recoverable metals may be going to waste which may result in resource scarcity issues in the future[92].

The lack of awareness regarding the manufacturing process of solar panels and to the issue of recycling these, as well as the absence of much external pressure are the causes of the insufficiency in driving significant change in the recycling of the materials used in solar panel manufacturing, a business that, from a power-generation standpoint, already has great environmental credibility.

It is expected however, that with an increase of abandoned and used solar panels; also the recycling industry will develop and realize effective recycling facilities for solar panels in order to reuse scarce and costly materials.

[92] *http://www.greenmatch.co.uk/blog/2015/01/impact-of-solar-energy-on-the-environment (ref. 12)*

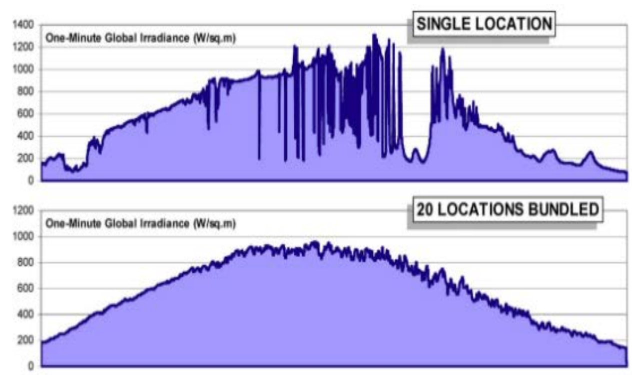
The output from solar panels obviously depends on the amount of sunlight, called sun irradiance. It shows a regular pattern with increasing output at sunrise, maximum output at solar noon and decreasing output at sunset.

However, the output will change suddenly due to clouds. Fast fluctuations in output disrupt the second-to-second balance between total electric supply and demand. Due to this variability of solar energy, backup power must be available at all time to ensure balancing of electricity production with consumption.

Back-up power should be provided for two different purposes. The first purpose is to provide energy when solar energy is not available, either during the night and early morning/afternoon, or during days with heavy clouding with reduced solar output.

The second purpose is to provide power in case of solar ramping due to short-term clouding effects. Short-term solar output variations occur on seconds scale due to the non-existence of any inertia.

Another way of addressing the effect of variability of solar power is to spread the capacity over multiple locations. A lot of research has been done by Hoff & Perez[93], showing that the relative output variability decreases as the number of PV systems increases. It eventually reaches the point where output variability is negligible relative to the total fleet capacity. The figure gives an impression what can happen with the output variability when spreading the solar capacity over 20 locations as compared to one single location. The latter shows far less variability, which results in a more predictable output. As cloud transit speeds influence the results, the effect of multiple locations will differ per case. Bottom-line, a distributed solar model is to be preferred in all cases.



In any case, either with one location or multiple locations, a certain amount of variability will remain and back-up power is needed. Backup energy and power can be provided through:

- Diesel generators, with sufficient flexibility;
- Energy storage (batteries; small hydro pumping).

Additionally, a power management system (PMS) is needed to control the total electrical system. The PMS is basically a control system with software, real-time connected to all mayor components like the diesel generators, the solar system, and storage devices. It continuously balances the demand and the supply of electricity by sending commands to all connected units based upon many variables. A proper functioning communication system is key.

[93] *Multiple publications amongst which the 2012 World Renewable Energy Forum "DISPERSED PV GENERATION: SOLAR RESOURCE VARIABILITY" (Ref.11)*

When increasing the penetration of solar and/or wind capacity, at a certain point the power output will exceed the demand during the day. This will open the way to shut down the diesel generators completely in order to harvest as much solar power as possible with minimum storage capacity required. As the diesel generators supply the frequency (control) of the network, this needs to be taken over. One of the main options being developed by the marketplace is the so-called grid-forming inverters (GFI)[94], which will take over the frequency control function. However, these electronic devices lack inertia and additional grid stability measures need to be taken to guarantee a stable frequency and voltage.

All aforementioned measures (storage, power management, GFI's, grid stability measures,...) induce additional costs and need to be included in the business case.

Summary

Based upon the above and analysis of all aforementioned sources, solar energy can be regarded as a feasible and favorite renewable source of energy for the CN-islands. The next table shows the applicable options and parameters. **These figures apply only to new solar energy to be established, not to existing capacity. Additional costs for grid extension, storage, power management systems, et cetera can be substantial and are not included. These costs have been addressed separately.**

Options / Parameters	Solar heating Residential	Solar PV Bonaire	PV Bonaire, small-scale	PV Large scale
Capacity	250 liter	1,000 kWp	5kWp	1,000 kWp
Capacity factor	-	18-20%	18-20%	18-20%
Yearly output/savings in MWh	2 – 3 [95]	1,577 – 1,752	7,9 - 8,8	1,577 – 1,752
Lifetime	20-30 years	> 25 years[94]	> 25 years[96]	> 25 years[94]
Capital costs	1,800-2,300 $	1,800 – 2,000 $/kW	2,000-2,200 $/kW	1,800-2,000 $/kW
Fixed O&M costs[97]	10-25 $/yr	15 $ /kw - yr	0-40$/kW-yr	34 $/kW-yr
Variable O&M costs[98]	-	-	-	-

[94] IEA-PVPS 2012 "PV Hybrid Mini-Grids: Applicable Control Methods for Various Situations"
[95] The savings of a solar heating installation in kWh depends substantially on the amount of hot water used.
[96] This refers to the lifetime of the solar panels only; the lifetime of the inverters is typically 10 years minimum.
[97] Fixed O&M costs for PV include inspection, cleaning, monitoring and insurance in case of large scale.
[98] Variable O&M costs are cost depending on the output in kWh like fuel or specific maintenance

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ANNEX 3: Factsheet Energy storage

General information

Electricity systems in remote areas and on islands can use energy storage to integrate renewable generation and help meet continually varying electricity production by renewable sources like solar power and wind power. Energy storage technologies vary widely in design, technological maturity and cost. There is no single best storage technology, and storage is not necessarily appropriate for all island electricity systems.

In addition to helping integrate renewables, storage can also contribute significant value by increasing the operating efficiency of diesel generators. These generators are much more efficient when operated at high load factors, and the addition of storage can significantly reduce the number of hours they operate at low or minimum load factors.

Case studies of storage applications for island and remote locations point to several lessons learned from project experiences elsewhere, including[99]:

- Pay close attention to system *design*, particularly ensuring that all system components are sized correctly and can work together.
- The more system components, the greater the complexity and challenge of system integration.
- Do not expect new technologies/pilots to be financially viable.
- Do not underestimate the transport costs, complexity and time requirements associated with getting equipment and expertise to rural/isolated locations.
- System monitoring and operation and maintenance (O&M) are critical to ensure system reliability/longevity.
- Test and debug system components *before* sending them out to rural/isolated locations.
- Diesel generator oversizing is rampant and contributes to high diesel consumption.
- It is critical to make systems financially sustainable. Even if subsidies cover first costs, operating costs (including battery replacement and O&M) will need to be covered by electricity sales/revenues or continuing subsidies.
- End-user buy-in (financially and politically) is critical

The first step when considering storage is to conduct careful analyses of the costs and benefits of storage. Storage can help integrate renewables and reduce diesel use; however it comes at a cost that must be considered. If storage is desirable, further system design analysis is needed to determine the optimal type of storage. This can be done with free or low-cost system design and analysis tools, such as the HOMER modeling system (see further).

[99] *IRENA 2012 Energy storage and Renewables for Island Power: a guide for decision makers (Ref.1)*

Storage technologies

Storage in electrical systems can take many forms. Energy can be stored in chemicals (e.g. batteries or hydrogen), as potential energy (e.g. pumped hydro or compressed air), as electrical energy (e.g. capacitors) or as mechanical energy (e.g. flywheels). Because of this diversity of technologies, the system of categorization and metrics used to compare them is abstracted from the underlying storage medium. These main metrics are:

- Energy storage capacity [kWh or Ah]
- Charge and discharge rates [kW or A]
- Lifetime [cycles, years, kWh life]
- Round-trip efficiency [%]
- Initial capital costs [$/kW, $/kWh cap, and $/kWh life]
- Operating costs [$/MWh, $/kW x yr]

Capacity

The first two metrics are related and differ substantially per technology. Storage technologies like pumped hydro, which is widely spread, can sustain high power (>100MW) for a very long time (days), whereas flywheels generally are just capable of supplying medium power for short period of time (see picture)[100].

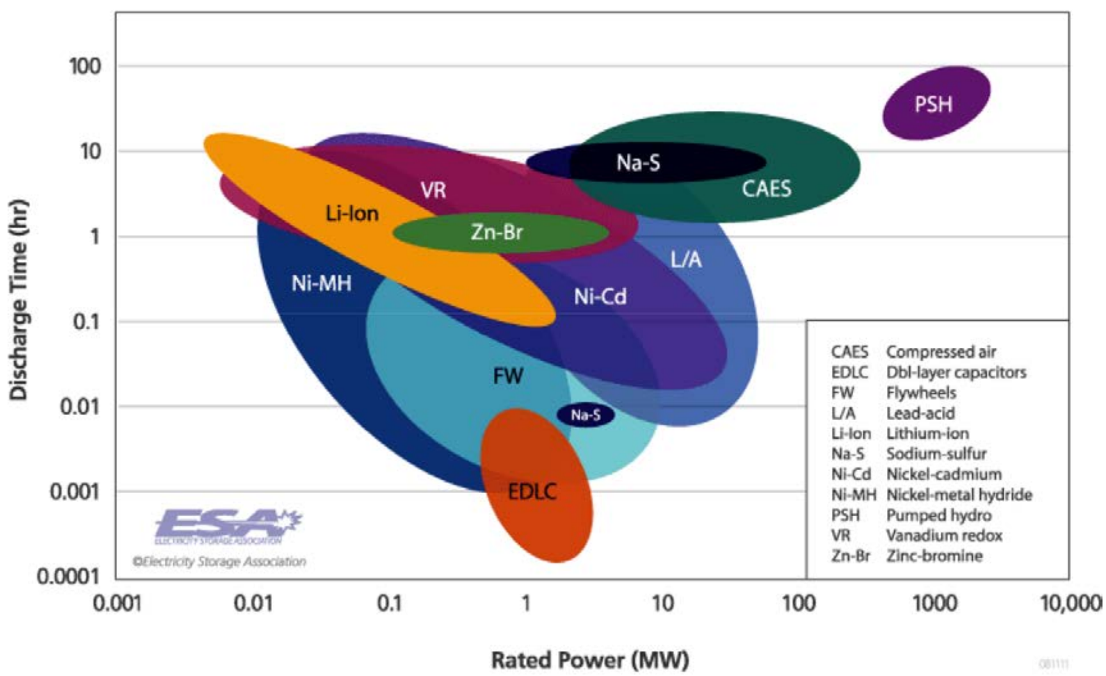
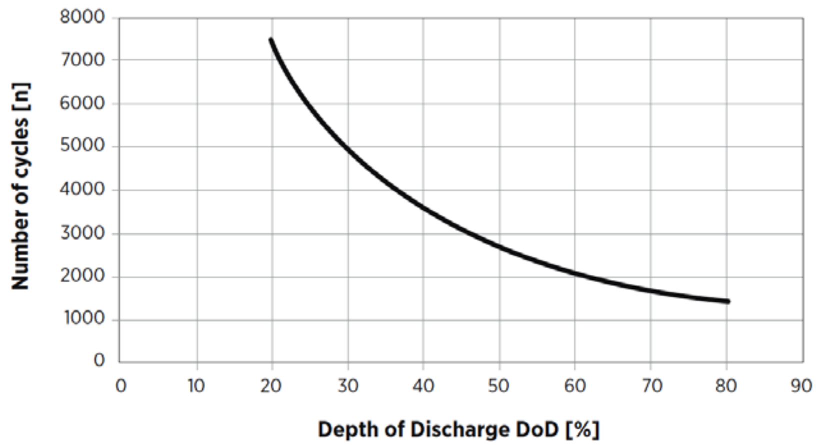


Figure 1: Storage technologies and their discharge time versus rated power

[100] *Energy storage Association (ESA)*

Lifetime

A second element to look at is the lifetime. Some technologies measure lifetime according to how much they are charged and discharged [cycles], while other technologies will lose functionality due to time passing [years] and yet others have lifetimes limited by total energy throughput [kWhlife or Ahlife]. As they age, most storage technologies will suffer from degraded performance.



For cell-based batteries, including lead-acid and lithium-ion, the expected lifetime shortens with deeper discharging the battery due to cell degradation. This means that these systems should be designed carefully as lifetime depends on the number of cycles. As the depth of discharge increases, the maximum number of cycles decreases. This can decrease lifetime substantially as can be seen in the illustrative figure.

Efficiency

Every storage technology will require more energy to charge than can be discharged. This loss of energy is typically expressed as a percentage known as round-trip efficiency [%], which is the ratio of energy discharged from storage to the energy input into storage. There will be some energy losses during the process of storing the energy and some energy losses when converting the stored energy back into electricity. These both contribute to the round-trip efficiency. Round-trip efficiency affects the costs of storage. A less efficient storage system will require more electricity to store the same amount of electricity supplied than a more efficient storage system. For example, if it costs $0.50/kWh to generate electricity and 20% of that is lost in the storage system, then the effective cost per delivered kWh is $0.625/kWh – plus the cost of the storage system.

Preferred technology

Storage technologies are undergoing rapid advancement, and there is as yet no clear winning technology, which can be selected at all times. This is partly due to the fact that different storage technologies have different applications. The selection of the right type of storage technology is not a straightforward exercise and many factors need to be taken into account, which include factors other than the aforementioned main technical metrics like space limitations or performance guarantees[101].

As rapid developments take place, many new technologies emerge. In Figure 2, some key technologies are displayed with respect to their associated initial capital investment requirements and technology risk versus their current phase of development[102]

[101] *IRENA 2015 Battery storage for renewables - market status and technology outlook (Ref.2)*
[102] *IEA 2014 Technology Roadmap Energy storage (Ref.3)*

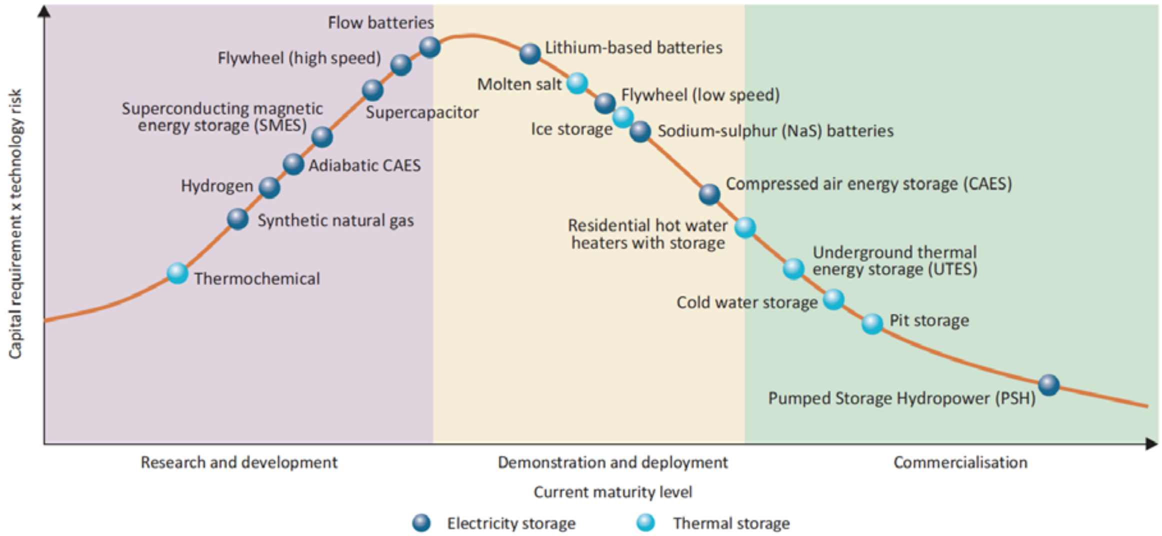


Figure 2: Storage technologies and their phase of development

It can be seen that Flow batteries are beginning to gain market acceptance at the small scale but are still considered an emerging technology, whereas Lithium-based and Sodium-sulphur batteries are at a more mature level. It must be said however that for most technologies many subcategories exist, which show substantial differences in technical metrics and also costs.

Generally speaking, a market trend can be determined. The battery storage landscape in the electricity sector is moving away from the former market concentration of sodium-sulphur batteries and has shifted towards lithium-ion batteries, as well as advanced lead-acid.

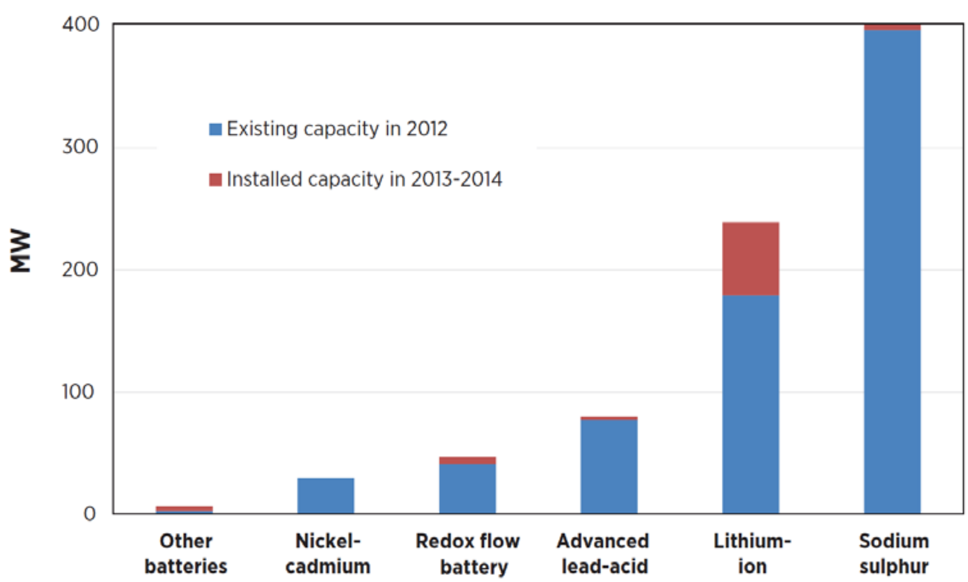


Figure 3: Comparison of Lead-Acid and Li-Ion batteries characteristics

This is depicted in figure 3. For many applications, lithium-ion has proved preferable to other chemistries with respect to energy and power density, cycle and calendar life, and cost.

Initial Capital Cost

The capital costs provided here are estimates based on professional experience and informal surveys of publicly available prices. Costs for a specific system will vary across a wide range of factors. These factors include system size, location, local labor rates, market variability, intended use of the storage system, local climate, environmental considerations and transport/access issues.

It is important to recognize that installing storage will impose additional costs, commonly called balance-of-system (abbreviated BoS) costs. These include safety equipment (e.g. fuses, current fault protection), inverters/rectifiers, system controllers, remote monitoring equipment and supplemental sensors. The needed equipment will vary considerably, depending on the specifics of the electricity system. BoS equipment can have a large impact on the total system cost, ranging anywhere from 100% to 400% more than the costs of the storage technology alone[103].

The principal price bases for comparing technologies are the prices per amount of power that the storage can deliver [$/kW] and costs per amount of energy capacity [$/kWh cap].

When looking at costs, it is also important to consider the expected lifetime of the technology because frequent replacement will increase costs of the storage system. To capture the entire lifetime cost, the capital cost of the battery is divided by the total expected lifetime energy throughput [$/kWh life]. The lifetime cost of storage provides insight into the cost of storing a kWh of electricity and indicates the expected additional cost for each unit of electricity stored. The costs do not include site-specific factors such as tariffs, taxes and shipping costs.

Operating Costs

Technologies require ongoing operation and maintenance to remain at peak performance. In reality, a number of factors will influence ongoing O&M costs, including how often the storage equipment is used, ambient temperatures, handling of the equipment, adherence to the recommended maintenance schedule, quality of installation, protection from overcharging, protection from over-discharging, the rate at which the equipment is cycled and the quality of the storage equipment.

For simplicity, all of these factors are generally bundled in a typical annual cost based on the size of the equipment [$/kW x yr].

Cost estimates

Table 1 shows cost estimates from IRENA in 2012 for most relevant storage technologies[4]. It also includes some of the aforementioned key metrics as lifetime in years and amount of cycles. The price bandwidths are relatively high, especially for Lithium-ion batteries. It must be emphasized

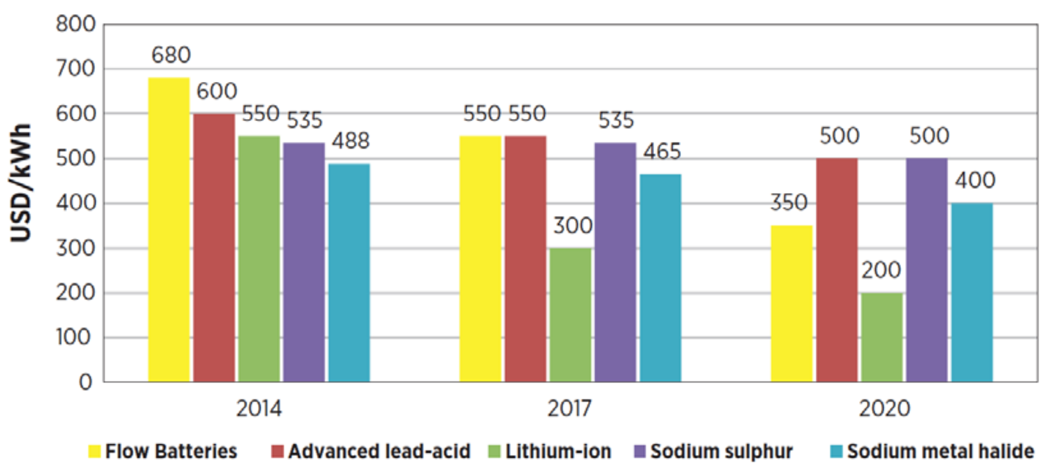
[103] *IRENA 2012 Energy storage and Renewables for Island Power: a guide for decision makers (Ref.1)*

that these cost do not include aforementioned BoS costs, which can be substantial and double the costs (or more).

	Lead-acid batteries	Li-Ion batteries	NaS batteries	Flow batteries	Fly-wheels	Pumped hydro	Large-scale CAES
Applicable grid system size [kW/MW]	≤10 MW	≤10 MW	≥100 MW	25 kW–10 MW	100 kW–200 MW	Mostly ≥200 MW	≥500 MW
Lifetime [years]	3–10	10–15	15	Cell stack: 5–15; Electro-lyte: 20+	20	25+	20+
Lifetime [cycles]	500–800	2,000–3,000	4,000–40,000	Cell stack: 1,500–15,000	>100,000	>50,000	>10,000
Roundtrip efficiency [%]	70%–90%	85%–95%	80%–90%	70%–85%	85%–95%	75%–85%	45%–60%
Capital cost per discharge power [$/kW]	$300–$800	$400–$1,000	$1,000–$2,000	$1,200–$2,000	$2,000–$4,000	$1,000–$4,000	$800–$1,000
Capital cost per capacity [$/kWh$_{cap}$]	$150–$500	$500–$1,500	$125–$250	$350–$800	$1,500–$3,000	$100–$250	$50–$150
Levelised cost of storage [$/kWh$_{life}$]	$0.25–$0.35	$0.30–$0.45	$0.05–$0.15	$0.15–$0.25	N/A	$0.05–$0.15	$0.10–$0.20
Annual operating costs [$/kW-yr]	$30	$25	$15	$30	$15	$5	$5

Table 1: Technical and cost data for energy storage technologies

As can be seen in figure 4, coming from the 2014 IRENA pricing schedules[104], particularly prices of Lithium-ion batteries have decreased and are expected to decrease further the next couple of years.



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[104] *IRENA 2015 Battery storage for renewables - market status and technology outlook (Ref.2)*

Figure 4: Technical and cost data for energy storage technologies

Price levels of other storage technologies have decreased (far) less as compared to Lithium-ion. Flow batteries are expected to show lower price levels in the near future. Bottom-line, price levels are volatile and need to be monitored closely, being one of the (key) factors when selecting a storage technology.

Key elements of storage in small island electricity grids

Small island electricity grids have a relatively low demand. When intermittent renewables like wind or solar, are implemented, it will easily lift the renewable penetration to substantial level as compared to the daily peak.

It is generally accepted that penetration levels up to 20-25% can be reached without any additional measures to be taken. Above that level, measures will most likely be necessary to address the following issues:

Intermittency causing output variability

The output variability can be categorized as a) short-duration or b) long-duration. Short duration variability – lasting a few seconds to many minutes – is caused by wind speed variability, sometimes involving significant moment-to-moment variations, and rapid fluctuations of solar energy due to clouds, generally called ramping. Storage can be used to address short-duration. In this case high-power, limited-energy storage capacity is needed, depending on the expected amount of ramping.

Time-related mismatch between generation and demand

Storage is also well suited to address intra-day and possibly day-to-day variability. A significant portion of wind generation output occurs at night when demand is low. With storage that “off-peak” energy from wind generation can be stored and used during the day. With high solar penetration, peak power which otherwise would be curtailed, can be stored to be available to serve demand as the solar generation is falling off during late afternoon. Both examples prevent curtailing wind- or solar energy at high penetration levels. In these cases limited-power, high-energy storage capacity is needed.

Energy storage installed in the Caribbean

As renewables are being implemented in the Caribbean step by step, the need for storage become apparent also. The U.S. Department of Energy (DoE) has setup a Global Energy Storage Database, which provides up-to-date information on grid-connected energy storage projects. The recorded storage facilities in the Caribbean are listed in table 2[105]:

Nr.	Country	Technology	Rated Power in kW	Status
1	Antigua and Barbuda	Flow Battery	3,000	Operational
2	Aruba	Compressed Air Storage	1,000	Contracted
3	Aruba	Flywheel	5,000	Contracted
4	Bonaire	Nickel based Battery	3,000	Operational
5	British Virgin Islands	Electro-chemical	1,000	Under Construction
6	Haiti	Electro-chemical	100	Under Construction
7	Haiti	Lithium-ion Battery	200	Operational
8	Haiti	Lithium-ion Battery	500	Under Construction
9	Martinique	Sodium based Battery	120	Operational
10	Martinique	Lithium-ion Battery	2,472	Operational
11	Puerto Rico	Sodium-ion Battery	250	Operational

[105] http://www.energystorageexchange.org

Table 2: DoE Global Energy Storage Database Caribbean

Table 2 shows a very limited amount of storage facilities, only 6 out of the 11 installations are recorded as operational. The recently installed and operational 1,400 kW Lithium-ion storage facility in St. Eustatius is not yet recorded in aforementioned list.

This overview, although it might not fully represent the current installed storage capacity in the Caribbean, shows that storage is still very limited in the Caribbean and will, given the expected growth of renewables, be subject to increasing implementation. Tender procedures for 5MW storage facilities for both Guadeloupe and Martinique are already being executed.

Model island simulation

To illustrate the potential role and added value of storage systems in small island electricity grids, a fictional island has been modeled and analyzed by IRENA[106], which will be par presented in the following paragraphs.

It must be said that this simulation and analysis are based upon assumptions, which will be different for the individual CN-islands today. Specifically the cost levels used do not reflect current pricing levels. It is therefore meant for illustrative purposes only in order to show the potential effects on the business case of adding solar and storage facilities to a fully diesel-operated production system.

The HOMER modeling system, which is emerging as the international standard for modeling of smaller and distributed renewable electricity systems, is used. HOMER[107] is an electricity system design tool that chooses an optimal mix of generation resources from a user-defined set of choices and provides as outputs capital and operating expenses. The results shown here are for a typical, or representative, small island electricity system. However, these results may not be applicable to all such systems. Costs, insolation (sunlight) levels, electricity demand, load shape and other variables vary across systems, and their values affect how renewables and storage interact and perform.

For this analysis, a fictional island located was created in the Caribbean, near Puerto Rico. The electricity system on this island serves 1,000 households, each with an average electricity demand of 500 watts, totaling 500 kW residential average demand. The island also has a comparably sized commercial and industrial average demand of 500 kW. The load factor is 0.37, meaning that the total *peak* demand is 2.7 MW. The daily load shape follows typical working hours with a midday peak. For a base case, it is assumed that a single diesel generator serves the island, with a peak rated output of 3.5 MW.

It is assumed that this diesel generator costs $250/kW. Furthermore, it is assumed that diesel fuel is available at a price of $1/liter. The efficiency of this diesel generator rises sharply with load, which is typical of diesel generators. The final critical assumption is that electricity supply always equals or exceeds demand.

To demonstrate the potential roles of storage and renewables, the island is then modeled with several alternative electricity generation scenarios:

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[106] *IRENA 2012 Energy storage and Renewables for Island Power: a guide for decision makers (Ref.1)*

[107] *http://www.homerenergy.com*

- Generator plus storage;
- Generator plus PV;
- Generator plus PV plus storage; and
- PV plus storage (100% renewables).

The results of these scenarios are summarized in Table 4. Note: "Renewables fraction" is defined as the fraction of annual electricity consumption that is provided by renewable sources. Storage is 7.6 kWh capacity lead-acid batteries, $2,000 each. The storage cost estimate includes balance-of-system costs. The levelized cost of electricity assumes a 6% real interest rate and reflects only generation costs.

There are several interesting implications of these results. These are best explained by discussing each scenario individually.

Generator + Storage. Adding storage increases the first cost significantly (i.e. an additional $2 million in this example). However, it also allows for a 25% reduction in diesel use. It does so largely by allowing the diesel generator to operate at higher loads (and thus higher efficiencies) and to switch off entirely when loads are low. In this scenario, the generator was able to reduce its run time from 8,760 hours/year (24 hours/day, 365 days/year) to 5,568 hours/year (an average of about 15 hours/day). Note that the levelized cost of electricity for this scenario is quite a bit lower than for the base case because the diesel savings more than outweigh the additional first cost of storage.

Generator + PV. This relatively small PV system did reduce generator run time, but mostly during midday, when demand was high, thus aggravating the inefficient-at-part-load problem with diesel generators. Diesel savings were modest and levelized cost increased. PV as a supplement to a diesel generator without accompanying storage is unlikely to be a financially attractive choice although it may be worth considering as an interim step to become familiar with the PV technology.

Generator + PV + Storage. This scenario has a very high first cost, but it cut diesel consumption by 50% and thus had the lowest levelized electricity cost. This is because the PV and the storage were able to work together such that the generator operated either at high output levels or shut off entirely. This is a technologically complex system, as it would require a sophisticated controller and software to optimize operation of the PV and storage. Nevertheless, as shown in Table 4, it can be cost effective from a long-term financial perspective.

PV + Storage. This system has both the highest first cost and the highest levelized cost. This is because a very large PV system (7 MW) and storage system (12 MW) is required to ensure system reliability. This nicely points out the challenges in going to a 100% renewable system. One needs to oversize the system significantly or allow for the possibility of occasional generation shortfall.

The results summarized above lead to several key findings:

- Diesel generators have very low first costs but high operating costs. Although alternative systems using storage and/or renewables can have lower levelized costs, as discussed above, implementing these systems requires finding the upfront capital to cover the higher first costs.
- Storage should be considered as a supplement to pure diesel systems, even without renewables. As discussed above, storage can allow diesel generators to operate at much higher efficiencies and to switch off entirely when appropriate. The diesel savings can more

than outweigh the higher first costs of the storage. It also prepares the system for integrating renewables later.

- Small amounts of renewables added to diesel-based systems are generally not a cost-effective option. This is because some renewables, notably PV, aggravate the low-load inefficiency of diesel generators.
- Combining diesel generators, renewables and storage can be the lowest cost option, based on levelized cost. However, such systems are complex and technologically sophisticated. It is suggested to add new technologies one at a time, rather than all at once.
- Pure renewable systems, particularly based on PV, can be very expensive, and they will need to be oversized to meet electrical needs throughout the year.

Scenario	Generator (kW)	PV (kW)	Storage (kW)	First cost ($1000)	Diesel use (mill. liters/yr)	Levelised elec. cost (¢/kWh)	Re-newables fraction
Gen Only	3,500	0	0	875	4.0	53.9	0
Gen+Strg	3,500	0	1,000	2,875	3.0	42.6	0
Gen+PV	3,500	500	0	3,375	3.9	55.0	0.10
Gen+PV+Strg	3,500	2,000	2,000	14,875	2.0	42.4	0.28
PV+Strg	0	7,000	12,000	59,000	0.0	68.4	1.00

Table 3: Results of adding storage to island electricity grids

Summary

Based upon the above and analysis of all aforementioned sources, energy storage can be regarded as a feasible and favorite technology for supporting renewable penetration. Price levels however are volatile with a downward trend and need to be monitored closely.

Based on the marketdriven position of large-scale Li-Ion batteries and its (predicted) price decreases, a basic price level of $500/kWh can be assumed with a mark-up for ancillary equipment, transport and implementation.

References

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2. IRENA 2015 Battery storage for renewables - market status and technology outlook;
3. IRENA 2014 “Technology roadmap energy storage”;

ANNEX 4: Factsheet Geothermal Energy

Geothermal energy technology

Geothermal energy is a continuous source of energy, unlike the variable renewable energy sources of wind and solar. Since the heat is trapped inside the earth, it is not depleted. With the high world oil prices (until mid-2014) and the oil and gas emission concerns, geothermal energy is generating greater interest everywhere. Geothermal heat was recognized first by the hot springs ancient cultures enjoyed at various hot spots around the world. Its capability to produce electricity came to light almost a century ago thanks to Italian Prince Piero Ginori Conti. Since then, as technology and understanding increased, two specific methods of creating energy have enabled people to generate both heat and electricity.

Geothermal heat is found at depths from 2,000 to 4,000 meters in water layers with water temperatures ranging from 100 to 300 degrees Celsius. This heat can be used directly when hot water or heating of buildings or processes is required but can also be used to generate electricity. Efficiency of electricity generation increases with water temperature. The technology used for geothermal energy is similar to oil drilling and production, combined with electricity production based on heat.

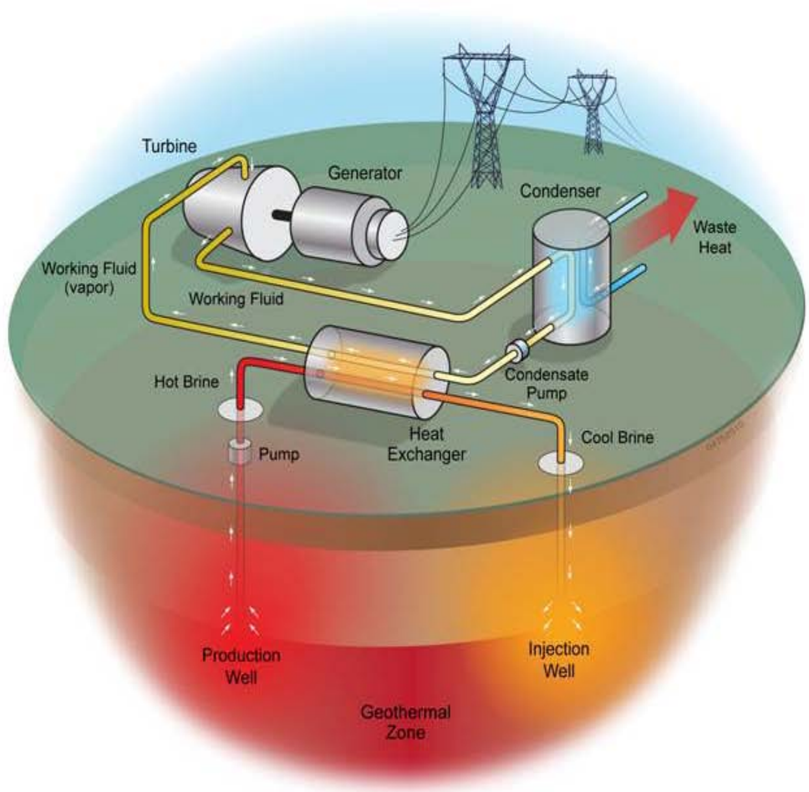


Figure 1: Schematic of a typical geothermal power plant

In general a geothermal electricity production plant will have the following main elements:

- Two wells, one for production of hot water and the other for injecting this water back to the same aquifer;
- Heat exchangers to transfer the heat to a working fluid that will drive the turbine;
- A turbine driven by the vaporized fluid that will drive an electricity generator;
- Power management and control systems.

Research and exploration activities in different Caribbean islands have shown the availability of suitable aquifers at depths between 2,000 and 3,000 meters, producing hot water at temperature levels between 200 and 300 degrees Celsius. These are favorable temperature levels for electricity generation[108].

[108] *Guidebook to Geothermal Power Finance, National Renewable Energy Laboratory, 2011 (Ref.1)*

General cost estimates

There are several phases between exploration of potential resources and construction of a power plant. Figure 2 shows the estimated development costs for a typical geothermal power plant. As shown in Figure 2, the upfront activities of Resource Identification, Resource Evaluation, and Test Well Drilling account for approximately 13% of the overall cost; these costs are nonetheless significant because they are risky activities (i.e., subject to dry holes) and, as a result, have high financing costs. The remainder of the capital investment (87%) comes in the later phases of drilling and construction.

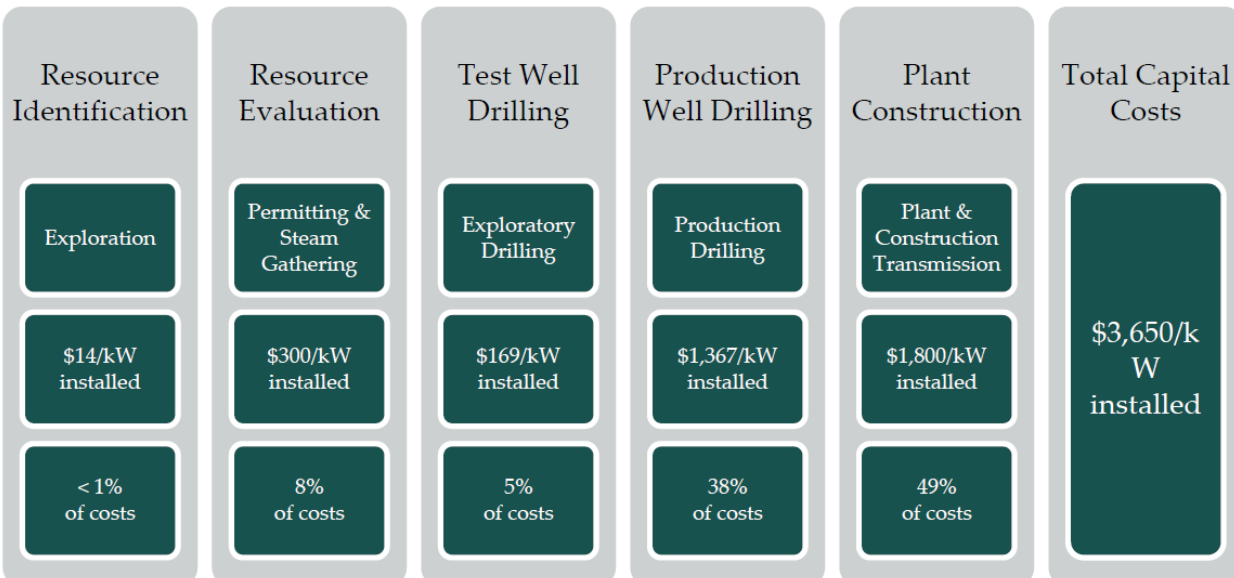


Figure 2: Sample costs per development stage of a geothermal plant of 50 MWe

The project costs presented in Figure 2 are location-specific and can vary significantly from one site to another. Costs depend on resource temperature and pressure, reservoir depth and permeability, fluid chemistry, drilling market, size of development, number and type of plants (dry steam, flash, binary or hybrid) used, et cetera.

The above costs are for geothermal plants in the US and Europe. The preparatory and development costs for similar facilities in the Caribbean will be considerably higher. The above cost estimates have been prepared for a 50MWe geothermal power plant. A smaller plant, less than 10 MWe or in the range of 1 – 2 MWe will be much more expensive. We expect investment costs for a 2 MWe geothermal power plant to be in the range of US$ 7,000 to 10,000 per kW, especially as there will only be a minor reduction in the costs of exploration and production drilling. The breakdown of costs among the various stages of project will also vary by site.
The lifetime of the upper ground facilities will be 20 to 30 years under normal conditions. The lifetime of the production and injection wells will depend on seismic activity and forms a risk, especially as these wells form a very important share of the overall investment costs[109].

[109] *Guidebook to Geothermal Power Finance, National Renewable Energy Laboratory, 2011 (Ref.1)*

Geothermal power plant Operation and Maintenance costs (O&M)

There are few publications presenting data on O&M for geothermal power plants. We expect these costs to be in the same range as O&M costs for OTEC facilities, as the technology for electricity production are similar, although at higher temperatures and with more corrosive brines from the underground aquifer. We estimate yearly O&M costs at 2.5% of total investment costs e.g. US$ 200/kW.

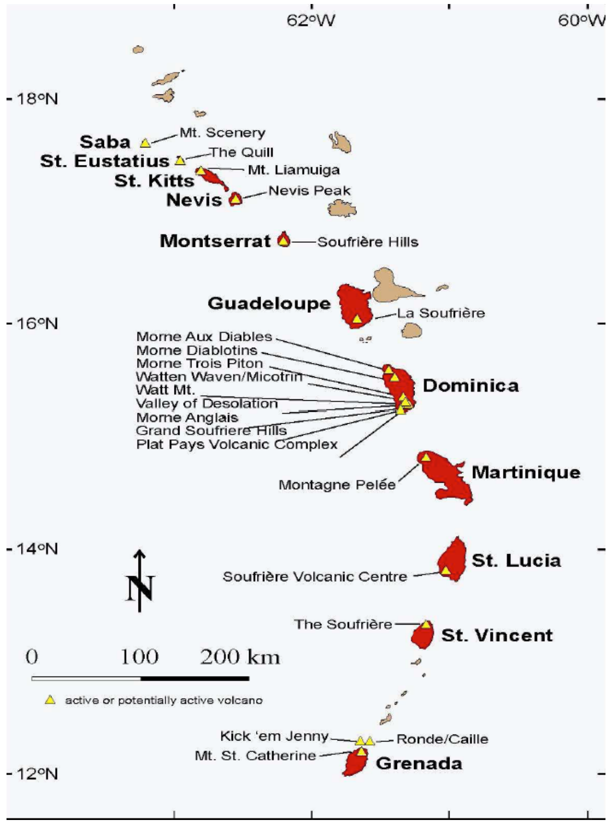
Barriers for the development and implementation of Geothermal Energy

There are several reasons why, in the past, there has been little geothermal project initiation in the Caribbean region:

1. The very small power demand in these nations;
2. The very high, marginally economical cost of undertaking projects small enough to sell all their power to the local utilities, and
3. The third problem is that there are few laws, regulations, or rules in place in these nations that will facilitate the licensing, permitting or creation of geothermal power sales agreements in the islands.
4. Finally, there is little technical or legislative capacity on these islands and commonly, responsible capacity that has been built is lost due to administrative change and replacement of personnel.

The variable (usually rising) costs of power caused by changing international oil prices have made even small sized geothermal developments more attractive. In, Nevis, Dominica, and St. Lucia there has been on-going work to clarify geothermal laws, rules and regulations. Most importantly, the successful 2008 drilling on Nevis and the 2013-2014 drilling on Dominica has attracted the attention of Multilateral Investment Banks and other international governmental entities whose financial and technical assistance may serve to decrease the perceived risks of early stage exploration and thus entice more private developers into the region[110].

[110] *Country update for Eastern Caribbean Nations, 2015 World Geothermal Conference (Ref.2)*



The Lesser Antilles island arc extends 850 km along the eastern edge of the Caribbean Plate. Volcanos above a subduction zone have largely built the islands of the arc, as the Atlantic Plate is being subducted under the Caribbean Plate. According to the Seismic Research Unit of the University of the West Indies there are 19 potentially "active" volcanoes in the Lesser Antilles, six of which have erupted in the past 400 years. Eleven volcanoes have either:

– had severe earthquake swarms
– had associated surface hydrothermal activity
– have deposits dated within the past 10,000 years
– have experienced all of the above

At the World Geothermal Congress 2015, Huttrer and Lafleur presented a geothermal update for Eastern Caribbean Nations[111]. Since 2010, geothermal exploration and negotiations for the rights to explore have increased in the region. Following the drilling of three successful slim holes in Nevis, the Nevis Island Administration signed a contract and a power purchase agreement with West Indies Power Holdings (WIPH). Also in 2010, the government of Dominica and Icelandic Drilling, Inc. initiated the drilling of three exploratory slim holes in the Wotton Waven district while in St. Lucia, the government signed a Memorandum of Agreement with UNEC Corporation for exploration and development in the Sulphur Springs region.

Below, a summary overview is presented of the geothermal exploration/development activities on nine Caribbean islands:

Dominica

The likely presence of geothermal resources beneath Dominica is suggested by a boiling lake, numerous boiling hot springs, several large solfataras and very recent (<500 years old) volcanic activity. There are at least 5 geothermal centers, of which two (Wotten Waven and Soufriere/Galion) appear to have the best prospects for early development.

In 2013, the Government of Dominica, with EIB assistance of € 1.1 million, sponsored the drilling of three slim exploration holes in the Wotton Waven area. Temperatures above 235°C were recorded in these wells and in 2014 the first of three planned production wells were drilled with similar temperatures encountered at a depth of just over 1,500 meters. Mid 2015, drilling has officially come to an end and the project is now a new stage of plant construction. The government has spent over $80-million in exploring the island's geothermal potential so far.

[111] *Country update for Eastern Caribbean Nations, 2015 World Geothermal Conference (Ref.2)*

Plans are reported to build a 10-15 MW power plant. The first small plant, which will supply Dominica with electricity, is expected to be commissioned by 2017, although delays are reported, caused by the devastating tropical storm Erika.

Montserrat

Even before the 1995 eruptions, the southwestern flank of the Sufriere Hills volcano was the site of solfataric activity and of numerous thermal springs. There was also significant seismic activity along several well-developed fracture systems that transect the island.

The UK Department for International Development initiated a number of studies and projects for the development of a 3 MW geothermal electricity generation facility at Montserrat. Activities started in 2010. The geothermal potential was studied prior to and following the most eruptive phase and this led to the drilling of two exploratory wells in excess of 2,350 meters deep by the Icelandic Drilling Company under contract of the UK Department for International Development. Temperatures of 298^{o}C were recorded and present (2014) plans are to build a 3 MW power plant. Recently UK DfID funded phase 4 of this project with an additional amount of GBP 12.9 mln. Total costs of all four phases amounted to GBP 27.6 mln for all technical and economic studies, drilling of wells and realization of the electricity generation plant including grid connection. Total investments thus were US$ 23 million e.g. US$ 7,700 /kW. As most of the drilling has been completed, the location has been prepared including additional infrastructure like roads, cabling and site preparation, this price level seems to be a realistic estimate for geothermal development in the Caribbean (ref.3).

For smaller facilities, the specific costs per kW will be somewhat higher, e.g. US$ 8,500 per kW.

Nevis

On Mt. Nevis' northwestern, western and southwestern flanks, there are two solfataras (Farms and Cades), numerous thermal wells (Charlestown and Browns), and a large area of hydrothermal alteration (Belmont). Also, strong earthquakes with hypocenters very near Nevis occurred in 1951 and 1961. The 1951 seismic event caused small fumarolic areas to develop in the Spring Hill Fault Zone in the northwest part of the island. There are encouraging geothermal indicia in at least 5 places on the island so that exploration should be focused and relatively inexpensive. (Huttrer, 1998).
Based on the data acquired to date, the hydrothermal system on Nevis is believed to have the potential to support power generation of 45 MW, adequate to meet the demand of both Nevis and adjacent St. Kitts. The Commonwealth would then have the potential to become the first totally geothermally powered country in the world. In 2008, West Indies Power Company drilled three small diameter exploratory wells about 3.7 km apart, to depths ranging from 782 to 1,134 meters in the Spring Hill, Jessups, and Hamilton Estates areas. All three wells encountered temperatures in excess of 225^{0}C and significant steam was produced. Geothermometric projections suggest reservoir temperatures of at least 260^{0}C. (LaFleur and Hoag, 2010).
In November 2013, Nevis Renewable Energy International was selected by the Nevis Island Administration to replace West Indies Power as the resource developer. This firm plans to build a 5-10 MW power plant to generate electricity for domestic use and, if possible, to export power to nearby St. Kitts. At this time, West Indies Power Company is challenging the right of the government to reassign the project.

St. Lucia

Geothermal indicia on St. Lucia comprise a very large solfatara near the village of Soufriere, thermal springs nearby, and very recent (<1000 years ago) volcanic activity including both phreatic and pyroclastic eruptions. Geothermal drilling conducted in the 1970's and 1980's disclosed the existence of a shallow (<700 meters deep) steam zone and of a hot (230ºC) resource at moderate depths. Unfortunately, the fluids produced from the latter zone were acidic and are therefore very chemically aggressive. The 1980's drilling also showed that there are areas of hot dry rock down to ~2 km and that the geology of the prospective area is far more complex than previously believed.

UNEC Corporation currently has a Memorandum of Understanding with the government for development of the Sulphur Springs resource, but, lacking funds with which to proceed they have been negotiating with a highly experienced international developer to take over their responsibilities and opportunities. In 2013 and 2014, geothermal experts employed by the World Bank conducted field visits to the Qualibou Caldera and have created a "Roadmap" document meant to guide the Government in its quest to speed up geothermal development.

St. Vincent

La Soufriere volcano has erupted three times since 1902, there is a steaming resurgent dome in the crater, and there are numerous hot springs in the Wallibou River valley on the western side of the volcano. Exploration will be difficult and expensive; however, the discovery of a geothermal reservoir could eventually bring financial rewards as there is a significant and growing demand for power on the island. (Huttrer,1996). In 2013, negotiations with the government and with VINLEC (the national electric utility) were begun by Reykjavik Geothermal seeking acquisition of exploration and development rights.

As of April 2014, geo-scientific fieldwork is reportedly underway, production well drilling is expected to begin in late 2016/early 2017 with power – in theory – to be delivered by 2018. A public private partnership, the St. Vincent Geothermal Company Ltd, comprised of the St. Vincent government, Emera Caribbean, and Reykjavik Geothermal, has been formed to enable the project.

Saba

Saba is a small island comprising a central volcano with at least 15 andesitic domes on its flanks and a prominent NE-SW trending fracture system that bisects the island. There is a record of volcanic eruption(s) less than 1000 years ago and there are numerous hot springs along the shoreline and just offshore. The islands volcanic carapace is highly fractured with some hot spring temperatures having risen within the last 45 years. (Huttrer 1999). West Indies Power signed agreements with the Government of Saba in 2008 and conducted some surface geo-scientific studies. To date, the results have not been made public, but plans were announced to drill exploratory wells and to construct a power plant. Activities came to a stop when transition from Netherlands Antilles to a special municipality was initiated.

According to the 2012 TNO desk study, Saba is located in a geologically active area. Numerous natural seismic events and hot springs observed on and close to the island imply that Saba is located on a geothermal potential area. The current probability of success (PoS) for geothermal energy is estimated at 21%, based on expert judgment. In order to increase the PoS, a geological exploration and analysis needs to be done, which would approximately cost 0.2-0.4 million euros.

A positive outcome of this analysis study will increase the PoS to about 70%, or demonstrate that geothermal energy is not a feasible option for renewable energy generation at Saba. The TNO cost estimate for a 2 MW geothermal power plant is € 10 million, € 5,000/kW. The TNO study includes all costs directly related to the geothermal power plant.

In case a geothermal power plant would be operated for Saba only, the TNO report calculates the (levelized) costs at 0.23-0.30 euro / kWh.

A combination with St. Eustatius would result in even higher costs per kWh due to the required sub-sea power cable, estimated at 27 mln Euros, and is not considered a viable option.

A combination of Saba with St. Maarten could lead to a 31 MW power plant, according to the report. The sea-cable is estimated at 33 mln Euros. Taking advantage of the scale, this would result in far lower (levelized) costs of 0.11-0.15 euro/kWh[112].

TNO prepared the cost estimate for the specific investments directly related to the development and realization of the geothermal power plant: slim and exploration well drilling, power plant construction etc. A number of other costs like site preparation, infrastructure development, environmental costs and grid connection costs were not mentioned. As the UK example for Montserrat shows, these costs may have a significant impact on overall realization. For the purposes of this study we estimate the realization costs for a 2 MW geothermal power plant to be higher, see next chapter.

St. Eustatius (Statia)

While some heat probably remains beneath The Quill as evidenced by reported occurrences of thermal water in two wells drilled for drinking water, there are no known hot springs or paleo-thermal areas on the island (Huttrer, 1999). Geothermal development interest on Statia has not been evidenced in the past 5 years.

According to the 2012 TNO study, the Quill shows no visible apparent fault zones like on Saba. It is very likely that they are covered by volcanic and marine deposits. The Quill on St. Eustatius is a young volcano and drilled water wells show some increased water temperatures towards the vent of this volcano. This suggests that infiltrated rainwater has been heated. As no detailed analysis of geothermal phenomena or natural seismicity data is available, this does not imply that there is no geothermal potential on St. Eustatius. Therefore, geothermal exploration is essential to further mature a business case. The most obvious area to explore for geothermal resources would be near the Quill.

[112] *Geothermal potential on Saba, TNO, 2012 (Ref.4)*

Economics

California Energy Commission (CEC) 2007 estimates place the levelized generation costs for a 50 MW geothermal binary plant at US$92 per megawatt hour, which over the lifetime of the plant can be competitive with a variety of technologies, including natural gas[113]. It will certainly be competitive with small-scale diesel generators.

An update of the CEC prepared by KEMA estimates the investment costs for geothermal power plants at an average of US$ 4,046 (high estimate: $ 5,948, low estimate: $2,353[114]).

On average the cost for new geothermal projects ranged from 6 to 8 cents per kilowatt-hour according to a 2006 report. It should be noted that the cost for individual geothermal projects can vary significantly based upon a series of factors discussed below, and that costs for all power projects change over time with economic conditions.

The above cost estimates relate to projects realized in the US or Europe where proper infrastructure is in place, equipment is available together with the required experienced staff.

The levelized generation costs for a much smaller geothermal plant of e.g. 2 MW in the Caribbean region, will be considerably higher.

From the UK Montserrat geothermal project, we expect the investment costs to be in the range of US$ 8,500 per kW, which is almost double the specific investment costs for similar plants in the US or Europe.

The levelized kWh costs are expected to be in the range of US$ 0.18 – 0.22 per kWh which can still be competitive with the fuel costs of diesel power plants at Caribbean islands including Saba. A geothermal plant will in fact replace the diesel power plants, as geothermal electricity is a very reliable and adjustable power source, nevertheless diesel generators as backup will be required during maintenance of the geothermal plants and to take over during accidental power interruptions. Lifetime of these diesel generators will be increased significantly as their operational time will be reduced substantially. A 2 MW power plant can produce up to 17 GWh per year.

[113] *Comparative costs of California Central Station Electricity Generation Technologies, CEC, 2007 (Ref.6)*
[114] *Renewable Energy Cost of Generation Update, CEC by KEMA, 2009 (Ref.7)*

Environmental impacts

The realization of a geothermal power plant has a series of more and less significant environmental impacts during the different phases of preparation, drilling and operation. The most relevant environmental issues are summarized as follows[115]:

- Site preparatory work and infrastructure: transport activities and site clearing together with road enforcement. This will result in transport related emissions and wastes from infrastructure works;
- Accidental discharge of drilling fluids and fuel: Drilling uses a number of chemicals and drilling fluids together with energy for which fuel tanks are installed. During drilling activities there will be risks of fluid and fuel spillages causing land contamination;
- Well failure/upset condition: the drill contractor must prepare an Emergency Plan for the case of well failure and upset conditions. He must confirm full insurance for such events.
- Drilling solid and fluid wastes: during drilling, solid and fluid wastes will be produced for which ponds will be realized at the drilling site. The contractor will have to ensure disposal of these wastes in accordance with environmental regulatory requirements. These wastes may contain heavy metals and toxic trace elements, especially when drilling in a volcanic area;
- Groundwater: at certain depths, before reaching the target aquifer, groundwater will be reached. The contractor must ensure effective measures to prevent groundwater pollution;
- Soil and land contamination from drilling lubricants and fuels: the contractor must prevent and/or minimize the risk of land contamination through different measures aimed at preventing any leakages and containment of possible spills;
- Other impacts like, noise, GHG emissions, landscape and visual disturbance etc.

The contractor will have to comply with environmental regulations and with international standards for this type of drilling and plant operational activities. An Environmental Impact Assessment will have to be prepared as soon as the site for the geothermal power plant has been identified.

Compliance with the above requirements minimizing environmental impacts will induce additional investments costs.

[115] *Environmental Impact Assessment for Geothermal – Drilling of the 3rd Exploratory Production Well, ATOM Solutions Inc. for Government of Montserrat, 2015 (Ref.7)*

Geothermal energy integration in (small) electricity grids

Geothermal power generation can easily be integrated in large electricity grids as these plants provide reliable and adjustable power. Electricity generation can be adjusted to demand if needed. A geothermal power plant has a theoretical capacity factor of almost 100% and thus normally fully replaces conventional base load power systems.

However, the CN-islands have small grids with hardly any base load power, only balancing power continuously adjusting to demand. A geothermal production plant will have to act similar to the current diesel generators. They have to balance supply and demand and therefore continuously ramp-up and down according to the daily demand profile. Although peak-load generators, or solar systems (off-setting the peak load) might support a geothermal system, it is inevitable that the capacity factor will be far lower than 100%. The total production mix will eventually determine the actual capacity factor of such a geothermal system. This will have to be taken into account when calculating the kWh price.

Summary

Based upon the above and analysis of all aforementioned sources, geothermal energy could be a feasible renewable source of energy for Saba with the following options and parameters. The table below presents the estimates for capital costs, including additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean:

- No local availability of knowledgeable staff who could be involved in installation and operation and management of the geothermal-facility and power station. Specialized staff for drilling, installation and most of the operation and maintenance is not available at CN;
- Problematic selection of locations, especially on Saba and St. Eustatius with limited land available for any type of installation. Locations will require more than average preparatory work to make it suitable for installation of drilling rigs and/or a geothermal facility;
- As site location is difficult, it will in most cases not be found at an attractive location for grid connection. Additional grid connection costs must be taken into account as new cables will have to be laid with routing in difficult terrain;
- Difficult and complex administrative and environmental procedures with insecure decision making. No procedures or requirements are in place for this type of installations which may result in relatively long term procedures.

Parameters	U.S./Europe	Caribbean
Capacity	100 MW	2 MW
Capacity factor	99%	99%
Yearly output in MWh	867,000	1,700[116]
Lifetime	20-30 years	20-30 years
Capital costs	3,500-4,000 $/kW	8,500 $/kW
Fixed O&M costs	100 $/kW-yr	200 $/kW-yr
Variable O&M costs	-	-

[116] *This is the theoretical output in case of a constant capacity factor throughout the year. Given the demand profiles of Saba and St. Eustatius, the average capacity factor will be lower.*

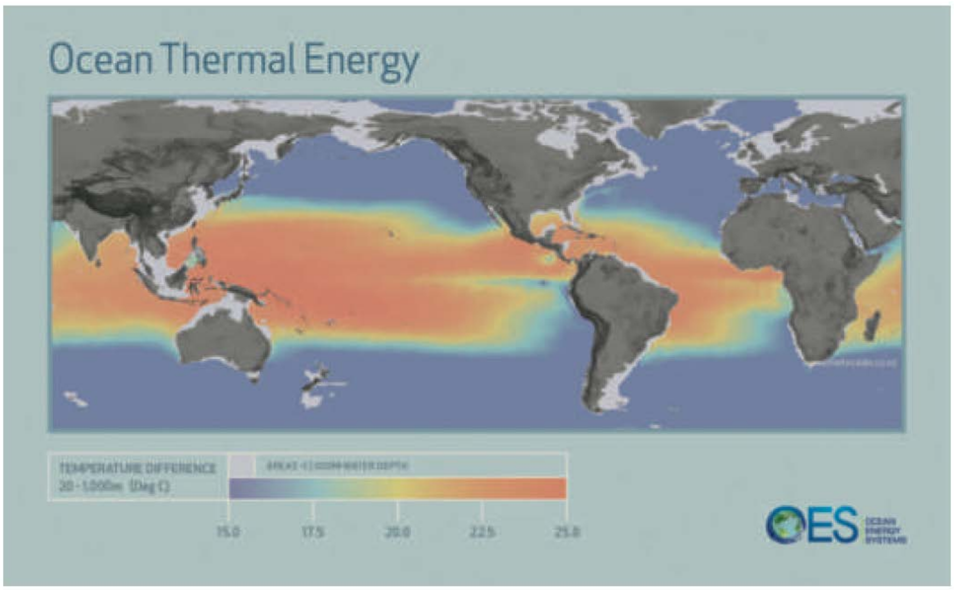
References

1. NREL 2015 “Guidebook the geothermal Power Finance”;
2. World Geothermal Congress 2015; Huttrer & Lafleur “Country Update for Eastern Caribbean Nations”;
3. 2015 Unlocking the Geothermal Energy Potential of Montserrat – Phase 4, UK DFID
4. TNO 2012 R10371 “Geothermal potential on Saba”;
5. California Energy Commission CEC 2007 - Comparative Costs of California Central Station Electricity Generation Technologies;
6. CEC 2015 - Renewable Energy Costs of Generation Update;
7. 2015 Environment Impact Assessment for Geothermal – Drilling of the 3rd Exploratory Production Well, ATOM Solutions Inc. for Government of Montserrat.

ANNEX 5: Factsheet OTEC

The Technology

Ocean Thermal Energy Conversion (OTEC) technologies use the temperature difference between warm seawater at the surface of the ocean, and cold seawater at between 800–1000 meters (m) depth to produce electricity. As OTEC installations generally operate with temperature differences of around 20°C or more, OTEC can only be applied in regions with high surface water temperatures, preferably over 25°C. Temperature levels at one kilometer depth are relative constant at about 4°C.



Source: International Energy Agency – Ocean Energy Systems (IEA-OES) 2014

Figure 1: regions with OTEC potential

Figure 1 clearly shows that seawater temperatures in the Caribbean are sufficiently high to allow OTEC applications. Many Caribbean and Pacific islands have sea surface temperature of 25°C to 30°C. More specifically, most Caribbean and Pacific countries have the required temperature degrees at 1-10 km of their coastline[117].

There are two main types of OTEC systems:

1. Open Cycle OTEC

Open Cycle OTES uses warmer surface water, which is introduced through a valve in a low-pressure compartment, and flash evaporated. The vapor drives a generator and is condensed by the cold seawater pumped up from below. The condensed water can be collected and because it is fresh water, used for various purposes (figure 2). Additionally, the cold seawater pumped up

[117] *IRENA Ocean Thermal Energy Conversion Technology Brief, 2014 (Ref.1)*

from below, after being used to facilitate condensation, can be introduced in an air-conditioning system. As such, systems can produce power, fresh water and air-conditioning.

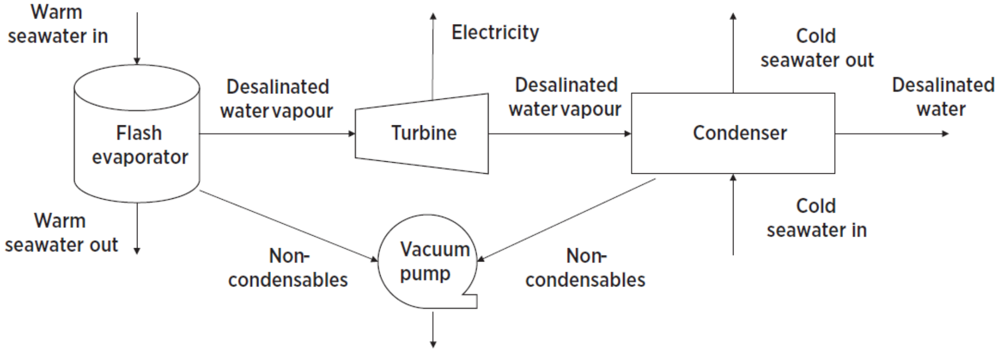


Figure 2: Open Cycle OTEC process scheme

Furthermore, the cold water can potentially be used for aquaculture purposes, as the seawater from the deeper regions close to the seabed contains various nutrients, like nitrogen and phosphates.

2. Closed Cycle OTEC

Surface water, with higher temperatures, is used to provide heat to a working fluid with a low boiling temperature, hence providing higher vapor pressure (see figure). Most commonly ammonia is used as a working fluid, although propylene and refrigerants have also been studied (Bharathan, 2011). The vapor drives a generator that produces electricity; the working fluid vapor is then condensed by the cold water from the deep ocean and pumped back in a closed system. The major difference between open and closed cycle systems is the much smaller duct size and smaller turbines diameters for closed cycle, as well as the surface area required by heat exchangers for effective heat transfer. Closed conversion cycles offer a more efficient use of the thermal resource (Lewis, et al., 2011).

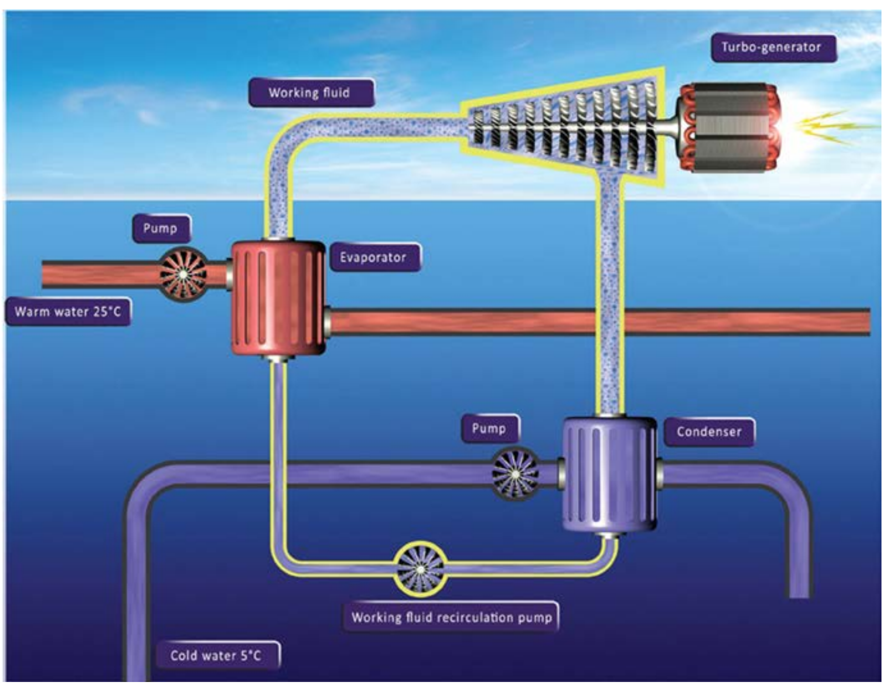


Figure 3 Closed Cycle OTEC (courtesy of DCNS)

A variation of a Closed Cycle OTEC, called the Kalina Cycle, uses a mixture of water and ammonia. The use of ammonia as a working fluid reduces the size of the turbines and heat exchangers further.

Other general components of the OTEC plant consist of the platform (which can be land-based, moored to the sea floor, or floating), the electricity cables to transfer electricity back to shore, and the water ducting systems. There is considerable experience with all these system components in the offshore industry. The technical challenge is the size of the water ducting systems that need to be deployed in large-scale OTEC plants. In particular, a 100 MW OTEC plant requires cold water pipes of yet to be constructed 10 m diameter or more and a length of 1000 m, which need to be securely connected to the platforms. Even 4-7 m diameter pipes needed for a 10MW plant still have to be demonstrated.

Besides electricity production, OTEC plants can be used to support air-conditioning, seawater district cooling (SDC), or aquaculture purposes. OTEC plants can also produce fresh water. In Open-Cycle OTEC plants, fresh water can be obtained from the evaporated warm seawater after it has passed through the turbine.

Another option is to combine power generation with the production of desalinated water. In this case, OTEC power production may be used to provide electricity for a reverse osmosis desalination plant. According to a study by Magesh[118], nearly 2.28 million litres of desalinated water can be obtained every day for every megawatt of power generated by a hybrid OTEC system (Magesh, 2010).

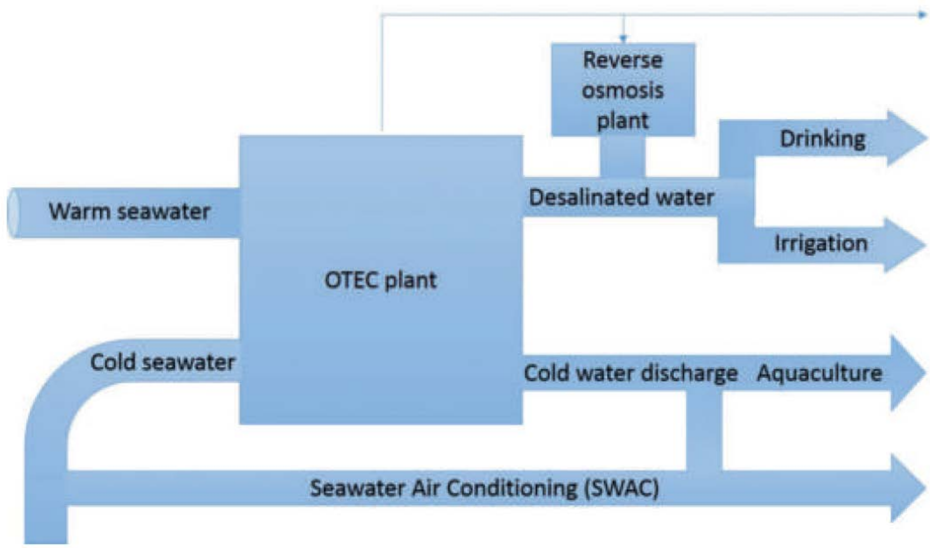


Figure 4: Multi-functionality of OTEC facilities

The potential multi functionality of an OTEC plant is shown in figure 4. Although additional products will support the business case, it will involve multiple sectors and thus increase complexity of decision-making and implementation[119].

[118] *A World of Clean Energy and Water, R. Magesh, 2010, (Ref. 9)*

[119] *IRENA Ocean Thermal Energy Conversion Technology brief, 2014 (Ref.1)*

There are only a few operational OTEC plants in the world, most of which are demonstration plants and relatively small. Hawaii Ocean Science & Technology (HOST) Park in Hawaii has established itself as a leading test facility for OTEC technology since 1974. Closed and open cycle systems, as well as onshore and offshore systems which aim to produce electricity using the temperature difference between cool deep and warm shallow sea water have been built and tested by various groups including the University of Hawaii, Lockheed Martin, Makai Ocean Engineering, and the US Navy. In 2015, Makai Ocean Engineering has constructed a 105-kilowatt test project at a cost of $5 million to prove the concept. It is currently the biggest operational OTEC plant. Several far smaller OTEC plants are operational in South Korea and Japan.

There are a number of 10 MW plants that are in various stages of development and planned for operation in the near future. For instance, a 2013 signed agreement between Lockheed Martin and the Beijing-based Reignwood Group should lead to the completion of a 10 MW OTEC plant by 2017 in waters off southern China's Hainan Island. In Martinique, a floating 10 MW OTEC plant is being designed by DCSN and planned go into operation in 2019 (originally 2016). Altogether, although it is technically feasible to build 10 MW plants using current design, manufacturing, deployment techniques and materials, the actual operating experience is still lacking.

Costs

There is limited actual project cost data available for OTEC. Instead, most cost references are based on feasibility studies from a limited number of sources. Figure 5 provides an overview of the latest cost projections for a range of OTEC plants.

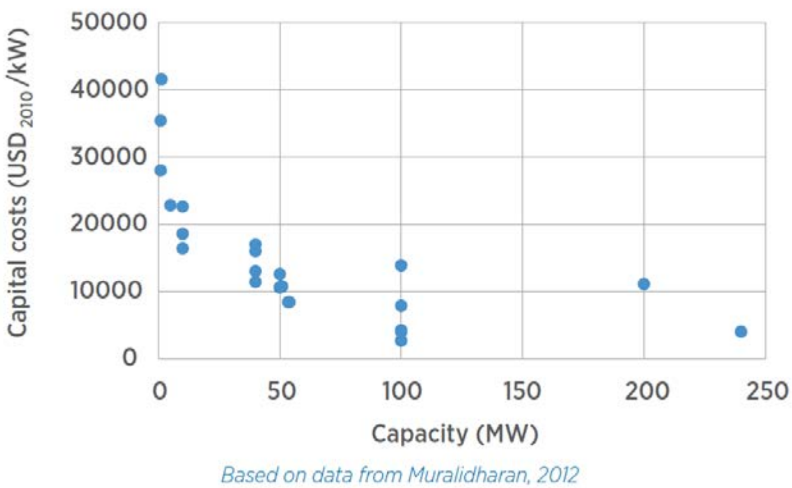


Figure 5: capital cost estimates for OTEC plants

It shows that capital costs per kW installed power is very high and only (theoretically) decreases when the capacity is increased substantially to 100MW or more. These economies of scale have yet to be demonstrated[120].

According to the 2014 IRENA report, the capital costs projections are a function of four parameters. First, the scale of the project has an important impact on the cost projections. Due to the large overhead costs, small-scale OTEC plants in the range of 1-10 MW have relatively high

[120] *Assessment of Ocean Thermal Energy Conversion, Muralidharan, (Ref. 2)*

installation costs of around $ 15,000–35,000/kW. OTEC plants in the 10-100 MW range are estimated to cost between $ 5,000-15,000/kW when installed. However, combined with the production of fresh water they could become economically viable for small island states or isolated communities (up to 100 000 residents), especially if OTEC resources are within 10 km of the shore[121][122].

The second parameter is the choice between open and closed cycle designs. Closed cycle designs are estimated to be slightly cheaper than open cycle designs. However, closed cycle installations do not produce potable water. Open cycle OTEC can provide an alternative for fresh water production based on reverse osmosis plants.

A third parameter is the production of by-products. Water can be produced as a by-product, which increases the initial installation costs, but improves the overall economics for regions where fresh drinking water is valued. Also, large-scale OTEC plants can be combined with the production of energy-intensive products or energy carriers, like hydrogen, ammonia or methanol.

A fourth parameter is the environmental conditions at the location where the cold water is extracted. On the one hand, the surface temperature gradient may be more beneficial off the coast, but would require either longer pipes (for an onshore plant) or longer subsea cables (for an offshore plant).

Yearly maintenance cost are reported to be 1.4-2.7% of the initial investment. Given the state of development, 2.7% will be taken as a current reference.

Few more recent financial figures are available as a reference. The aforementioned 105-kilowatt test project in Hawaii, which was installed in 2015, showed installation cost of approximately $48.000 /kW[123].

The planned off-shore 10 MW OTEC plant in Martinique (see further), which was awarded a 72.3 M€ subsidy as winner of the European program NER 300[124], is announced by DCNS and Akuo energy to be built for (<) 300 M€. This equals approximately $33,000 per kW. The complementary onshore 5.7-megawatt Nautilus OTEC plant in Martinique is announced to cost about $ 32,000 per kW, but will also provide cooling and fresh water.

These numbers show that the investment costs are still substantial and do not show a (steep) decline as for other renewables. This relates to the development stage these technologies are still in.

Potential and Barriers

121 IRENA OTEC Technology brief, (Ref. 1)

122 Economics of Ocean Thermal Energy Conversion (OTEC): An Update Luis Vega, 2010 (Ref. 3)

123 Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into their Adjacent Waters, US Department of Energy, Makai Ocean engineering, 2012, (Ref. 4)

124 http://ec.europa.eu/clima/funding/ner300/index_en.htm (Ref. 5)

OTEC has the highest potential when comparing all ocean energy technologies, and as many as 98 nations and territories have been identified that have viable OTEC resources in their exclusive economic zones. Recent studies suggest that total worldwide power generation capacity could be supplied by OTEC, and that this would have no impact on the ocean's temperature profiles. Furthermore, a large number of island states in the Caribbean and Pacific Ocean have OTEC resources within 10 kilometers (km) of their shores. OTEC seems especially suitable and economically viable for remote islands in tropical seas where generation can be combined with other functions e.g., air-conditioning and fresh water production.

The existing barriers are high up-front capital costs, and the lack of experience building OTEC plants at scale. Most funding still comes from governments and technology developers, but for large-scale deployment, suitable finance options need to be developed to cover the upfront costs.

From an environmental perspective, OTEC plants at scale will require large pipes to transport the volumes of water required to produce electricity, which might have an impact on marine life, as well as the infrastructures to transfer the water (for land-based systems) or electricity (for off-shore systems) to and from the coastline. Also because it is not a tried and tested technology at large scale, there are unknown risks to marine life at depth and on the seabed where there is large scale upward transfer of cold water with high nutrient content.
From a technical perspective, the large-scale pipes, bio fouling of the pipes and the heat exchangers, the corrosive environment, and discharge of seawater are still being researched.

OTEC economics in the Caribbean

Today, only one project under implementation is known in the Caribbean region, which is the NEMO facility. NEMO is an ocean thermal energy project off the west coast of Martinique in the Caribbean Sea. A moored barge will be installed housing four turbo-generators. Each will be driven by an Ammonia closed Rankine cycle utilizing the circa 20°C temperature difference between the cold seawater at 1.1 km depth and the warm surface waters. The cold water is pumped via a single large diameter riser. Each turbine will produce roughly 4 MW resulting in a total nominal installed capacity of 16 MW with a maximum available capacity of 10.7 MW. The net generated power is exported to the grid via a subsea cable and a substation at an existing conventional fossil fuel power plant. The overall investment costs of the NEMO plant are close to US$ 300 million. The project received a EU grant from the NER 300 program of € 72 million[125].

This project falls within the scope of the partnership agreement signed in January 2013 between DCNS and Akuo Energy to combine their respective skills with a view to marine renewable energy (MRE) developments.
Furthermore, a low-power OTEC plant is planned to be installed on-shore to combine air-conditioning, freshwater production and aquaculture solutions with electricity production by using deep-sea cold water. This NAUTILUS project will complement the NEMO offshore OTEC plant project. As published by Bloomberg[126], this 5.7-megawatt project at Bellefontaine in Martinique will cost about $183 million to build, which equals about $ 32,000 per kW. This facility will also provide fresh water and cooling capacity, which reduces the costs for electricity generation. There is insufficient information available concerning this project to assess the costs directly related to the electricity generation plant.

The Dutch company Bluerise has developed a small pilot scale OTEC project at Curacao, at Hato airport. This installation will produce fresh water for an agricultural project, cold water for cooling of several buildings of the airport and in the direct neighborhood and produce electricity. Technical development is completed, the project is supported (not financially) by the Curacao government. Discussions on guarantees for the supply of cooling water are ongoing. As soon as this will be resolved, the project will be realized[127].

In view of the above cost information, we estimate the investment costs for a 10 MW OTEC facility at US$ 300 million, e.g. US$ 30,000 per kW, with 2.7% of investment costs for the yearly O&M costs.

[125] *Project NEMO, New Energy for Martinique and Overseas, Akua Energy presentation, 2015, (ref. 6)*
[126] *http://www.bloomberg.com/news/articles/2014-12-23/akuo-energy-plans-ocean-thermal-power-plant-in-martinique (Ref. 7)*
[127] *Ocean Ecopark Curacao, Bluerise presentation, (Ref. 8)*

Environmental impacts

Some of the main environmental impacts of OTEC facilities are summarized as follows:

- For larger installations, *e.g.*, 10 MW or even 100 MW, the pipes are of considerable width – from 4 m to 20 m, which may impact the coastal structure, and more importantly, the transfer of the cold water up and the discharge in the warmer water could affect the marine life in the vicinity of the plant (*e.g.*, exhaust water at 3 degrees below surface water temperature could cause algae bloom). Thus, water effluent needs to be discharged at a certain depth, as the discharged cold water at the surface could influence the temperature of the surface water required for power production.
- The siting of OTEC projects combined with protection of marine bio-diversity and recreational activities and tourism can create problems. There is unknown risk for marine life at the seabed due to the large-scale upward transfer of cold water with high nutrients content. The same applies for marine life at higher surface waters.
- Another environmental aspect to be considered is fish entrapment although this could be resolved by fencing. Some of the problems can be solved by locating the larger installations farther off the coast. The U.S. Department of Energy (DOE) has recently brought out a more detailed study regarding the ecological aspects of OTEC (DOE, 2012). This study, which is based on computational models, suggests that OTEC plants with discharge at 70 m of depth or more have no effect on the upper 40 m of the ocean's surface, and that the effect on picoplankton in the 70-110 m depth layer is well within naturally occurring variability[128].

The above findings have been studied using an oceanographic model. No real research and measurements have been done as only few such installations are in place. It's clear that further research is required to assess the real effects of OTEC discharges and water extraction at water quality and fish life. These findings can then be used to develop specific ecological requirements and measures to prevent and minimize environmental impacts for OTEC plants.

[128] *Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into their Adjacent Waters, US Department of Energy, Makai Ocean engineering, 2012, (Ref.8)*

Summary

Based upon the above and all sources analyzed (see last page), OTEC technologies energy cannot be regarded as a feasible renewable source of energy **YET** for the CN-islands as it is still in the development phase. The table below presents the estimates for OTEC capital costs.

These costs include additional costs resulting from a number of issues relevant for the CN-islands as for many other similar islands and locations in the Caribbean:

- No local availability of knowledgeable staff who could be involved in installation and operation and management of the OTEC-facility, specialized staff for installation and O&M is not available at CN;
- Problematic selection of locations, especially on Saba and St. Eustatius with limited land available for any type of installation. Locations will require more than average preparatory work to make it suitable for installation of an OTEC facility. The direct coast line has high nature values and requires in depth investigation on the possibilities to install a cold water sea pipe. Around Saba and St. Eustatius offshore and onshore facilities must be hurricane resistant. Especially Bonaire has coral reefs all around the island;
- As site location is difficult, it will in most cases not be found at an attractive location for grid connection. Additional grid connection costs must be taken into account as new cables will have to be laid with routing in difficult terrain;
- Difficult and complex administrative procedures with insecure decision-making. No procedures are in place for this type of installations which may result in relatively long term procedures;
- None of the islands have favorable locations for SWAC, as there are no or almost no buildings with a high cooling demand (large hotels, hospital, office buildings etc.). In case additional hotel accommodation is realized at the Plaza Bonaire area in the vicinity of Bonaire Airport, this could become a suitable location for an OTEC/SWAC facility;
- The combination with fresh water production is possible on all three islands resulting in improved economics of the OTEC facility.

Currently the following options and parameters apply:

Parameters	Small-scale		Large-scale
Capacity	2 MW	10 MW	100 MW
Capacity factor	95%	95%	95%
Yearly output in GWh/MW	8,3 [129]	8,3	8,3
Lifetime	20 years	20 years	20 years
Capital costs	41,000 $/kW	30,000$/kW	15,000 $/kW
Fixed O&M costs	1,100 $/kW-yr	800 $/kw	400 $/kW-yr
Variable O&M costs	-		-

[129] This is the theoretical output in case of a constant capacity factor throughout the year. Given the demand profiles of Saba and St. Eustatius, the average capacity factor will be considerably lower.

References

1. IRENA 2014 “Ocean Energy Technology brief, ref 1
2. 2012 Assessment of Ocean Thermal Energy Conversion, Muralidharan, ref. 2
3. 2010 Economics of Ocean Thermal Energy Conversion (OTEC): An Update Luis Vega, ref. 3
4. 2012 Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into their Adjacent Waters, U.S. Department of Energy, Makai Oceanengineering, ref. 4
5. http://ec.europa.eu/clima/funding/ner300/index_en.htm ref. 5
6. 2015 Project NEMO, New Energy for Martinique and Overseas, Akua Energy presentation, ref. 6
7. http://www.bloomberg.com/news/articles/2014-12-23/akuo-energy-plans-ocean-thermal-power-plant-in-martinique , ref. 7
8. Ocean Ecopark Curacao, Bluerise, ref. 8
9. A World of Clean Energy and Water, R. Magesh, 2010, ref. 9

ANNEX 6: Factsheet Wave and tidal Energy

The Technology

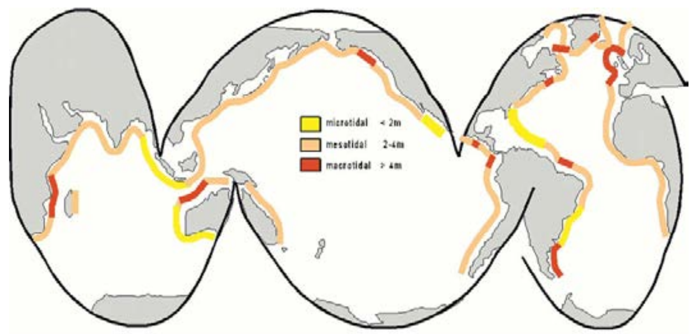


Figure Worldwide distribution of coastal tidal ranges.

Tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. Due to the consistent pattern of the moon's orbit around the earth, the gravitational forces create motions or currents in the world's oceans. The temporary increases in sea level forces water from the middle of the ocean to move toward the shorelines, creating a tide. According to the general tide classification, The Caribbean has the lowest tide class of less than 2 meters (microtidal)[130]. As a tidal range of at least 7 meters is required for economical operation[131], tidal energy is not regarded a feasible renewable source of energy for the CN-islands.

Wave energy is the transport of energy by wind waves, and the capture of that energy to do useful work – for example, electricity generation, water desalination, or the pumping of water (into reservoirs). A machine able to exploit wave power is generally known as a wave energy converter (WEC). According to several studies, WEC technology can potentially extract 100GW of wave power worldwide.

There is a wide range of wave energy technologies. Each technology uses different solutions to absorb energy from waves, and can be applied depending on the water depth and on the location (shoreline, near shore, off shore).

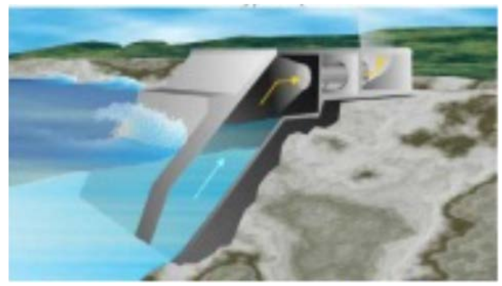
Wave energy technologies consist of a number of components:

- The structure and prime mover that captures the energy of the wave,
- The foundation or mooring keeping the structure and prime mover in place,
- The power take-off (PTO) system by which mechanical energy is converted into electrical energy, and
- The control systems to safeguard and optimize performance in operating conditions.

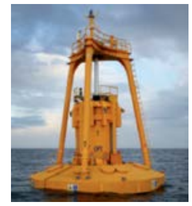
A common way of categorization of WEC installations is as follows[132]:

[130] http://geology.uprm.edu/Morelock/tide.htm
[131] http://www.oceanenergycouncil.com/ocean-energy/tidal-energy/
[132] *IRENA 2014 Ocean Energy Technology Brief 4: wave energy (Ref.1)*

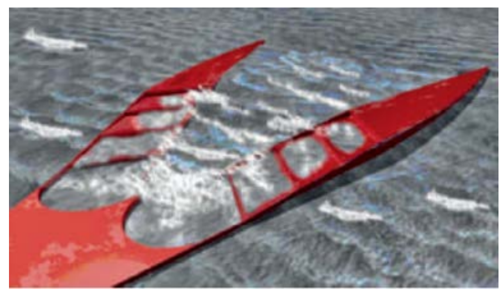
- **Oscillating Water Columns (OCW)** are conversion devices with a semi-submerged chamber, keeping a trapped air pocket above a column of water. Waves cause the column to act like a piston, moving up and down and thereby forcing the air out of the chamber and back into it. This continuous movement generates a reversing stream of high-velocity air, which is channeled through rotor blades driving an air turbine-generator group to produce electricity.



- **Oscillating Body Converters** are either floating (usually) or submerged (sometimes fixed to the bottom). They exploit the more powerful wave regimes that normally occur in deep waters where the depth is greater than 40 metres (m). In general, they are more complex than OWCs, particularly with regards to their PTO systems.



- **Overtopping converters (or terminators)** consist of a floating or bottom fixed water reservoir structure, and also usually reflecting arms, which ensure that as waves arrive, they spill over the top of a ramp structure and are restrained in the reservoir of the device. The potential energy, due to the height of collected water above the sea surface, is transformed into electricity using conventional low head hydro turbines (similar to those used in mini-hydro plants).

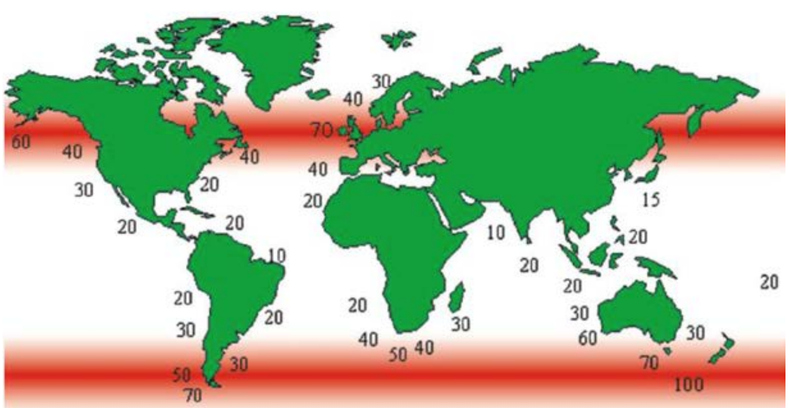


Wave and Tidal energy worldwide

Starting in the 1970s, the ocean energy technology has evolved to a phase where different concepts are being tested at a full scale, pre-demonstration phase, and commercial demonstrations are being deployed. In 2013, there were more than a hundred projects at various stages of development, but only a handful of technologies are close to commercialization. The wave energy devices being developed and tested today are highly diverse, and a variety of technologies have been proposed. Some of the more promising designs are undergoing demonstration testing at commercial scales.

According to a 2015 report from the European Commission's Joint Research Centre (JRC)[133], ocean energy (still) faces four main bottlenecks: technology development, finance and markets, environmental and administrative issues, and grid issues. Technological barriers represent the most important challenge that the ocean energy sector needs to address in the short–medium term. Overcoming technology issues is key for ocean energy to become commercially viable; today public financial support is still needed for its development.
The potential environmental impacts of ocean energy projects are not yet definitive due to the early stage of development of the technology, causing regulatory licensing issues. Last but not least, as ocean energy can only be harvested at specific locations, which are remote and not connected to the grid, grid extensions and enhancements needs to be taken into account.

The JRC has identified 45 wave energy companies that have reached or are about to reach open-sea deployment of their technologies. Most R&D dedicated to wave energy takes place in Europe, with the US and Australia also proving fertile grounds for the development of wave energy technologies. As the next figure shows, these areas have the highest wave power expressed in kW/m crest length, in contrast to the Caribbean.



The global installed capacity of wave energy remains low. Most leading wave technologies are still at an advanced R&D stage, and only a few machines have sustained long operational hours. Wave energy technologies and markets still have much to prove on their path to commercial viability. The costs of wave energy are therefore considerably higher than other renewables and are only expected to drop substantially over many years, if and only if the technology matures.

[133] *JRC 2014 Ocean Energy Status Report (Ref.2)*

Wave and tidal energy in the Caribbean

No (near) commercial projects are known in the Caribbean.

The 2010 Nexant report on renewables in multiple Caribbean islands[134] did not regard wave energy as a commercially demonstrated technology.

Also, the 2014 study on renewable energies and green policy in the Overseas Countries and Territories (OCT)[135] concluded wave energy not being an optional renewable technology for the Caribbean OCT countries. Wave energy could have future potential but is still very innovative and is not expected to be commercially developed in the near future.

Due to the technology status of wave energy as well as the non-favorable location and related non-existing track record of wave energy in the Caribbean region, this technology is not considered to be part of the future renewable energy production mix of the CN-islands.

The Caribbean region also is a non-favorable location for tidal energy.

[134] *Nexant 2010 - Caribbean Regional Electricity Generation, Interconnection, and Fuel Supply strategy (Ref.3)*
[135] *OCT 2014 Study on Renewable Energies and Green Policy Final Report (Ref.4)*

Summary

Based upon the above and analysis of all aforementioned sources, both tidal and wave energy cannot be regarded as a feasible and favorite renewable source of energy for the CN-islands.

References:

1. IRENA 2014 Ocean Energy Technology Brief 4: wave energy;
2. JRC 2014 Ocean Energy Status Report;
3. Nexant 2010: “Caribbean Regional Electricity Generation, Interconnection, and Fuels Supply Strategy”;
4. OCT 2014 Study on Renewable Energies and Green Policy Final Report.

ANNEX 7: Case studies

An increasing number of relatively small islands with decentralized electricity grids move forward with renewables. In most cases small island grids and their production facilities are vulnerable and depend fully on expensive fuels like gasoil. On the other hand, as islands are small, they can be changed relatively easily, quite often with financial help of the parent country and/or financial institutions.

Throughout the past couple of years, several news items have been established on islands "going green". Often high numbers are stated, even up to a 100%, although actual electricity production by renewables is often confused with for instance penetration of renewables in term of capacity, not taking into account the actual capacity factor.

Part of this assignment a selection of green islands has been analyzed based upon publically available information. The highlights are stated in the following table:

Territory	Renewable fraction %	Peak demand MW	Production mix	Key technology for balancing	Main barriers
King Island	45%	2.3	- Diesel 6.0MW - Wind 2.5 MW - Solar 0.4 MW	-Flywheel -Batteries (3MW)	Smart grid and demand management needed to increase renewable fraction further
Tokelau	88%	0.13	- Diesel - Solar (0.93MW)	- Batteries (8MWh) - Off-grid inverters	Strict demand regulations to create a predictable low demand (air-conditioning and electric ovens forbidden, et cetera)
Kodiak	99.8%	27	- Wind 9MW - Hydro 30MW	-Flywheels -Batteries 3MW/2MWh)	Integration with hydro power, supplying 75% of all electricity
El Hierro	32.2%	7.5	- Diesel 12.7 MW - Wind 11.5MW - Hydro 11.3MW	- Water storage	Wind- pumped hydro integration and grid stability

The references presented below provide more detailed information in order to understand even better the characteristics of the examples given. The main findings from the analyses are as follows:

- All islands are different with regards to size, demand, supply, natural resources, et cetera. There is no single solution when looking at implementing renewables in island grid;
- The main challenge is not so much financing as these examples were mainly financed externally, but the technology to balance demand and supply. Batteries, water storage and flywheel but also smart grids and demand management are examples of technologies used to guarantee a reliable power supply.

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