Nexus interventions for small tropical islands: case study Bonaire

Energy

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Small tropical island states are heavily dependent on imported fossil fuels for the provisioning of energy, and Bonaire is no exception. As a consequence electricity costs are high and vulnerable to oil price fluctuations, which both present major risks to social and economic security. Yet, environmental conditions on most of these tropical islands offer many opportunities for the generation of sustainable energy. For Bonaire these include wind and solar energy, Ocean Thermal Energy Conversion (OTEC) and third generation biofuels (microalgae), which may provide an optimal solution for affordable, safe, reliable, and sustainable energy supply. Apart from differences in development costs and required technical capacity, each of these technologies has their own benefits and shortcomings with regard to land use, water use, and ecological impact. The transition from fossil fuels towards 100% sustainable energy on Bonaire thus requires a holistic (nexus) approach that also takes these interlinkages between water-food-energy-ecosystem domains in to account to identify potential trade-offs and seek for synergies among these domains. Using this approach, on the short term, investment in wind energy and decentralized solar energy seems most ideal, due to relatively low development costs, available technical experience, limited ecological impact and positive impact on water and food security and public support. However, variability of solar and wind power does not allow to make electricity supply fully sustainable. On the long term, 100% renewable electricity supply can only be achieved with OTEC and/or production of third generation biofuels. From a nexus point of view, we recommend to conduct a feasibility study into OTEC, that addresses its ecological impact, and its potential to be combined with Seawater Air Conditioning, fresh water production and microalgae farming to enhance its economic feasibility. Apart from shifting to renewable energy, policy measures directed to energy conservation may also greatly contribute to energy security on Bonaire.

Current state (2018)	Desired state	Challenge	Nexus intervention
69% energy supply from burning fossil fuels (300 heavy oil barrels per day) Remaining supply from renewable energy produced by wind turbines (33%) and solar panels (1%) Energy consumption ~ 110GWh/year (with peak demand at ~16MW) Capacity and quality of the electricity network limits expansion of renewable energy generation	Affordable, safe, reliable and 100% renewable energy supply that is integrated with other resource sectors to reduce trade-offs and provide synergies between water-food-energy-ecosystem domains More efficient use of energy and reduced consumption of energy	Quality and capacity of the electricity network limits expansion of wind/solar energy generation Expected shortage in production capacity **Technical challenges:** - Human capital - OTEC - Replacement of grid - Electricity storage capacity Scale: costs and investment risk on small island Integration with other resource sectors and creating a shared vision	Develop and implement Sustainable Energy vision that integrates the Food, Water and Ecosystems domains to simultaneously aid energy, water, food and ecosystem security Facilitate decentralized solar energy production by subsidies, tomake energy more accessible and affordable for people living in rural areas, with positive effects on economic development and public support for renewable energy **Feasibility studies on:** - Ocean Thermal Energy Conversion (OTEC) that integrates electricity generation with cooling, microalgae production, aquaculture & fresh water production - Microalgae production and processing for biodiesel, feed, fertilizer, cosmetics - Energy storage by means of water reservoirs - Multi-use of solar panels for renewable energy generation, protection of crops from UV, and rainwater collection - Promotion of decentralized solar power on Bonaire - research and policy directed to energy saving through enhanced efficiency, awareness and isolation

Box 1. Summary factsheet Nexus Energy

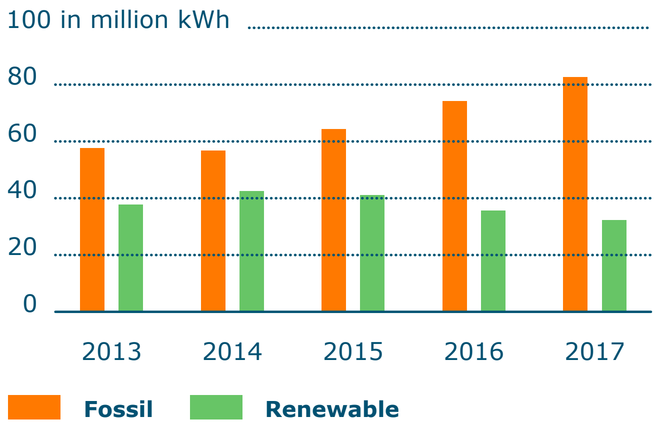
INTRODUCTION

Small Island Developing States (SIDS) base some 90% of economic and social activity on energy derived from imported fossils. Because most SIDS are located far from centres of fossil fuel extraction and production, they have high freighting costs (Thompson, 2016). Their small sizes and population bases also act as a barrier against competitive volume pricing; the creation of economies of scale makes profit generation for power producers and distributors difficult (Thompson, 2016). As a consequence of these combined factors, the energy prices in SIDS are extraordinarily high. As the majority of this energy is used for the production and distribution of both water and food, the high energy price also results in high water and food prices. In addition, burning of fossil fuels contributes to air pollution and climate change though emission of sulfides and carbon dioxide respectively, while storage and transport of oil contains risk of oil leaks. Moreover, the high dependency on fossil fuels make the vast majority of SIDS highly vulnerable to oil price fluctuations, with their economies being hit particularly hard when oil prices rise. Together, high energy prices, high ecological risks, and oil price fluctuations thus present major risks to the social, environmental and economic security. At the same time, the climate on most small tropical islands, offers many opportunities for sustainable energy, such as wind and solar energy. **Replacement of fossil electricity production with sustainable production on SIDS, is thus a very feasible and effective way to reduce energy costs, environmental impact, and economic vulnerability to fluctuating oil prices.** As a result, the current energy policy on Bonaire also aims to provide a sustainable, safe, reliable and affordable energy supply and is focused on the required CO^2 reduction in accordance with the Paris climate agreement (Ministerie van Economische Zaken, 2017).

CURRENT STATE, TRENDS & DRIVERS OF CHANGE

On Bonaire the production capacity consists of generators on oil fuel, wind turbines, a power management system and batteries (to absorb short-term fluctuations in wind production). In recent years, the electricity producer Contour Global Bonaire (CGB) has managed to gradually increase the actual wind share within this production capacity to as much as 43% (on average over 2014, see Fig. 1), which makes Bonaire among the islands with the highest share of sustainable energy worldwide. In addition, in 2015 the Water and Electricity Company WEB Bonaire (hereafter referred to as WEB) has installed a small solar energy plant of 0.20 MW as a test. In 2016, WEB added leased diesel aggregates to meet growing demand. These diesel generators can also run on biodiesel, but currently biodiesel is not available on Bonaire. As a result, the share of fossil energy increased again slightly to almost 70% of the total electricity production in 2017 (Fig. 1). This equals more than 300 barrels of oil used per day, which is a substantial amount with negative impact on energy security and the environment. At the moment, a Green Study is being carried out for further development of the Energy Policy, which is directed towards a more sustainable energy production.

Figure 1. Electricity production on Bonaire between 2013-2017 (source CBS, 2018)



In 2017, the electricity production of Bonaire that was sold by WEB increased to ~110 GWh/year (CBS, 2018) with peak demand varying throughout the year up to a maximum of ~16MW during September mostly due to electricity use for air-conditioning, as this is the warmest period of the year. In January and February, peak demand is at the lowest at ~13.5 MW (Fig. 2).

On Bonaire, all drinking water is being produced by desalination of seawater through reverse-osmose (SWRO), which is an electricity demanding process. As a result, the price of water is closely linked to the price of electricity. Apart from cooling/air-conditioning and the production of drinking water, electricity is also used for production and transportation of food, for example for irrigation of crops. As such the energy sector is strongly connected to the water and food sector on Bonaire. In addition, on small islands like Bonaire, diesel, solar and wind power plants all compete for space with nature, each in their own way, and also can have specific detrimental effects on wildlife and the environment. Given these interlinkages, it becomes evident that energy security is essential for water, food and ecosystem security on Bonaire, as illustrated in Figure 2.

As a result of population growth and economic growth, the energy demand is expected to increase rapidly in the near future, with peak demand predicted to be ~22 MW by the year 2021 (Pers. comm. Hans Staring, WEB). However, the production capacity is expected to lag behind with this growing demand (Fig 3). Moreover, the capacity and quality of the current electricity network is becoming inadequate, possibly also as a result of growth in decentralized generation (Schelleman & van Weijsten, 2016).

In 2016, WEB added leased diesel aggregates to meet increased demand. Nevertheless, there is no spare capacity available in some windless, very warm moments in the autumn. The windmills are then stopped and the electricity demand is high as a result of increased use of air conditioning for cooling. Decentralized capacity of solar panels does not solve this problem sufficiently because one of the two daily peaks in the evening is when there is no solar energy. It is of primary importance that sufficient production capacity with a high availability is placed. In the short term this resulted in more production capacity on fossil fuel. To increase sustainability of this expansion, WEB is investigating the use of more environmentally and climate-friendly fuel (LPG Propane) and more efficient generators, but this is not yet operational. In addition, the current status of the electricity network is not sufficient to meet the growing demand and suffers from disruption and technical grid losses. It seems necessary to strengthen the networks to accommodate decentralized production.

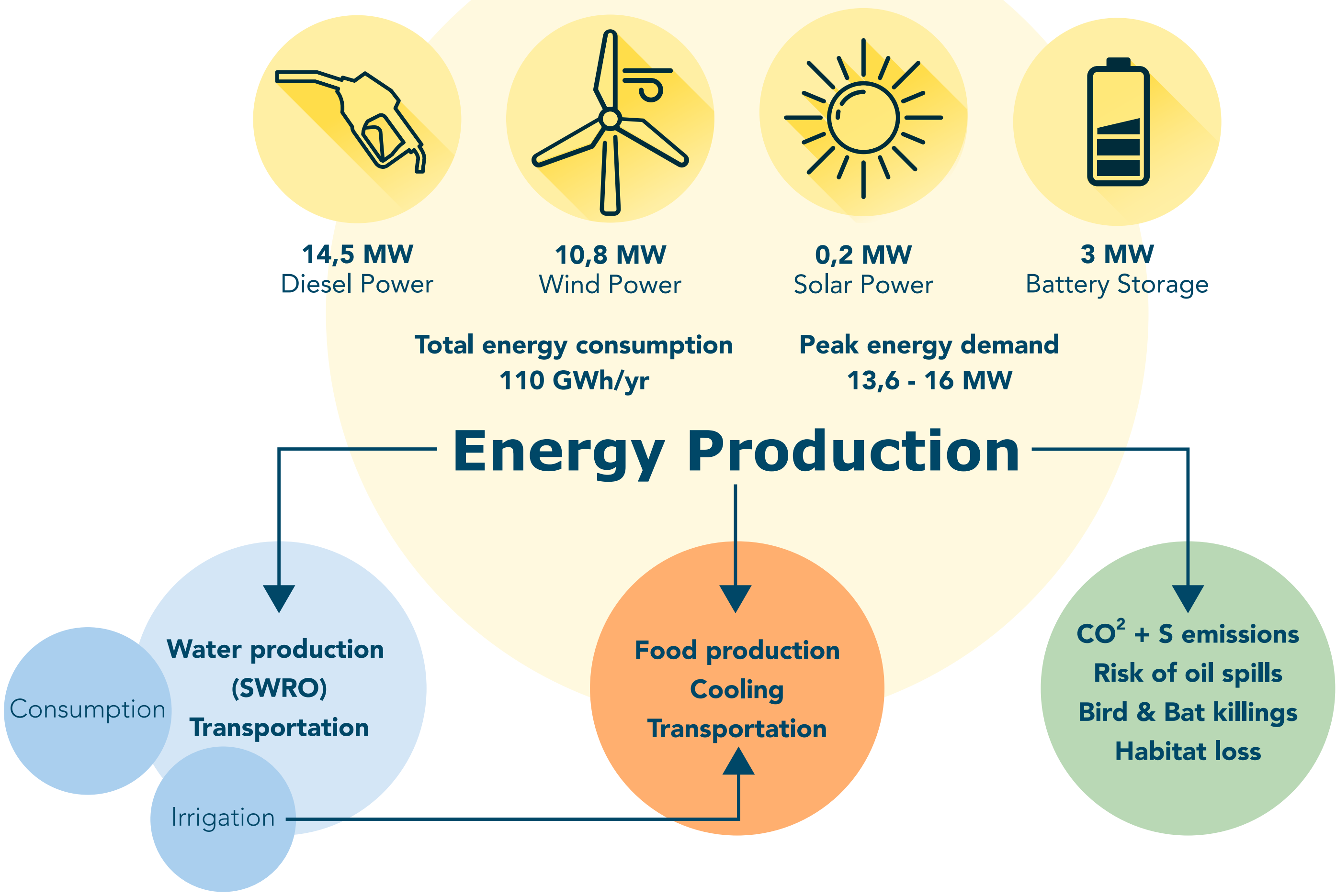


Figure 2. Energy production and allocation on Bonaire in 2017 and interlinkages among energy, water and food sectors and ecosystems.

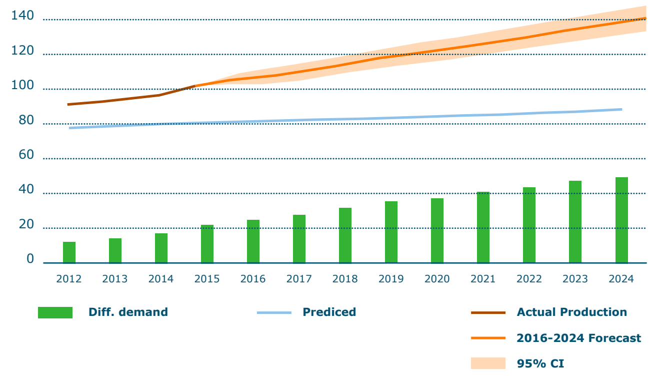


Figure 3. Predicted, realized and forecasted energy demand Bonaire, clearly showing the need for additional capacity (copied from Schelleman & van Weijsten 2016)

The Ministry of Economic Affairs and Climate (EZK) has a strong lobby for development of a second wind park to increase the share of sustainable energy on Bonaire to 60%. This is technically possible, and EZK and WEB have shared vision, but there is still a debate whether solar energy should also be included in the plan for generation of sustainable energy. WEB prefers to invest in wind energy as they already have experience with wind energy production and distribution and effect on distribution network. In order to be able to guarantee energy production, 60-65% energy from wind is maximum according to WEB as this means that you also need to have the capacity to provide energy on days when wind energy supply is limited. It is now technically possible to transport state-of-the art wind turbines that generate 2.3 MW and are 70-80 meter high instead of current wind turbines of 60 meter height, that only generate 0.9 MW. A plan is being developed to place 5 of these wind turbines on Bonaire, which would generate an additional ~11 MW of renewable energy. Additional solar energy is only an option if storage capacity increases, which requires technical innovation, qualified human resources and financial means that are not yet available.

As a long-term perspective and the possibility for a growth path towards full sustainability, an exploration of Ocean Thermal Energy Conversion (OTEC) that generates electricity from the difference in temperature between surface water (> 26˚C) and water at 1000 meters depth (4˚C), and a pilot study on production of third generation biofuels from algae (AlgaePARC) is carried out, the latter in collaboration with Wageningen University. Decentralized production with solar panels also has potential. WEB is drafting the practical rules and conditions and will decide on the basis of experience whether grid reinforcement or other infrastructural measures are necessary to fit decentralised electricity generation.

DESIRED FUTURE STATE

In line with the current energy policy on Bonaire, the desired future state should provide a sustainable, safe, reliable and affordable energy supply that is focused on the required CO^2 reduction in accordance with the Paris climate agreement. Ideally, a transition to 100% renewable energy is achieved that involves the integration of multiple renewable energy resources to improve energy security and create different fields of expertise which will lead to more jobs and increased capacity building on Bonaire.

Based on the findings of the exploratory study 'Renewable Energy Future for the Dutch Caribbean islands of Bonaire, Sint Eustatius and Saba' from research firm Schelleman & Van Weijsten Sustainable Energy Consultancy who identified , wind, solar and Ocean Thermal Energy Conversion (OTEC) as the only suitable options for renewable energy generation on Bonaire, and more recently identified possibility to produce biodiesel from algae as an additional feasible renewable energy resource (AlgaePARC), we have identified possible scenarios from changing the current matrix into a more sustainable one (Fig. 4). Using a nexus-approach, we will discuss the pros and cons of each scenario in relation to food, water and ecosystems in more detail.

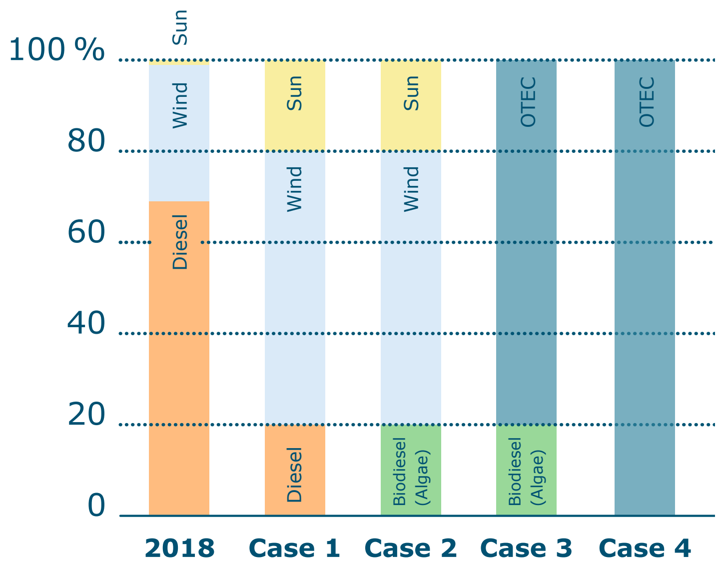


Figure 4. Identified scenarios to make the transition from Diesel-fueled energy supply towards a more sustainable energy supply on Bonaire using most suitable renewable resources (Wind, Sun, Biodiesel from microalgae, or Ocean Energy obtained from Ocean Thermal Energy Conversion (OTEC)

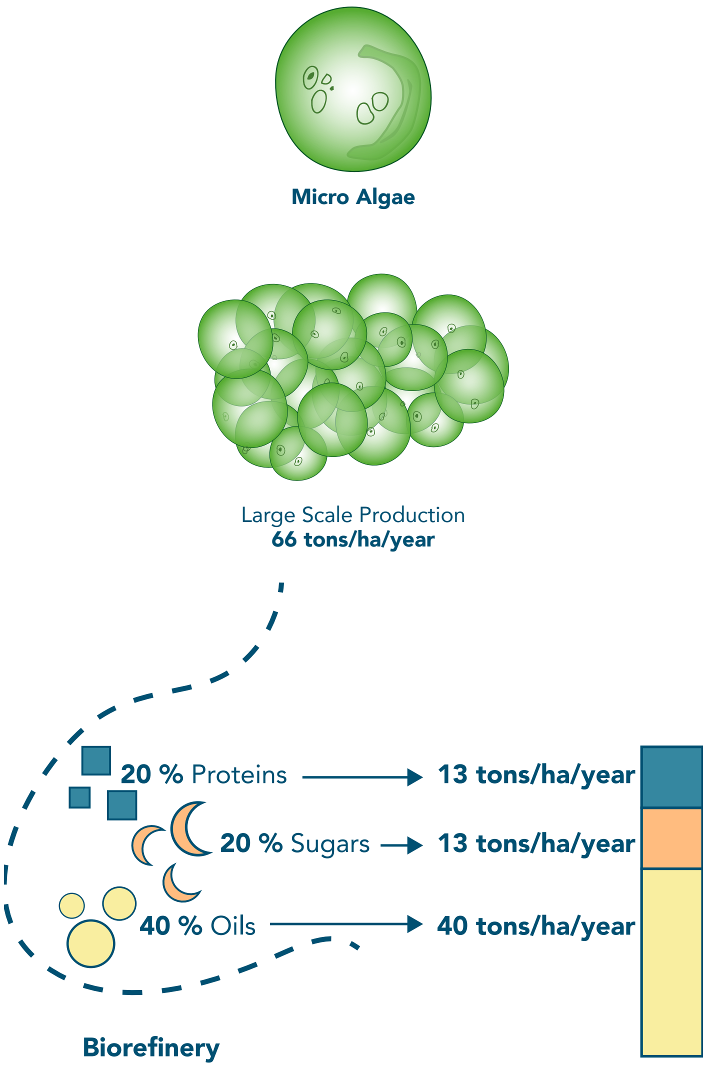
POSSIBLE NEXUS INTERVENTIONS & SYNERGIES

Ideally, Bonaire should reach a 100% renewable energy matrix in the near future. This will only be possible by investing in third generation biofuels and/or Ocean Energy via Ocean Thermal Energy Conversion (OTEC) (see Fig. 4). Whereas biofuels will need to be combined with production of either wind, solar or ocean energy to provide 100% renewable energy supply (case 2 in Fig.4), OTEC has the potential to supply the current demand on its own and to generate a surplus of electricity that should be enough to support new economic activities (case 4 in Fig. 4). Each scenario must follow a thorough environmental assessment of impact to the island resources. The main issue will be use of space, as decision-making includes the choice of where to set such new initiatives. A secured energy supply will guarantee that Bonaire also has a secured water and food supply, which makes the energy sector indirectly/directly connected with local natural resources (water, seawater, and soil), and with other economic activities, such as agriculture, aquaculture, and the current touristic sector (the main economic activity for local residents). Therefore, an integrated approach should be adopted, in which energy is not only seen as an isolated resource, but as the base of all human activities taking place on the island and their impact on water and food supply and ecosystem functioning. Below we describe possible nexus interventions per sustainable energy resource for both the short term and the long term.

Short term nexus interventions

In the short term, investments in both wind and decentralized solar energy together can provide up to 80% of sustainable energy on Bonaire (cases 1 & 2, Fig. 4). Simultaneous investment in wind and solar energy will not only bring more knowledge, industry and jobs for highly educated people to the island, it will also make the energy supply more secure, as on cloudy windy days energy can still be provide by wind, while on calm sunny days energy can still be solar power. Investing in decentralized solar energy systems also provides a great opportunity to let local communities feel the benefits of renewable energy projects and understand their advantages in a more direct personal manner. For example, excess solar power can be sold back to the grid and therefore alleviate electricity bills. This calls or a well-considered policy for the return to the grid. Likewise, placement of solar panels on kunuku's in rural areas that are not connected to the grid will greatly improve life standards of people living there. In this way, decentralized solar energy systems also provide an essential tool in educating local communities about the various benefits of clean energy and climate change. To make the transition to wind and solar energy successful, great priority should be given to increase storage capacity, so that surplus wind and solar energy can be stored for periods without wind and sun. A possible way to store energy is by means of water reservoirs (pumped hydro), which may also benefit water security. In the case of wind energy, care should be taken where to place wind turbines and at what height. The best location and height can be identified by taking in to account both energy yield and environmental impact (i.e. bird and bat killings). In the case of solar energy, solar panels should be placed on existing roofs of houses and other buildings spread over the island to reduce the use of natural habitat and to reduce variability in energy supply to the network. Solar panels also provide great opportunities to be used as collectors of rainwater thus aiding water security. In addition, when placed above crops, solar panels can reduce UV stress to crops and reduce evaporation of soils, which can enhance crop yields, thus contributing to food security.

Figure 5. Maximum yield that can be realized on Bonaire for proteins, sugars and oils extracted from microalgae and used for different commercial applications



Long term nexus interventions

Above a share of 80% in total production, fluctuating solar and wind power is quickly becoming more expensive because disproportionately more storage is required. Sustainability of the remaining 20% with wind and sun is technologically and financially unwise, but could be achieved by investing in third generation biofuels made out of microalgae (case 2 in Fig. 4). Microalgae are small plants, that grow on sunlight, seawater and CO^2, all of which are widely available on Bonaire. They are champions in converting sunlight into different products and fit very well into a circular bio-economy concept. Large scale production on Bonaire can generate 66 tons per hectare per year (pers. comm. Iago Teles). This algae biomass contains 20% proteins (for animal or human nutrition), 20% sugars (for nutrition or industrial uses) and 40% oils (for fuel production, for example, see Fig. 5). Using a biorefinery running on renewable energy, these 66 tons of microalgal biomass can be processed by breaking microalgal cells open to extract different products (i.e. proteins, sugars, oils) with different commercial applications (e.g. biofuel, nutrition, cosmetics).

Unlike third generation biofuels, Ocean Thermal Energy Conversion (OTEC) has the potential to supply the current demand for renewable energy on its own and even generate a surplus of electricity that is enough to support new economic activities. Yet, from a nexus perspective it is more optimal to invest in multiple renewable energy sources as diversification will bring more jobs and increase the capacity building of the island (i.e. cases 2 & 3, Fig. 4). In addition, diversification will contribute to energy security by spreading possible risks associated with each renewable energy resource. A great advantage of OTEC is that it not only allows to integrate different renewable energy sources, but also provides possibilities to link with the water and food sector. **Electricity generation by OTEC can be combined with cooling of buildings (Sea Water Air Conditioning (SWAC)) and fresh water production and microalgae production as illustrated in Figure 6.** The new desalination plant next to OTEC could increase the supply of drinking water and water usable for irrigation (supporting agriculture and local food production), salt would be the by-product, while the airport and surrounding buildings could use cold seawater for air-conditioning. Microalgae production could supply the island with new products, bioenergy, food and feed for animals (for example, for the goats that now can be kept behind fences to reduce ongoing erosion (see factsheet "Nexus Ecosystems"). Specifically, algae can be used to feed fishes, supporting an Aquaculture industry, another source of food for the island. Such scenarios not only supply the demands of the people of Bonaire, but could be further exploited to export products, giving additional income possibilities to island.

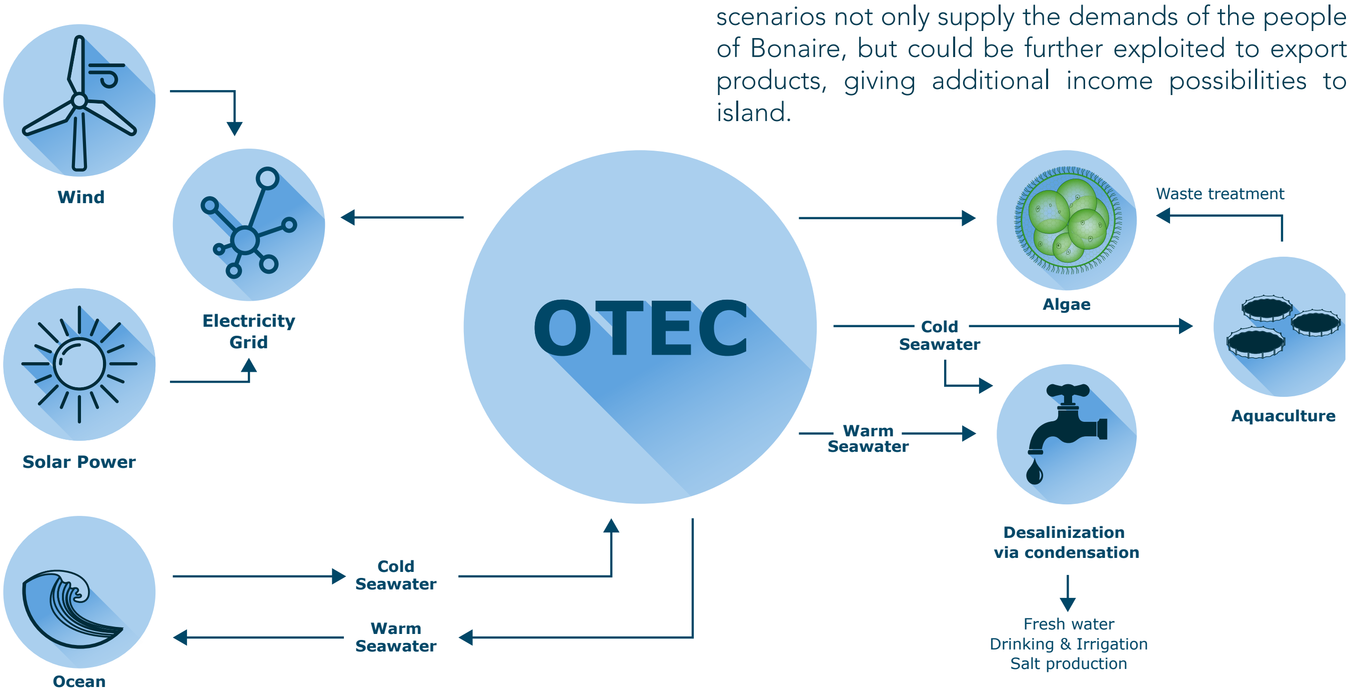
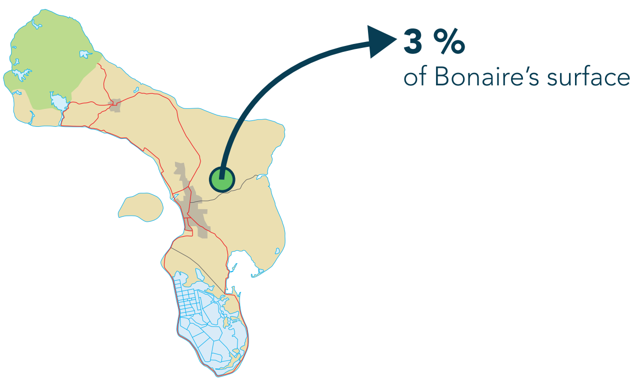


Figure 6. Example of how different renewable energy sources could be integrated to supply the full energetic demand of Bonaire while simultaneously contributing to energy, water, food and ecosystem security

Achievement of both the short and the long term transitions to renewable energy on Bonaire thus requires setting up a multidisciplinary integrated electricity network. This can only be achieved through:

- Provision of specific training for local communities to increase capacity building and prevent brain-drain. Integrate Energy Policy in Ecosystem Based Management plan
- By integration of the Energy Policy in an Ecosystem Based Management plan (see factsheet "Ecosystems", it will be possible to identify the best locations where wind/solar/algae farms should be developed, with regard to minimal impact to nature
- Establish investment projects to diminish risks for further development. For example, facilitate synergism between microalgae production and renewable energies, as illustrated in Figure 6
- Strong policies for sustainable development of the energy sector that is based on shared fact finding. The challenge is how to bring investors and stakeholders. For example, figure 7 shows how much of Bonaire's surface area is needed to replace the current use of fossil fuels (300 Barrels of Oil Equivalent/day) by biofuels produced in Algae farms and what other benefits can be achieved by doing so (pers. comm, Iago Teles)
- Setting stepwise targets for clean energy production. The best solution to avoid detrimental activities for the environment and local communities is to follow a stepwise approach. Targets must be set considering the appropriate scale for Bonaire while keeping energetic demands in mind
- Creation of a governmental funding body focused on clean energy for the region (to make risks lower to attract new capital, expertise and investments.)

Figure 7. Example of what can be achieved when allocating 3% of Bonaire's surface area for production of microalgae.



- **Sufficient electricity for the island**
- **Enough biodiesel for cars & planes**
- **Feed for goat farming**
- **Food products**
- **Potential to an export economy**

IDENTIFIED KNOWLEDGE NEEDS & CHALLENGES

- Qualified human resources: training is needed in all designed scenarios towards a more sustainable energy supply on Bonaire. Special training should be provided to cover the fields of sustainability, novel bio-based technologies, and specific training for each new industrial activities
- Integration of different fields/multidisciplinary approach setting targets. The most successful predicted scenario involves the integration of different technologies, a concept also known as Industrial symbiosis, where different technologies take advantage of the energetic surplus of each other and also can recycle each other's waste streams. Although integration of different technologies and different sectors will support the business case, it will increase complexity of decision-making and implementation
- Costs of bringing so much expertise together. Bringing different expertise's together to a relatively isolated region such as Bonaire can be costly. An advice is to set a network of experts to cover costs of mobility and training. It is essential that such network include stakeholders from the private sector, to guarantee that industrial needs are addressed. A network of this sort could be supported by National Dutch Program or European funds
- Investment risks for such a small market (Bonaire). A program to bring sustainable and bio-based development to Bonaire should include mechanisms (public policy) that could minimize the risks of setting up new sustainable energy sources to the island. Subsidies or public investments must be discussed and included in a broader program. Bonaire's small population is challenging to gather enough investments from the private sector to establish new enterprises. New sources of energy have a special attention in the local development plan, as the current prices for energy and drinking water are way too high considering the local average income

Factsheet 5. Energy 9

FUTURE PRIORITIES & RESEARCH NEEDED

- A full assessment of the integrated environmental impact of bringing a diversified energy grid to Bonaire must be the core of any considered intervention and should take an ecosystem approach combining an environmental and economic point of view (see factsheet 'Ecosystems')
- Assessing OTEC potential and environmental impact on the island. OTEC has the highest potential to supply electricity to Bonaire's grid in the long term. It is also fundamental to support new economic activities. However, OTEC might have impact on marine life, which should evaluated on forehand
- Cost analyses of new energy scenarios to confirm financial sustainability and compatibility with local people's economic power. A full assessment of the costs involved should be made available in future reports, as an additional tool to attract new investments to the island
- Social impact. Social impact for the lives of locals must be taken into consideration

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Colophon

January 2019

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Graphic design and lay out: Kinga Bachem

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Special thanks go to Hans Staring from WEB for sharing information.

The KB program "Nexus Strategic policy case", included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement