Gibraltar's Renewable Energy Strategy

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About this document

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The views and opinions expressed in this report are those of the authors and do not reflect the opinions of Her Majesty's Government of Gibraltar. The analysis is based on the data available at the time of writing, which were not exhaustive. This analysis does not constitute a basis for investment decision-making.

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1. Introduction

Her Majesty's Government of Gibraltar (HMGOG) has adopted the target of meeting at least 15% of Gibraltar's energy consumption from renewable energy (RE) sources by 2020. HMGOG wishes also to pursue the target of 27% of energy consumption from renewables by 2030, in line with proposed EU-wide targets.

This report highlights much of what needs to be done to encourage the deployment of renewable electricity capacity. Additional analysis of renewable energy options in the water heating, space cooling, and transport sectors may also be appropriate.

It presents a Technology Scenario that illustrates what Gibraltar's portfolio of RE technologies might look like in 2020 and 2030. This is based on the market-readiness of RE technologies, as well as the particular resources and deployment constraints found in Gibraltar.

It should be highlighted that the Technology Scenario is not definitive: the amounts of specific renewable energy technologies ultimately deployed may differ from what is presented. It is intended simply to be illustrative; and to provide a context for the actions that will need to be taken to facilitate the deployment of renewables.

The analysis takes into account the knowledge and opinions of a wide range of stakeholders interviewed during the course of the project. In particular, the Gibraltar Electricity Authority (GEA) has contributed its deep understanding of power sector issues in the peninsula, and provided much of the data that supports the analysis.

Chapter Two describes briefly how electricity is generated, distributed, and consumed today, as well as how electricity demand is likely to evolve in the timeframe of this analysis. It then continues to describe ongoing government initiatives, including targets for renewable energy deployment.

Chapter Three describes the potential value of renewable electricity to Gibraltar, in terms of economic benefit, energy security and environmental quality.

Chapter Four highlights the renewable energy technologies most appropriate for Gibraltar at present, and which of these offer the most value in terms of the aspects discussed in Chapter Three.

Chapter Five describes how HMGOG might achieve its targets for renewable energy share as described in Chapter Two. It presents the Technology Scenario to illustrate what the technology portfolio in 2020 and 2030 might look like.

Chapter Six provides a summary of findings and future research requirements.

2. Electricity in Gibraltar Today

Gibraltar is – electrically speaking – an island, having no interconnection to its neighbours. At present it is almost entirely powered by diesel engines, serving a geographically small, heavily urban and densely populated area. The power system of Gibraltar served a peak demand of 36.5 megawatts (MW) in 2014.

Like many isolated power systems worldwide, Gibraltar produces nearly all of its electricity using expensive, imported diesel fuel, which results in a high electricity production cost, as well undesirable environmental side-effects.

The power system is operated by a government agency, the Gibraltar Electricity Authority (GEA), and power plants are publicly owned, mainly by the government. The Ministry of Defense owns the ISGS power plant, which is operated by GMES, a government owned company[1].

The power system in Gibraltar – as elsewhere in Europe – was not planned as a single entity. Rather, it has grown "organically" to meet the demands of a growing population. The distribution network is essentially an amalgamation of three distinct, almost entirely cabled (underground) networks, connected to the three main power plants on the peninsula – Waterport, ISGS, and the South District Power Station[2].

All three power plants are of different manufacture, age and unit size, requiring diverse operating approaches. All are old, subject to reliability failures [3] resulting in black-outs, and produce high noise emissions, as well as oxides of nitrogen (NOx) and particulate emissions (see Section 3.2).

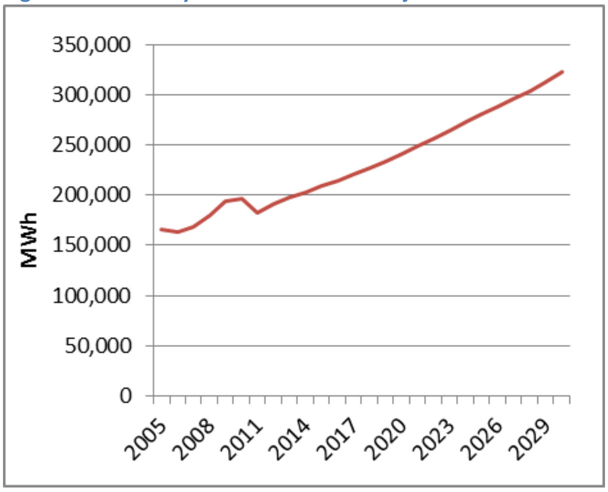
[1] "Inter Services Generating Station" operated by Gibraltar Mechanical & Electrical Services Ltd. (GMES).
[2] Previously operated by Ormrod Electricity Supply Company Ltd. (OESCO).
[3] There was for example a major fire at the Waterport power plant in April 2014, which has resulted in the permanent closure of one unit.

To help manage reliability issues, a number of temporary plants have been installed, notably on the North Mole, although these too have brought new operating challenges.

2.1 Electricity Demand

As Gibraltar's demand for electricity has grown, so new generating capacity has been installed to meet it. Demand is projected to continue to grow, in line with economic growth, physical growth (land reclamation) and development of new buildings, as illustrated in Figure 1.

Figure 1: Electricity Demand Growth Projections for Gibraltar



Source: GEA

Some capacity may only be required for a matter of a few tens of minutes in the day, to meet "peak demand", which in Gibraltar occurs at around 13h in the summer and 19h – 20h in the winter. Again, this phenomenon is common elsewhere.

At present, relatively little data has been collected of the demand profile (this describes when electricity is used and for what purpose). Thus the shares of total consumption of different end-users (e.g. residential, commercial, industrial) are unknown. Nor is it yet known how these shares fluctuate during the day, or exactly what the electricity is being used for (e.g. water heating, space cooling, lighting, appliances).

Knowledge of the demand profile is invaluable for planning generation capacity additions, as well as for planning when to start / stop existing capacity. Such data would also indicate what opportunities exist in Gibraltar to shift electricity demand – without interrupting services (e.g. heating and cooling) – to better fit with electricity supply.

2.2 Government Initiatives

The Government has committed itself to deliver a number of significant upgrades to electricity provision in Gibraltar, embracing modern approaches to both conventional and renewable energy technologies.

2.2.1 Conventional Energy

Gibraltar has considered more than one conventional solution to its energy needs in recent years. Variables have included location and fuel type. The Government has accepted a tender from Bouygues Energies to deliver six MAN engines of 13.2 MW or 14 MW each, to a total plant output of 80MW.

Three units will be gas-fired and three more will have the capability to be fired by both gas and diesel fuels. This distinction is intended to enable diesel-firing of the engines in the event of liquid natural gas (LNG) supply being unavailable.

LNG fuel is preferable for its reduced emissions and lower cost, relative to diesel fuel. It will require the development of new LNG delivery infrastructure, including transport, regasification and storage.

Importantly, this move to modernise conventional electricity production will be highly advantageous to the uptake of renewable energy technologies. Modern gas engines are very flexible – able to increase or decrease output with little notice. Consequently, their operation can be more easily adjusted to fit in with the shifting output of RE technologies such as solar and wind power, which varies according to the weather. The "intermittency" presented by some renewable technologies is thus made more manageable.

As more renewable energy capacity is deployed, its output will increasingly displace the burning of gas fuel, reducing conventional production costs, while these plants will be maintained to provide reliable electricity when renewable power plants are not generating.

2.2.2 "Smart" Electricity Meters

The GEA is planning the roll-out of smart meters. Pilots are expected to take place at the Laguna Estate, the Beach View Terraces development at the Aerial Farm site and in other housing estates around Gibraltar. This will provide valuable knowledge of the domestic demand profile described above.

2.2.3 Renewable Energy

HMGOG has embraced the UK's target of 15% of energy to come from renewable energy technologies in 2020, and would like to go further, to meet the EU-wide target of 27% in 2030.

The targets are stated in the Government's National Renewable Energy Action Plan (NREAP), as part of the requirements under Gibraltar's Environment (Promotion of Energy Produced from Renewable Sources) Regulations of 2011.

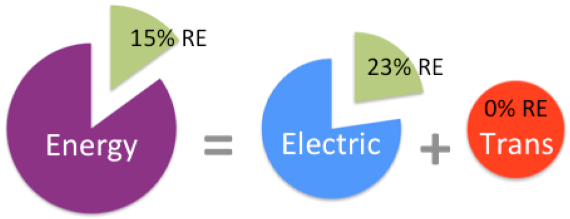
The 15% and 27% energy targets could be achieved in 2020 and 2030 respectively by "greening" energy supply in one or more of the three main energy use sectors: electricity, transportation, and building heating and cooling.

However, as nearly all heating and cooling in Gibraltar is done electrically (as opposed to being gas-fired as in the UK for example) greater effort will be required in other sectors. Greening of the transport sector, although an important avenue for exploration, was not included in the scope of this analysis.

Electricity is by far the dominant form of energy consumed in Gibraltar. Although data on its share of total energy consumption are not currently available, discussions with stakeholders suggest a share of around two thirds.

Assuming then that electricity amounts to two thirds of energy consumption, the rest being transport, and assuming transport remains conventionally powered, then the 15% of energy consumption target translates into a share of approximately 23% of electricity in 2020 (Figure 2).

Figure 2: HMGOG Energy Targets If Met By Electricity Only



Source: NRP analysis

Similarly, the 27% of energy consumption target in 2030 translates into a share of approximately 41% of electricity.

The assumption that transport would remain conventional up to 2030 is a significant one. If this is not the case, and for example the use of electricity or biofuels in transport is seen in the intervening period, this would have an impact on the proportion of electricity to come from renewable energy sources.

The Government has responded actively to a number of proposals from private sector developers to install solar PV and wave power, among other technologies. Comprehensive assessment of such proposals is needed to ensure that estimates of energy output are reliable, that the technologies themselves are reliable, that they are cost effective, and that their impact on the existing electricity system is manageable.

The Government has signed a power purchase agreement (PPA) with a wave power technology company, which plans to install a demonstration plant of 100 kW, with the potential to increase up to 5 MW in due course.

A PPA has been signed with a solar PV investor, which intends to install arrays at the megawatt scale. Smaller solar PV arrays have already been deployed in a number of locations, including at the GASA Swimming Pool.

HMGOG is investigating the possibility of installing wind turbines at the Beach View Terraces housing development, while an opportunity may exist to generate electricity from waste as part of the planned municipal solid waste management plant[4]. Finally, the Government has also carried out a preliminary marine current resource assessment.

[4] The Government of Gibraltar has requested tenderers for the new municipal solid waste plant to consider opportunities to generate electricity from waste disposal, based on advanced thermal technologies such as gasification and pyrolysis.

3. The Value of Renewable Energy to Gibraltar

Cost benefit analysis of renewable energy is fraught with potential pitfalls. For example, how should one value the so-called “external costs” of a technology – shorthand for the positive and negative costs that are not commonly quantified in economic analysis, usually because it is very hard to do so.[5]

A simple comparison of the capital (investment) costs associated with different types of power plant – as is often done – is also insufficient. Some technologies are able to operate more or less around the clock (such as gas and diesel fuelled plants), unlike weather-dependent renewable energy technologies. For example, a gas-fired engine can produce more electricity over a year than the same capacity of solar PV (and so is said to have a higher “capacity factor”).

On the other hand, gas-fired engines require costly fuel that must be imported – unlike renewable technologies that exploit a free and local resource.

One of the more subtle errors is to overlook cost impacts on the wider power system. These may relate to increased cycling of conventional power plants – to fit in with fluctuating RE output – which were not designed for such; or the cost of the distribution network, which may be less used by a building that is now producing its own electricity with solar PV.

These and other elements need to be considered when comparing the cost of conventional and renewable energy technologies; and comparison should be done in terms of the cost of electricity generated – rather than simply the cost of the power plants’ installation.

[5] Recent analysis from Imperial College in London has shed new light on the extent of these external costs. See http://www.icroa.org/42/icroa-research/

3.1 Cost of Electricity Production

At present, the production of electricity in Gibraltar using diesel fuel is very expensive, as is the case in many small, isolated power systems. A direct cost-comparison with, for example, the UK would be misleading (Gibraltar being unable to take advantage of the wider range of fuels, more efficient generator types, and economies of scale in the latter), but it is nevertheless important to note that electricity in Gibraltar is much more expensive[6]. This difference in cost means that while solar PV, for example, is not yet fully competitive in the UK, it can compete in Gibraltar, where in addition it is helped by a far superior solar resource.

The largest component of the operational cost in Gibraltar is fuel, the price of which has increased fourfold over the last ten years. As shown in Figure 3, the crude price (which is closely followed by diesel prices) is also subject to great volatility.

This volatility has been strikingly demonstrated in recent months during which the price of crude has fallen by more than 45%[7]. While in this instance, this fall may work in Gibraltar’s favour, the past has shown that the price can recover quickly.

Figure 3: Crude Oil Price (2003 – 2013)

Note: The graph shows the price in $/barrel on the y-axis and the timeline from July 2003 to July 2013 on the x-axis.

Source: S&P Capital IQ

Liquefied natural gas (LNG) also is costly, though less so than diesel, and the price will be subject to

[6] According to the UK Government: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65713/6883-electricity-generation-costs.pdf

[7] This is the difference in the price of Brent crude in April 2014 and 2015.

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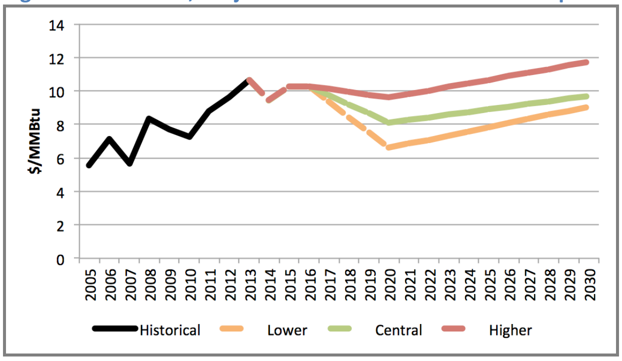
market and other forces beyond Gibraltar's control. Gas prices in recent decades have not shown as high volatility as oil prices. However, and despite recent low gas prices in the wake of the shale-gas revolution in the USA, gas prices may rise from 2020 (Figure 4).

Figure 4: Historical, Projected Natural Gas Prices in Europe

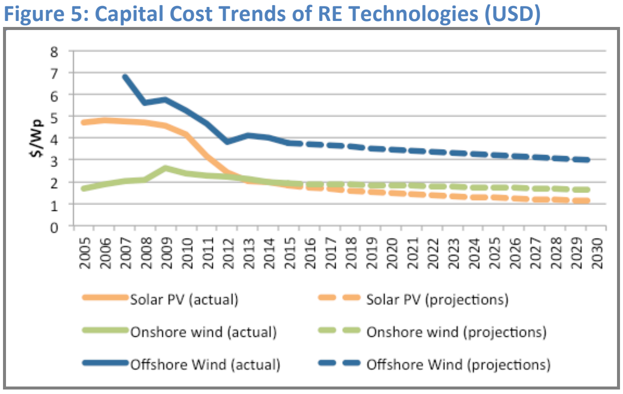


Source: Bloomberg New Energy Finance projections

Moreover the price of gas may also be subject to short-term fluctuations, as upstream production is influenced by geopolitical events. These may be muted by recently geographically diversified gas production (as in shale gas extraction in the USA), but nevertheless represent risk for decades to come.

In contrast, the cost of RE technologies has steadily decreased over the last ten years (Figure 5). Unlike conventional technologies, the cost of operating RE technologies is very small, as there is no fuel component. It follows therefore that there is also no exposure to fuel price volatility.

Figure 5: Capital Cost Trends of RE Technologies (USD)



Note: the lift in wind technology costs (and the humped solar PV curve) related mainly to component supply tightness.

Sources: BNEF (solar PV), IRENA (wind)

3.2 Reduced Local Pollution

Diesel engines, particularly older units, may emit considerable amounts of local pollutants, in particular oxides of Nitrogen (NOx), and tiny particles of soot and other potentially carcinogenic materials, collectively referred to here as PM10[8]. Older units may also be very noisy.

In addition, the combustion of fossil fuels, including diesel, is a major source of carbon dioxide (CO_2) (although in the global perspective the absolute amounts emitted from Gibraltar are negligible).

The negative economic impacts of these emissions fall into the category of "external" costs mentioned earlier. They are very complex to quantify and this analysis does not attempt to do so. However they too should be borne in mind when considering the economic benefit of renewables.

3.3 Indigenous Energy

At present, Gibraltar depends on imports for 100% of its energy needs, having no fossil fuel resources of its own. This will remain the case after deployment of the new conventional power plant, if no renewable capacity is deployed.

As long as imports remain the mainstay of energy procurement, the question of Gibraltar's resilience in the face of supply shocks will remain. Rising price and the risk of volatility, coupled with the bulkiness of fuel and resulting limitations on its storage, suggest a significant value in reducing fuel consumption, which would both reduce the cost of imports and well as increase the duration of stocks on (or off) Gibraltar.

[8] Particulate matter with a diameter of 10 microns or less.

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3.4 Reliable Electricity

The output of such technologies as solar PV and wind power is variable – output increases and decreases in line with the weather – and uncertain, which is to say that exactly when it does so cannot be forecast with complete accuracy. In contrast, electricity production based on the combustion of a storable fuel such as diesel or gas, can be planned regardless of the vagaries of the weather.

But a high share of solar PV, for example, does not imply reduced reliability. In terms of annual averages, output can be predicted with good accuracy, which will give a clear idea of the conventional fuel savings to be had from a given capacity of solar PV.

Precisely when output will occur is less certain however. Thus the need to ensure that the planned new gas/diesel-fuelled engines are able to increase / decrease output as necessary, to correspond with the fluctuating output of renewables. With a high share of electricity supply from renewables it may in due course also be necessary to supplement this flexibility with battery storage. Alternatively demand-side response, facilitated through smart meters, may serve.

4. Renewable Energy Technologies

The term "renewable energy" incorporates a large number of technologies, differing considerably, and of which only some will be appropriate to Gibraltar. Based on existing knowledge of the resources present, we have selected six technologies for assessment, as follows.

1. Solar photovoltaic (PV).
2. Wind energy on land.
3. Wind energy offshore.
4. Wave energy.
5. Marine current / tidal energy.
6. Waste-to-energy[9] (W2E).

4.1 Assessing the Options

A simple feasibility study of these technologies follows. This examines technology maturity, cost, energy resource, data relating to that resource, constraints on sites for deployment, and integration aspects. ("Integration" refers on the one hand to the connection of power plants to the distribution network, and to the management of their output on the other.)

We use a simple "traffic light" graphic to score each characteristic. In addition, each technology is given an overall grade, which indicates its overall appropriateness to Gibraltar at present.

It should be noted that this initial appraisal is based on a limited data set; further analysis will require more complete data.

4.1.1 Solar Photovoltaics (PV)

Maturity. PV technology for converting solar radiation to electricity has matured to the point where it is being deployed at an ever-increasing scale worldwide. Crystalline silicon (c-Si) remains the dominant material, although younger technologies may challenge this status quo in the period assessed in this analysis (to 2030). Present day commercial c-Si conversion efficiencies can reach above 21%, and continue to rise[10].

Cost. Cost reduction has been steep – over 60% in average CAPEX since 2005 (see Figure 5). PV electricity is cheaper than diesel alternatives in most island situations [11] and is increasingly competitive with fossil fuels in larger power systems also. Global levelised cost of electricity (LCOE) in 2013 varied in the range of 9-18p/kWh.

Resource. The solar resource in Gibraltar is good, with an average annual irradiance (GHI) of 199W/m^2, indicating a capacity factor of around 21%[12], according to the European Commission's PVGIS tool[13]. Local resource data is available also, and will be important to assess the impact on these values of the Levanter cloud formation and the Rock's shadow.

Siting. Deployment locations are constrained by dense urban development on the one hand, and by sites that are protected for environmental reasons, on the other. Ground-mounted solar PV arrays are perhaps unlikely to be viable. However, there appears to be significant potential for installation of arrays on rooftops and in due course as wall cladding in the newer, larger-scale building stock away from the old town.

Integration. The existing grid connections of this modern building stock are likely to be sized for high load, reducing the likelihood that utility scale solar PV will require significant upgrade to the connection. Finally, the variability of output of solar PV will be a major consideration. Sudden and/or prolonged cloud cover will have significant impact on PV output and will need to be planned for.

[9] W2E in the analysis refers to advanced thermal treatment of municipal solid waste such as through gasification or pyrolysis, rather than more simple methods such as incineration.

[10] Conversion efficiency is the ratio of the electrical output to the energy incident on the photovoltaic panels from the sunlight at standard test conditions (25^{o}C and 1000W/m^2).

[11] Gibraltar can be considered an electrical island given that it is not interconnected with any of its neighbours.

[12] Capacity factor is the ratio of actual electrical output to the idealised output at full capacity.

[13] This tool is available at: http://re.jrc.ec.europa.eu/pvgis/

	Maturity	Cost	Resource potential	Resource data	Site constraints	Connection & Operation	Overall Feasibility
Solar PV	Green	Amber	Green	Amber	Amber	Amber	Green
Onshore Wind	Green	Amber	Green	Amber	Red	Green	Amber
Offshore Wind	Amber	Red	Amber	Red	Amber	Red	Amber
Wave	Red	Amber	Amber	Red	Amber	Green	Amber
Tidal Current	Red	Red	Amber	Amber	Amber	Red	Red
Gasification / Pyrolysis	Amber	Amber	Red	Amber	Green	Green	Amber

Table 1: RE Technology Assessment in Gibraltar

4.1.2 Onshore Wind

Maturity. Wind turbines may rotate on either a horizontal or vertical axis. By far the more common of the two, the horizontal axis type is mature and can be cheaper than solar PV, where the resource is strong.

Vertical axis technology is less mature, which may result in lower efficiency and higher cost. However, vertical axis technology may be more suitable for small-scale applications, such as the tops of buildings. The main advantages of vertical axis machines are 1) lower sensitivity to wind direction, and 2) greater space efficiency than horizontal axis turbines. The helical blade design makes for quiet operation, which is important in an urban setting.

Cost. The LCOE of onshore wind in 2013 ranged between 5-14p/kWh. Given that in Gibraltar projects are likely to be of small scale, the cost is likely to lie closer to the upper value.

Resource. According to wind resource data collected around Gibraltar Airport[14], the average annual wind speed is around 6 metres per second (m/s) at a hub height of 10m for 70% of the time. This is adequate for small-scale installations[15]. However, this estimate should be supplemented with more measurements at project sites and likely hub heights[16].

Siting. The amount of land on which conventional, horizontal turbines could be mounted is very constrained by the potential for negative visual and ecological impacts. Onshore deployment may be limited to smaller installations on buildings.

Integration. At small-scale, grid connection is unlikely to be problematic. System operation with onshore wind is perhaps easier than with solar PV because although the resource is variable, it can be easier to predict in the short term[17].

4.1.3 Offshore Wind

Maturity. Offshore wind energy technology is less mature and more expensive than its cousin on land. It is both younger and more challenging to deploy. However, the experience of the offshore wind industry is growing rapidly. Currently in Europe operational capacity equals 9 GW; market commentators expect this to rise to 112 GW by 2030.

Cost. It is difficult to predict the deployment cost in Gibraltar. Individual projects, for example on UK,

[14] Data was provided by Ricardo-AEA.

[15] Wind speeds required for an effective wind project: http://www.deac.co.uk/Editor/Files/Small-scale-wind.pdf.

[16] Hub height is the distance between the turbine base to the central axis of the rotor of the turbine.

[17] For a discussion on the intermittency of solar PV and wind please refer to: http://cleantechnica.com/2013/08/12/intermittency-of-wind-and-solar-is-it-only-intermittently-a-problem/

German and Danish coasts, differ so much from one another that direct comparison among them can be misleading; and cost reduction over time is hard to project. The UK Department of Energy and Climate Change expects capital costs to decrease by up to 43% by 2040, relative to 2009 levels[18]. Current European CAPEX is observed between GBP 1.9 million per MW and GBP 2.6 million[19].

Resource. European wind atlases indicate that an average wind speed of between 6-7m/s might be expected off the East coast of Gibraltar, which would translate into a 35% capacity factor, which is moderate for offshore deployment. However, local offshore wind data does not yet exist. For this analysis, we have created a data set extrapolated from onshore values[20].

Siting. The main siting constraints are likely to be shipping routes and anchorages, marine habitat protection, defense issues, and water depth. These factors are well understood, although further data on seabed conditions are required.

Integration. As individual offshore wind turbines are powerful (3.6 MW is common in UK developments at present), they would need to feed in to a strong point on the 11kV network, most likely at the site of the new LNG/diesel fired station. For the same reason, system operation can be an issue in case of a sudden loss of a turbine. This might be helped by the deployment of batteries in due course.

4.1.4 Wave

Maturity. Wave energy can be converted into electricity in a number of ways. Prototypes, demonstration plants, and pilots exist in many forms. The fact that individual technologies have not yet emerged to dominate the field probably reflects the relative immaturity of wave energy technology generally.

Cost. The costs of demonstration projects in Gibraltar are assumed in this analysis to lie at a similar level to those in Great Britain, in the range of 38p-48p/kWh.

Resource. Given Gibraltar's peninsular geography, it is possible that resource potential is high, although no comprehensive data has been collected so far. Data from locations with a similar resource indicate a possible capacity factor of around 20%.

Siting. Wave energy technologies may be mounted on the shore or anchored offshore. If offshore they may be visible on the surface, though low-lying, or anchored so that they remain submerged. Siting constraints are likely to revolve mainly around the natural and protected habitats, as well as shipping routes, existing cables and pipelines.

Integration. The size of existing installations suggests the need for connection to a strong point in the network. A significant advantage is the relative predictability[21] of output in comparison to solar PV and wind technologies.

4.1.5 Marine Current

Maturity. Marine current technologies convert the kinetic energy held in tides and currents into electricity. Water passes through one or more submerged rotors, driving a generator[22], not dissimilarly to wind passing through the rotor plane of a wind turbine.

Similarly to wave energy, a clear technology has yet to become dominant. This fact, combined with limited experience of deep-water installations, suggest that considerable research and development, and demonstration projects, will be

[18] For projections of wind power price reductions, please refer to a report by IRENA: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-WIND_POWER.pdf

[19] Costs according to DECC, "Renewables Obligation Banding Review 2013-2017"

[20] The extrapolation was based on the "Power Law" as outlined, for example, by the University of California Santa Cruz: http://es.ucsc.edu/~jnoble/wind/extrap/index.html

[21] See recent study on the predictability of the wave energy resource: http://vbn.aau.dk/files/75674382/Predictability_and_Variability_of_Wave_and_Wind.pdf

[22] The second prominent tidal energy technology is tidal range, which harnesses the difference in height between high and low tides using an artificial tidal barrage or lagoon.

necessary to bring the technology to commercial maturity. Thus marine current technologies may yet represent an important opportunity for Gibraltar in the period considered in this analysis.

Cost. Cost is still high due to the novelty of technologies. According to Bloomberg New Energy Finance, the technology is expected to reach commercial viability by 2020 when a number of projects are expected to go beyond 10 MW. Global marine current projects have averaged a cost of 28p/kWh in 2013.

Resource. A study of two different locations off Gibraltar, at 26 and 37 meters depth respectively, indicate average current velocities of 1.2m/s[23]. While this would be sufficient to drive medium-size turbines (up to 1 MW for example), only a low capacity factor (up to 15%) would be achieved at such velocities. This suggests a weak economic rationale for this technology. However, given the strength of anecdotal evidence of the resource, it would seem appropriate to engage in more comprehensive analysis of the resource, prior to deployment of demonstration plants.

Integration. Connection of marine turbines to the grid could require the installation of electricity cables at a depth of 50 metres or more. While not challenging from a technical perspective, this would represent an additional cost. On the upside, the output of marine current turbines tends to be very predictable, limiting the likelihood of significant impact on system operation.

4.1.6 Waste-To-Energy

Maturity. Advanced waste-to-energy (W2E) technologies, such as gasification or pyrolysis, convert waste into a variety of energy products. They are both relatively young technologies.

Possible feedstocks (to fuel the process) include municipal solid waste, biomass, wood waste, and plastics. The two technologies are similar in many ways though they operate at different temperatures. Both produce a synthetic gas (syngas), unlike more conventional incineration technology, which uses the heat given off in the combustion of waste to produce steam to drive a turbine.

Resource. After recycling and extraction of non-combustible materials, the available waste feedstock in Gibraltar is currently around 15,500 tonnes per year, suggesting a maximum plant size of 1-2 MW, at present likely conversion efficiencies (0.5-1.3 MWh per tonne)[24].

Siting. A previous incinerator at Europa Advance Road has been dismantled, and this site is likely to be appropriate for a new W2E plant.

Integration. The output of W2E plants, as with conventional generation (e.g. diesel and gas), is not governed by weather conditions. Therefore, assuming that the design is appropriate for the feedstock available and that the plant operates effectively, W2E technology should pose no additional challenge from an integration perspective[25].

4.2 Case Studies

The following section consists of short case studies of different RE technology deployments in Great Britain. These are intended to illustrate the RE technologies that may be appropriate in Gibraltar. However, the deployment contexts of the two locations are quite different – solar resources in Gibraltar for example are much greater – and the projects described should not be assumed to be directly applicable to Gibraltar.

Rooftop Solar PV: Bentley Factory in Crewe

Completed in March 2013, this rooftop solar PV power plant is one of the UK's largest. It consists of

[23] According to a report prepared by Van Oord for the Government of Gibraltar (April 2013).

[24] As identified by CleanTech Consulting: http://www.slideshare.net/olsenii/ibd-clean-tech-w2e-presentation

[25] It should be noted that the previous incinerator plant suffered from continuous stoppages due to technical problems, resulting in its decommissioning early on in its life. Due attention needs to be paid to choosing mature technology to avoid a similar recurrence.

over 20,000 solar panels covering an area of 34,500 m^2 resulting in a system size of 5.2 megawatts-peak[26] (MWp) generating 4,500 MWh per year[27], and supplying up to 40% of the factory's electricity requirements. The system contributes CO_2 savings of 2,558 tonnes annually. Bentley has an agreement with Lightsource Renewable Energy, under which it uses electricity generated during working hours, while Lightsource exports it to the grid at weekends, and other times of low demand. According to the developer (SolarCentury) the panels were installed at an average rate of 700 a day.

Figure 6: the Bentley Factory in Crewe[28]

Solar PV Façades: CIS Tower in Manchester

In 2005, the CIS tower in Manchester was fitted with solar PV modules on its central service tower, which previously had been covered with grey tesserae. In total 7,244 Sharp 80 Watt modules were used, amounting to 0.4 MWp, and delivering approximately 183 MWh of electricity per year, which meets 10% of the building's energy needs and saves 104 tCO_2 annually. It has been feeding electricity into the National Grid since November 2005. The project demonstrates how solar PV can be incorporated into building refurbishments as an alternative to conventional building materials.

Figure 7: the Solar PV Façade in Manchester[29]

Rooftop, Vertical Axis Wind Turbines: Fairview Homes in Croydon

In 2009, eight roof-mounted vertical-axis wind turbines (VAWTs) were installed on a Fairview Homes development in Croydon. The turbines are mounted on 6m masts, have a capacity of 6.2 kW and can deliver up to 10 MWh of energy per year. The supplier guaranteed a capacity factor between 8-20%.

Small-Scale Offshore Wind: Blyth

Commissioned in 2000, this 4 MW wind farm was the first to be built in UK waters. It consists of two 2 MW turbines that deliver up to 6,000 MWh of energy per year, and save 2,000 tCO2 annually. It is located a mile off the Northumberland coast at a maximum water depth of 11m[30]. Current plans consider expanding the wind farm to 100 MW.

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[26] MWp (Megawatts Peak) represents the maximum output. PV relies on solar irradiation, which peaks at noon; output at other times will be lower. Note that the UK solar energy resource is significantly lower than in Gibraltar. The same plant in Gibraltar would generate considerably more electricity.

[27] 4.5 GWh is approximately 2.3% of Gibraltar's overall energy consumption. However, a 5.2 MWp system would deliver more energy in Gibraltar than the UK due to a higher capacity factor resulting from better resource.

[28] Picture source: http://www.lightsource-re.co.uk/operational-assets/case-studies/3-5/bentley-factory-5-0-mwp/

[29] Picture source: http://www.sharpmanufacturing.co.uk/cps/rde/xchg/sukm/hs.xsl/-/html/cis-tower-manchester.htm

[30] Likely water depths in Gibraltar are deeper than this, closer to 60m.

Figure 8: an Offshore Wind Turbine at Blyth[31]

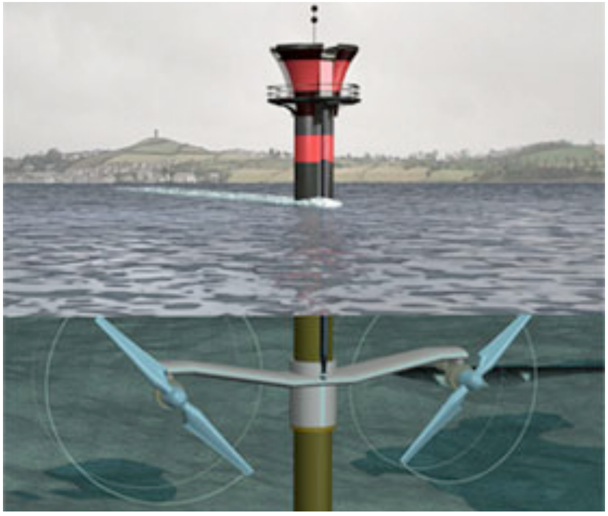
Wave Energy: European Marine Energy Centre on Orkney

Pelamis and ScottishPower have deployed two 0.75 MW "Pelamis" wave devices two km west of Orkney. To date, the test programme has accumulated 10,000 grid-connected operating hours and has exported over 200 MWh of electricity to the grid. The proven average output capability of the device is now close to 200 kW, and is expected to improve as testing progresses. Pelamis has conducted a number of projects elsewhere in Europe, including a 2.25 MW demonstration in Aguçadoura in Northern Portugal.

Marine Current Turbine: Strangford Lough in Northern Ireland

The Seagen "S" 1.2 MW device was the world's first grid connected commercial scale tidal device. Since its installation in August 2008 it has generated over 8,000 MWh of electricity. It is planned to deploy a two-megawatt, 20-meter diameter rotor. Commercial arrays are planned for installation in UK waters in 2015. The project appears to have had negligible environmental impact on marine life (which had been a concern previously).

Figure 9: Illustration of a Seagen Marine Current Turbine[32]



4.3 What Other Energy Options Might Be Considered?

Which renewable energy technologies to deploy is only part of the question. There are a number of related technology options that can have a major impact on the overall efficiency of electricity provision in Gibraltar. Assessment of these was beyond the scope of this study, but full analysis of them should be done in due course as they may have important bearing on the opportunity to deploy renewable energy in Gibraltar.

Electricity Storage

Storage technologies provide the opportunity to set aside electricity for use at a later time. Such technologies tend to be able to discharge the electricity stored very quickly; consequently they can be a valuable complement to the deployment of large shares of renewable energy capacity.

Electricity storage is mainly done in pumped hydropower plants, in which electricity is transformed into potential energy. Recent technology advances however mean that electricity can increasingly be stored efficiently in

[31] Picture source: http://www.dynamoelectrical.com/offshore-wind/

[32] Picture source: http://www.renewableenergymagazine.com/article/ocean-power-generator-riding-high-as-siemens

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battery form, which is likely to be more applicable to Gibraltar.

Energy Efficiency

Increased efficiency of electricity consumption results in the provision of the same services or value to society, but using less electricity. For example, Gibraltar has begun to deploy LED technology in street lamps, which uses much less electricity.

Energy efficiency measures can reduce peak demand, meaning that less installed capacity is required. Measures to increase energy efficiency include improved building insulation, education on energy-use, efficiency labeling on electrical appliances to inform consumers, and more efficient appliances (e.g. fridges, boilers, air-conditioning systems, washing machines, etc.).

Demand Side Response

Because it is inefficient to use expensive generators only for short periods, many countries, including for example the UK and France, have introduced "time-of-use" tariffs. These encourage consumers to move their demand to off-peak times, and thus reduce or at least slow down demand growth at peak times. Gibraltar has not introduced such measures, with the result that total capacity has simply had to grow to meet its peak demand.

Demand side response may also ease the integration of variable output renewables such as solar PV and wind power. At high market penetration of solar PV, shifting demand to the midday peak when PV output is greatest will ensure that surplus solar electricity is minimised, thus maximising the value of the solar capacity installed, also resulting in less need for storage, and reduced electricity demand at other times of day.

In addition, electricity demand that can be reduced at short notice – without affecting the services provided, such as refrigeration – can reduce the impact on system frequency that might otherwise result from rapid drops in solar PV output due to moving cloud cover for example.

Electric Vehicles

Although this analysis considers renewable energy solely in the electricity sector, it is recommended that a study be conducted to analyse the potential for greening the transport sector also. It is expected that the most potential would lie in electric and hybrid vehicles, being the most mature of all available alternative propulsion technologies.

Electric vehicles are also attractive conceptually, as a complement to renewable electricity production. When connected to the power system for charging they could represent an electricity storage capability – of use in periods of surplus RE output. Connected vehicles might also discharge electricity into the network, when electricity output from conventional or renewable plants reduces sharply. Such applications remain at the conceptual stage although they may become more relevant over the period to 2030.

4.3.1 Trade-Offs

Considering the opportunity for each RE technology in isolation should be avoided. The output of different technologies may be negatively correlated, meaning that they produce output at different times (i.e. they complement one another). This is an important aspect for which local, hourly resolution resource data for all technology options are required.

There may also be trade-offs to be considered among technologies – i.e. occasions where rather than being complementary they are to some extent mutually exclusive. Two examples are highlighted below of technologies competing for the same resource. Both at this stage represent areas for further analysis.

Solar PV or Solar Water Heating?

Although SWH technology is not considered elsewhere in this analysis, which is related to electricity only, it is appropriate to mention it here because its deployment should be considered alongside that of solar PV technology.

Both solar PV arrays and solar water heating (SWH) units must be mounted on a flat area that is angled towards sunlight, ideally south-facing[33]. The most appropriate locations in Gibraltar are on the tops of buildings, and thus the two technologies may in some cases compete for the same space.

Unlike solar PV arrays, which convert solar radiation into electricity, SWH panels heat up a working fluid, often water, which is then distributed into the building on which it is mounted. SWH is cheap, mature and in the case of Gibraltar displaces the use of electricity (unlike for example in the UK, where the majority of heating comes from gas).

SWH is suitable for both residential and commercial buildings only where there is significant demand for hot water (in the absence of a district heating system). For example, a building may have a large and appropriately positioned roof space for a SWH array but only a small demand for hot water. The same space, on the other hand, may be appropriate for a solar PV array as the electricity produced can be fed into the electricity grid and consumed elsewhere also.

Little is known about the proportion of electricity demand used for water heating in Gibraltar. Smart meters could help in this regard, and indicate appropriate sites for SWH deployment. This would in turn support the appropriate apportioning of SWH versus solar PV at a given site.

Waste-To-Energy or Recycling?

At present, the majority of waste in Gibraltar is either separated and sent to Spanish re-processors, or landfilled. While it may be more appropriate environmentally to recycle some waste streams, it should be noted that to do so is to reduce the feedstock available to a putative W2E plant.

Critics of W2E technology argue that recycling is in all cases preferable, and that energy recovery from waste undermines the drive for recycling. In any case, this trade-off is an important factor in the design of a W2E plant as fuel stock flexibility and scale are important factors.

When considering this tradeoff, the following characteristics are important: the cost of both options; market demand for the outputs of recycling; and the feedstock flexibility of the W2E technology under consideration. The last point is critical: only some forms of waste will be appropriate – others will need to be recycled or landfilled.

[33] SWH may also be referred to as solar thermal. This can mislead however: there are other technologies that can be described as solar thermal, which are very different, in some cases operating at much higher temperatures, and to produce electricity.

5. Deployment Potential

HMGOG aims to achieve the UK's target (set by the EU) for the amount of energy supplied by renewables by 2020. This stands at 15% of total final energy consumption[34]. As discussed in Section 2.2, if we assume that the target will be met solely through changes in the electricity sector, then the 15% target translates into a 23% target of electricity to be generated by renewables.

In this chapter, we highlight one possible technology deployment scenario. It is an illustration only, and reflects the technologies already identified as likely to be appropriate in Gibraltar's case.

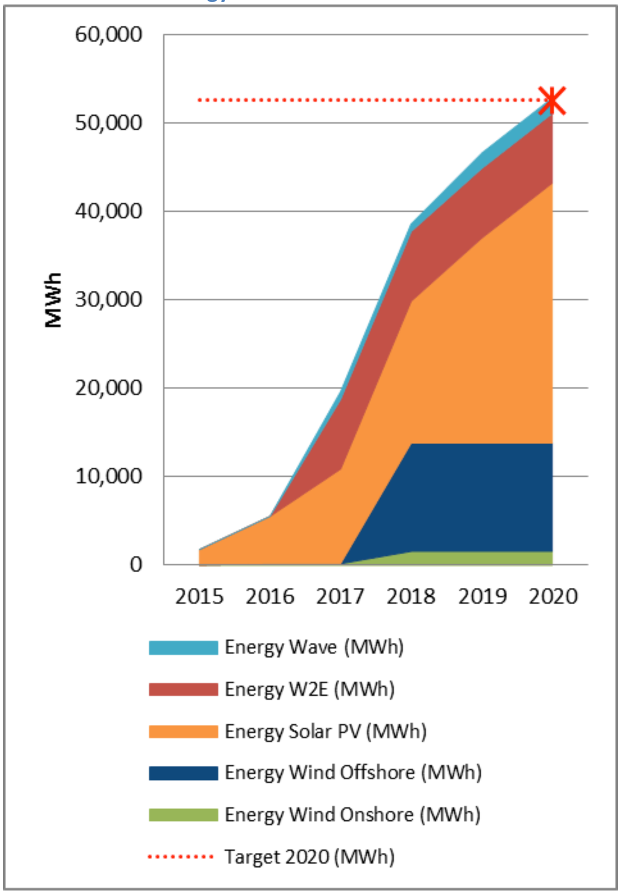
The charts below illustrate the amount of capacity that could be deployed, and when, over the period to 2020. Given that 2020 is only five years away, mature technologies are favoured. We also take a cautious look at 2030 although it should be noted that much technology disruption could occur in the meantime, affecting energy outcomes.

The capacity needed to meet renewable electricity targets will depend on the strength of renewable energy resources, which have yet to be measured in sufficient detail. This analysis is based on best available data at the time of writing. If the resource in reality is stronger, the required capacity will fall, and vice versa.

5.1 Renewable Pathways to 2020

This analysis assumes an electricity demand of 43.4 MW in 2020. A 23% target of electricity would therefore correspond to approximately 52,600 MWh, as illustrated by the dashed line in Figure 10 (electricity demand is not shown)[35]. The figure also shows the amount of electricity provided annually up to 2020 from each of the five renewable energy technologies included in the illustrative Technology Scenario, in order to meet the 23% target.

Figure 10: Renewable Electricity Supply to 2020 in the Illustrative Technology Scenario



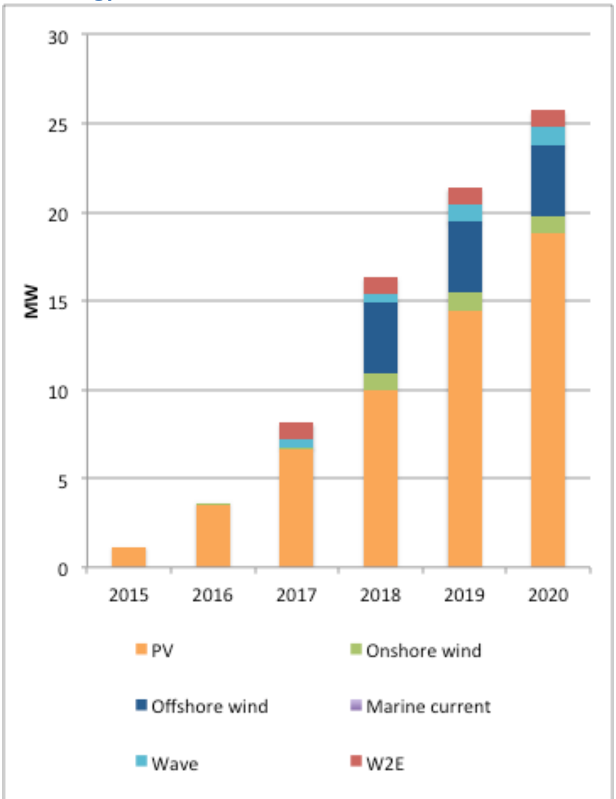
Source: NRP own analysis

Figure 11 breaks down the required RE capacity installed over the same period. Figure 12 shows the proportion of electricity generated by each technology annually, including the planned conventional power plant on the North Mole.

[34] Total final energy consumption includes electricity as well as energy consumption in transport, heating, cooling et cetera.

[35] The GEA projects a minimum of 42MW peak demand in 2020 and a maximum of 45.3MW. Use of the central case of 43.4MW[35] for peak demand is founded on plans to deploy a range of energy efficiency schemes. Calculation of the RE target in terms of MWh is based on a load factor of 61%.

Figure 11: RE Capacities Deployed to 2020 in the Illustrative Technology Scenario



Source: NRP own analysis

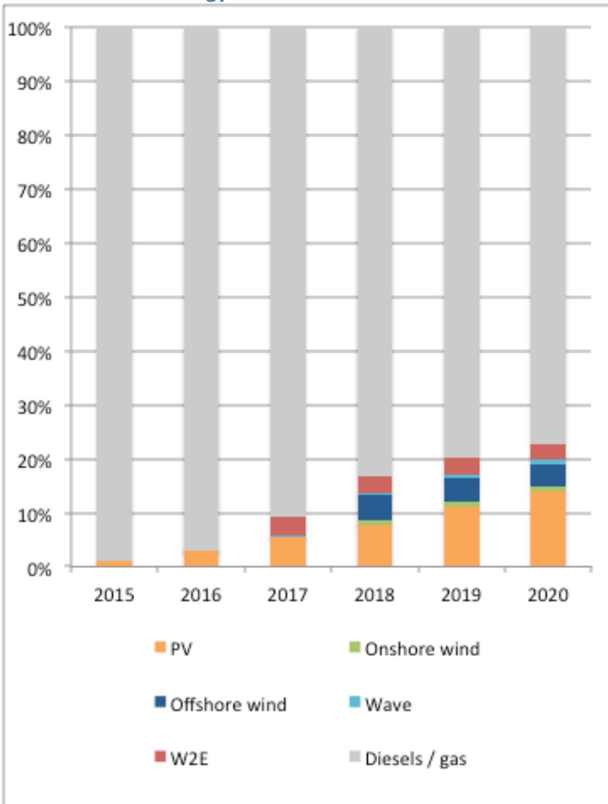
Solar PV is likely to be the dominant technology over the period, with approximately 19 MW deployed by 2020. Some 85,434 m^2 of roof space would be covered with PV panels by 2020. This equates to around 13% of the roof surface area identified for further investigation in preliminary government analysis.

A single 4 MW offshore wind turbine[36] is proposed for 2018, which would provide the second largest RE supply. Though the offshore wind resource has yet to be measured locally, local onshore analysis suggests that the resource is of a medium quality.

Due principally to the likelihood of negatively perceived visual impact, and a lack of space, onshore wind seems likely to deploy only in the form of small turbines, to an overall capacity of perhaps 1 MW.

The waste-to-energy (W2E) plant is small in terms of capacity but its high capacity factor – comparable to that of the planned North Mole power plant – means that it provides a disproportionately large share of energy. The scenario assumes that the W2E plant would consume half of the waste resource remaining after recyclables have been extracted, i.e. around 8,000t (of a total of 15,657 tonnes in 2015[37].

Figure 12: Shares of Electricity Generated to 2020 in the Illustrative Technology Scenario



Source: NRP own analysis

The analysis assumes that marine energy technologies will still be in their demonstration and research phases in 2020. A recent and substantial downgrading of projections for worldwide wave capacity, from 73 MW to 21 MW by that date, supports this assumption.

It is estimated that 1 MW of wave capacity would be operational by 2020. This would be a significant

[36] Offshore wind turbines tend to be large. 4 MW reflects the approximate size of turbines currently being deployed around the UK (mainly 3.6 MW Siemens turbines).

[37] Waste data taken from the Golder Associates Waste Characterisation Study, December 2014.

achievement and would place Gibraltar among the leaders in wave energy technology demonstration.

Tidal / marine current energy capacity is not deployed in the illustrative Technology Scenario. This is because marine current technologies, although promising, remain relatively immature. Anecdotal evidence of strong marine currents in Gibraltar suggests that demonstration of this technology would be appropriate. Existing (albeit only preliminary) analysis of the resource suggests that it is limited, but further analysis should be undertaken to establish conclusively the strength of the resource.

Table 2 summarises technology deployment milestones in 2020 under this scenario.

Table 2: Highlights of the Technology Scenario in 2020

RE tech	MW (2020)	Cap Factor	Details
Solar PV	18.8	20%	85,434 m^2 of PV panels at an average efficiency of 22%
Onshore Wind	1	18%	Small turbines of 30m hub-height
Offshore Wind	4	35%	1 turbine of 4 MW capacity of 120m hub-height, probably off the East coast
Waste-to energy	1	90%	1 plant, located at the old incinerator site
Wave	1	20%	Demonstration project

Source: NRP own analysis

5.2 A Cautious Look Further to 2030

2030 is another milestone in terms of EU targets for renewable generation. The EU's 27% target, under the same assumptions as for 2020 – that transport remains conventional, which is considerably less likely in 2030 – translates into a 41% share of electricity.

Of course, much can change in the years intervening to 2030. Indeed the energy technology sector is evolving so fast that the estimates included herein must be read as very tentative.

Again the GEA's central projection for peak demand is used (58.1 MW), meaning that 127,100 renewable megawatt hours would be needed to satisfy the target. Figure 13 illustrates shares of electricity by renewable energy technology up to the 2030 target (red dashes). The starting point is the 2020 target (black dashes).

Box 1: How Was the Technology Scenario Arrived At?

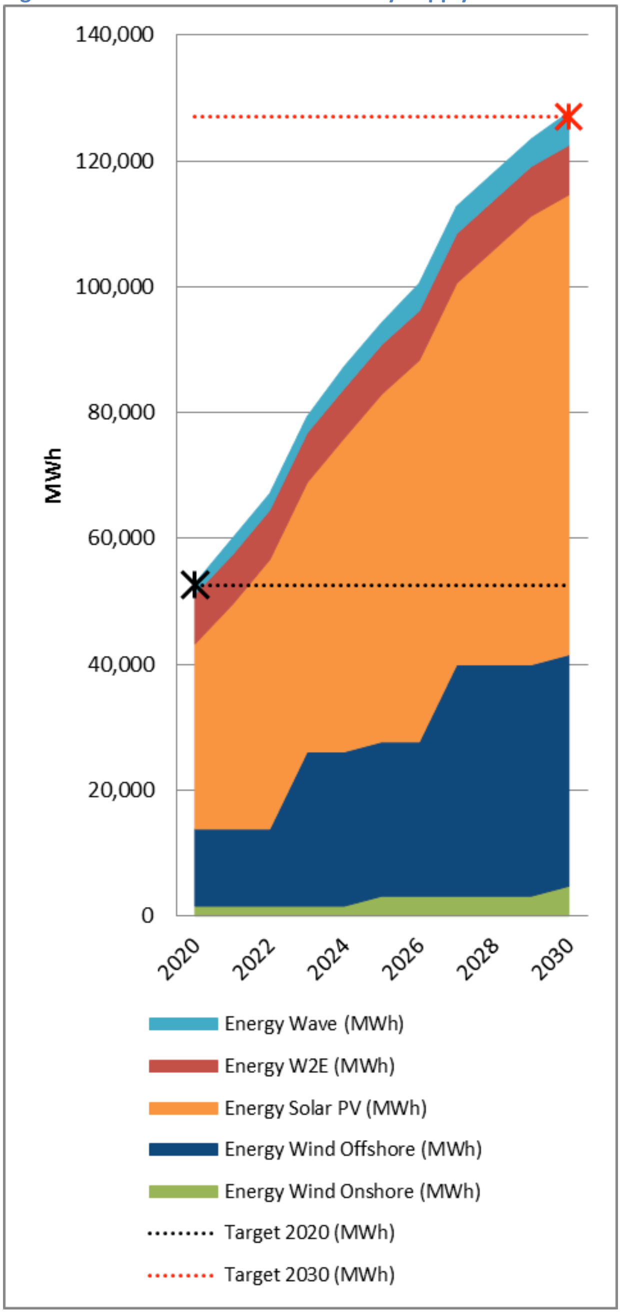
The Technology Scenario represents just one possible version of Gibraltar's electricity future, based on an heuristic and iterative examination of the criteria discussed in Chapter 4, i.e. cost, resource, siting constraints and grid integration aspects.

It is not intended to be conclusive but rather to provide a point of departure for deeper analysis of which technologies should be deployed and when.

It is based on present understanding of energy costs and resources, of which further analysis is needed. In particular the – key – spatial constraint, and deployment lead-times, require careful examination.

Technology disruption – the emergence of a new technology that changes the energy landscape – is, by its nature, hard to predict, especially in the energy sector where new advances are made continually. Indeed the dramatic reductions in the cost of solar PV in recent years are an example of this. Less so up to 2020, but increasingly from then on to 2030, there is every possibility that technology disruption will occur, and that new technology will change the basis for decision-making.

Figure 13: Annual Renewable Electricity Supply to 2030

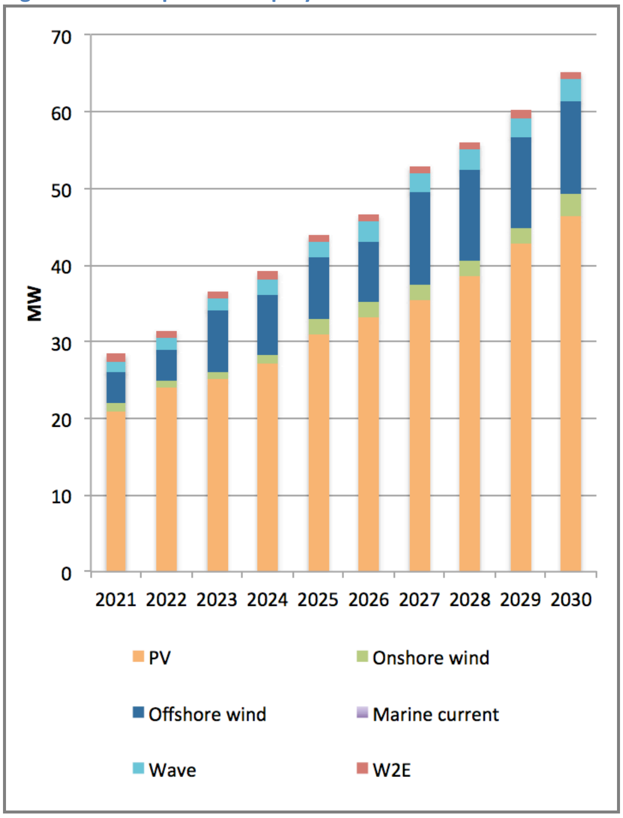


Source: NRP own analysis

Solar PV remains the dominant technology in the RE portfolio of Gibraltar in 2030, amounting to 46.3 MW. The roof surface area required for solar PV has increased to 185,289 m^2, approximately 28% of the roof space presently identified as having potential for solar PV.

Due to an expected decrease in capital expenditure costs, as well as increased comfort with operating the power system with intermittent renewable energy, offshore wind could be increased threefold from the 2020 level, to a total of 12 MW (three turbines).

Figure 14: RE Capacities Deployed to 2030



Source: NRP own analysis

Figure 14 shows cumulative renewable energy capacity in each year, while Figure 15 shows the proportions of electricity generated by each RE technology, as well as by the planned North Mole plant.

Wave energy increases to 3 MW of installed capacity by 2030. Marine current technologies, if proven, and if the resource is proved to be sufficient, could also play a part to 2030, although they are not included in this scenario.

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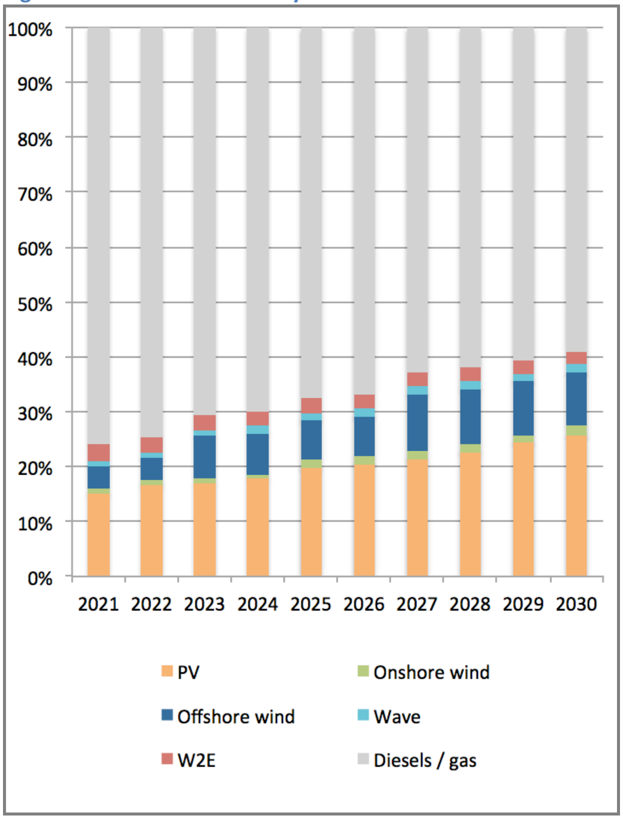
Figure 15: Shares of Electricity Generated to 2030



Source: NRP own analysis

Table 3 highlights key points of the Illustrative Technology Scenario.

Table 3: Highlights of the Technology Scenario in 2030

RE tech	MW (2030)	Cap Factor	Comments
Solar PV	46.3	20%	185,289 m^2 of PV panels with an average panel efficiency of 25%
Onshore Wind	3	18%	30 turbines of 100kW of 30m hub-height
Offshore Wind	12	35%	3 turbines with 4MW capacity of 120m hub-height
Waste-to-energy	1	90%	1 plant, located at the old incinerator site
Wave	3	20%	Wave technology is mature

6. Conclusions

The renewable energy deployment proposition for Gibraltar presents three major benefits in energy terms:

- Reduced operating costs of electricity generation (displaced gas / diesel fuel burn).
- Reduced local pollution and associated ecological benefits.
- Security of energy supply – reduced reliance on fuel imports.

Though not explored in this analysis, renewables also offer employment opportunities and other societal benefits.

From the spectrum of renewable energy technology options, we have identified those most likely to be appropriate to the resources present in Gibraltar. These are solar photovoltaic (PV), wind energy, both onshore and offshore, wave and marine current technologies, and advanced thermal treatment of municipal solid waste (MSW) with gasification or pyrolysis, known as waste-to-energy (W2E).

Of these, solar PV is both sufficiently mature and the best suited to Gibraltar's constrained site availability. Solar PV would require significant roof space. While the Department of Environment and Climate Change's preliminary investigations suggest that this is feasible, further examination of suitable locations should be a high priority.

This analysis is preliminary. It includes a number of analytical gaps, the full investigation of which would further increase the robustness of the analysis. Meanwhile, assumptions have been made based on best available proxies. Considerable additional data are required to fully establish feasibility. In order to acquire these data, a number of research tasks should accompany the deployment of RE capacity. Deployment should not be delayed but should proceed in tandem.

Further analysis should consider the following areas:

Solar PV

- Quantification of roof space potentially available for PV deployment. Research should consider roof pitch, orientation and shadow effects, as well as development aspects such as roof integrity, access and warranty issues.
- Measurement of irradiance on key rooftops; and assessment of the impact of the Rock's shadow and the Levanter cloud formation at these sites.
- Assessment of the present consumption of electricity for water (and space) heating, to identify sites appropriate for the deployment of solar water heating arrays.

Wind Energy (on Land and Offshore)

- Collection of hourly onshore wind resource data at approximately 30m hub-height in potential locations.
- Collection of hourly offshore wind resource data off the eastern shore of the peninsula at appropriate heights. Two to three years of data is usually considered essential to (partially) account for annual fluctuations. Consider usage of LIDAR technology for cost control.

Wave Energy

- Identification of additional potential sites other than the Ammunitions Jetty.
- Resource assessment at potential locations.

Marine Current / Tidal Energy

- As for wave energy, the focus should be on resource assessment.
- Site research should take into account anecdotal information on marine currents.

Waste-To-Energy

- Careful analysis of the benefits and trade-offs between W2E-based electricity generation and the recycling of municipal solid waste.
- The opportunity to derive feedstock from the proposed waste water treatment facility should be examined.

Finally, this analysis looks solely at technologies that have reached or passed the demonstration phase. New technologies might, and probably will disrupt the picture post 2020. So might dramatic, unexpected cost reductions, as seen with solar PV recently. Emerging technologies, such as new storage, deserve further analysis.