

Can the Isle of Man power itself with renewable energy?

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Executive summary

- Manx natural assets of strong wind, shallow sea and mountainous terrain offer significant value in the transition to net zero emissions.
- Using a selection of renewable power and energy storage projects (Fig. 6, page 8), an area equivalent to less than 2% of Manx territory is sufficient to supply the entire energy needs of the Isle of Man by 2035-2040.
- Assuming the Island is entirely electrified, wind and solar energy with storage can meet all residential, transport and industrial demand for power, and without the high expense of retrofitting existing buildings.
- The Isle of Man will no longer need to import oil, gas or electricity, a major saving over the long term.
- Significant revenue can be produced by selling surplus electricity to UK and Ireland via interconnectors.
- With the supply of clean, inexpensive electricity, new industry will relocate to the Island and existing companies can meet their own emissions targets. Local residents will benefit from warmer, drier houses.
- The value of green energy means that the private sector will pay for most of the up-front investment, managing the projects and absorbing the financial risk, provided appropriate legislation is in place.
- The window of opportunity is relatively short and therefore prompt action is required. A clear Government strategy will allow the local community to make prudent investments in energy efficiencies.
- The alternative scenario, that the UK supply most of the Island's electricity, brings risks of security of supply and price volatility as well as carbon tariffs and a loss of business if the UK fails to reach its emissions goals.

Abstract

Ahead of the 2050 commitment to net zero emissions, the Isle of Man can be entirely powered by its own renewable energy, such that it no longer needs to import oil, gas or electricity. Not only is there sufficient wind and solar energy to supply all the Island's needs but, through an integrated approach, it will cost significantly less than power generated from fossil fuels, even without carbon tariffs. Manx resources and a stable Government regime meet investors' demand for green energy projects. It is envisaged that the future energy system will largely be electric, generated from renewable sources and utilising storage schemes to balance and stabilize the power. The availability of cheap, emissions-free power will benefit residents and businesses, whilst attracting new industry. In addition, a significant surplus of green electricity can be produced and temporarily stored on-Island to be exported to UK and Ireland when market demand is high, thereby commanding a premium price and significant revenue to the Manx economy.

The opportunities offered by the move to net zero emissions are significant but there are numerous different options. To build an optimum pathway will require engagement and collaboration across every sector. A key part of the vision is ensuring that the Isle of Man Government avoids taking large financial or technical risk. Private funding will be required, attracted by enterprising and innovative legislation which offers a profitable route to market. Therefore, to maximize the benefit of a low-carbon energy system, it is essential that the necessary statutory framework, partnerships and decisions are built, not just with care but with some urgency, before neighbouring countries and industry choose alternative paths.

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INTRODUCTION

This paper examines whether the Isle of Man can become carbon neutral by developing its own renewable energy resources. Although there are many different views on what is technologically feasible and commercially viable, we think it is important to consider whether Manx wind and sun could power the future. At present, there is no right answer but there are many different options to choose from, some of them offering economic opportunities as well as environmental responsibility.

In October 2019, the Curran report on climate targets and actions for the Isle of Man was published. The recommendations were taken fully on board by Government and led to the 2020 Climate Change Bill, a legally binding commitment to reduce emissions of greenhouse gases to net zero by 2050. The justification for this momentous decision and the transformation that is implied can be found at the end of this paper (Appendix 4).

Many commentators point out that rather than focussing on emissions per se, it is better to transform the way power is produced and utilized. At present, the Isle of Man is wholly dependent on oil and gas and the majority of the Island's direct emissions come from fossil fuels used in heating, electricity generation and private vehicles (Fig. 1). Therefore, a huge step can be made towards net zero goals by decarbonizing power. This is feasible because certain renewable energies are nowadays commercially attractive.

There is nonetheless concern about the cost implications of the energy transition leading to an argument that it might just be easier to hand over the responsibility, by buying electricity from the UK. However, there are disadvantages with this path. Not only does one have to pay for the electricity but the price is unpredictable - volatility in energy markets is expected to increase in the future. There is also of risk in security of supply - the more the UK relies on wind power, the greater the challenge the National Grid has in avoiding blackouts. If electricity supply gets critical, then one way of avoiding a blackout is to temporarily turn certain consumers off and the Isle of Man could be one such consumers. Furthermore, it is expected that, as part of United Nations' efforts to mitigate climate change, carbon border taxes will be applied to imported energy. Thus, the Island will become dependent on the UK meeting their own emissions targets if such taxes are to be averted.

We therefore ask the question can the Isle of Man utilise its own natural assets of wind, shallow sea and uplands to become self-sufficient in renewable energy? Furthermore, can the Island's central position relative to energy markets in the UK and Ireland offer a new source of revenue?

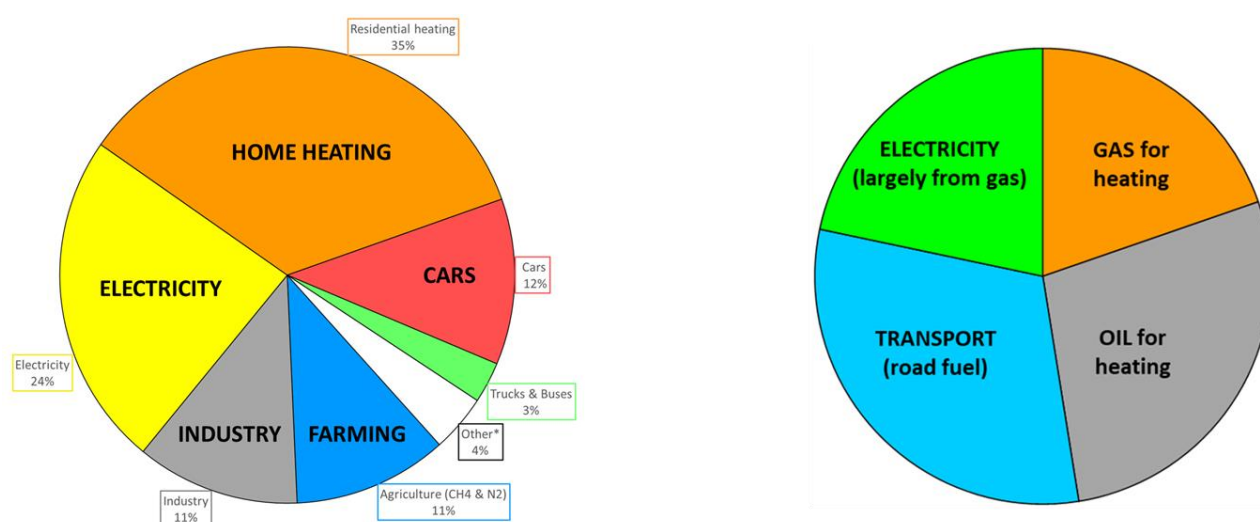


Fig. 1. Left: the relative proportion of greenhouse gases emitted directly from Manx sources in 2018, out of a total amount equivalent to 840,000 tonnes of carbon dioxide. Right: relative proportion of power consumed either as electricity or as fuel on the Isle of Man in 2018. Around 97% of the power was derived from oil or gas. Data sources: Isle of Man Government (2019).

Although the “fuels” for renewable power such as wind and sun are essentially free, the up-front investments are significant. Nonetheless, the Isle of Man is in a better financial position than most nations by virtue of a high per capita gross domestic product and significant financial reserves. More importantly, there are substantial economic opportunities with the transition from fossil fuels to sustainable sources, particularly as the Island possesses world class renewable energy resources and occupies a central position between the power-hungry nations of UK and Ireland.

From another perspective, the impending cost of not undertaking radical steps to lower the Island’s carbon footprint loom large. Already the business sector is expected to reduce their emissions from energy use (known as “Scope 2” emissions) and those from their suppliers and customers (“Scope 3”). It is anticipated that the United Nation’s Conference of Parties (CoP) will at some stage impose penalties, not only for direct, in-country emissions but also those of third parties resulting from imported electricity, fuel and goods. This puts pressure on the Government to find practical solutions which will substantially lower the carbon footprint and environmental impact of Manx society.

A MANX GREEN ENERGY HUB

Natural advantages of the Isle of Man for renewable energy

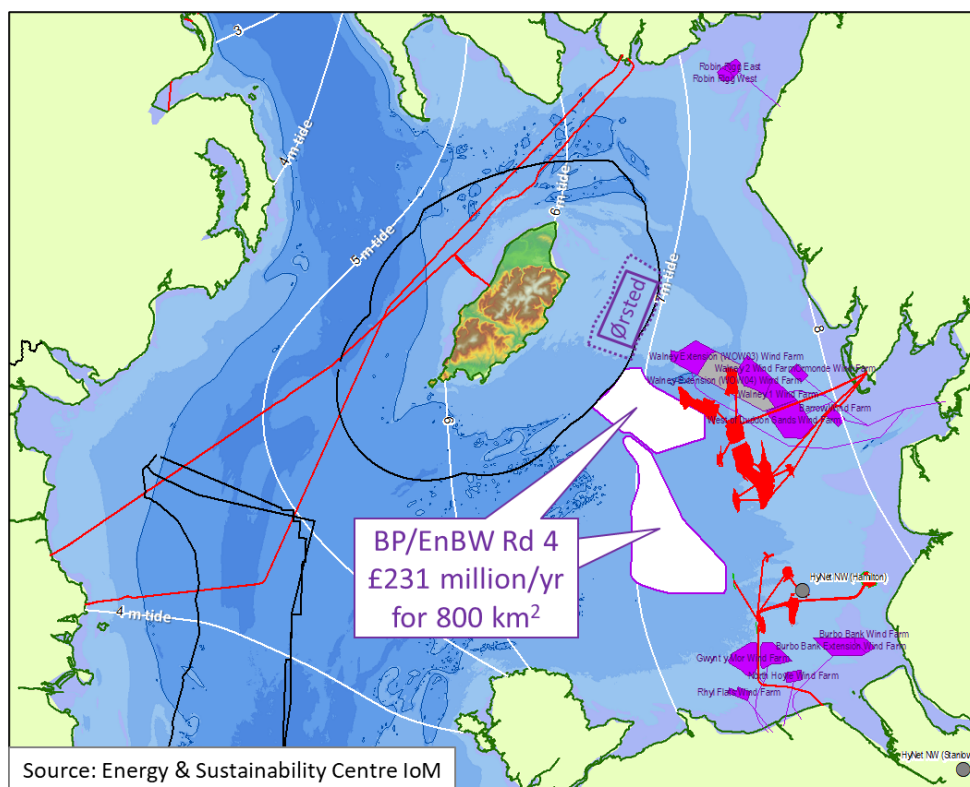


Fig. 2. Location of BP/Energie Baden-Wuerttemberg AG (EnBW) 60-year leases awarded in February 2021 as part of the UK Crown Estate fourth offshore wind licensing round. With an annual licence fee of £231 million, these licences were valued higher than any others in the auction, including those in the Southern North Sea. They lie on the border of Isle of Man territorial sea which has similar water depth and wind strength. Also shown are existing wind farms (purple polygons), an existing Manx licence for wind (Ørsted), gas fields (red polygons), pipelines (red lines), tidal range (white contours) and planned hydrogen projects (grey dots).

Similar to other parts of the Irish Sea, Manx territorial sea is ideal for siting offshore wind turbines. It covers a total area of 5000 km² and has strong and reliable winds, amounting to approximately 67 TWh[‡]/year. 70% of

[‡]67 TWh (terawatt hours) of energy equals 67,000 GWh (gigawatt hours) or average power of 7650 MW (megawatts).

the area is shallower than 50 m, the water depth at which turbines can be easily fixed to the seabed. The average offshore wind speed is more than 10 m.s^{-1} at the height of the turbine blades and the Irish Sea is protected from extreme wave conditions. Also, the weather is different in the Irish Sea than that of the Southern North Sea where most of the UK's and northern Europe's wind power is currently sourced, meaning there is often wind around the Isle of Man when it is relatively still further east. Like the Island itself, the offshore is relatively sunny and eco-productive, allowing for options such as floating solar, aquaculture and marine rewilding projects between individual turbines. Other natural assets which play in favour of generating low-carbon power are mountainous land, numerous rivers and a sunny northern plain.

As governments attempt to reduce their reliance on traditional fossil fuel power plants, the value attached to wind is high. Most of the offshore wind farms in the UK are situated in the Southern North Sea but there is insufficient room to meet future plans. They are therefore turning to the Irish Sea. The results of the most recent licence round, where companies bid for seabed leases to investigate options for wind farm projects, was announced in February 2021. BP and partner Energie Baden-Wuerttemberg AG (EnBW) broke all records, agreeing to pay £231 million pounds each year for an 800 km^2 area on the eastern side of the Isle of Man (Fig. 2). 800 km^2 is the same area as 20% of Manx territorial sea. The surprising thing is that this annual payment does not include a contract to supply power to the UK. This still has to be negotiated.

Dealing with potential drawbacks in renewable energy

There are two issues with wind and solar energies.

The first issue is that relatively large areas of land or sea are required to provide the amount of power required for a nation. This is particularly true of wind, which is a rather diffuse or low-density form of energy. Fortunately the Isle of Man has around 3000 km^2 of territorial sea with a water depth of less than 50 m, ideal for siting fixed base wind turbines.

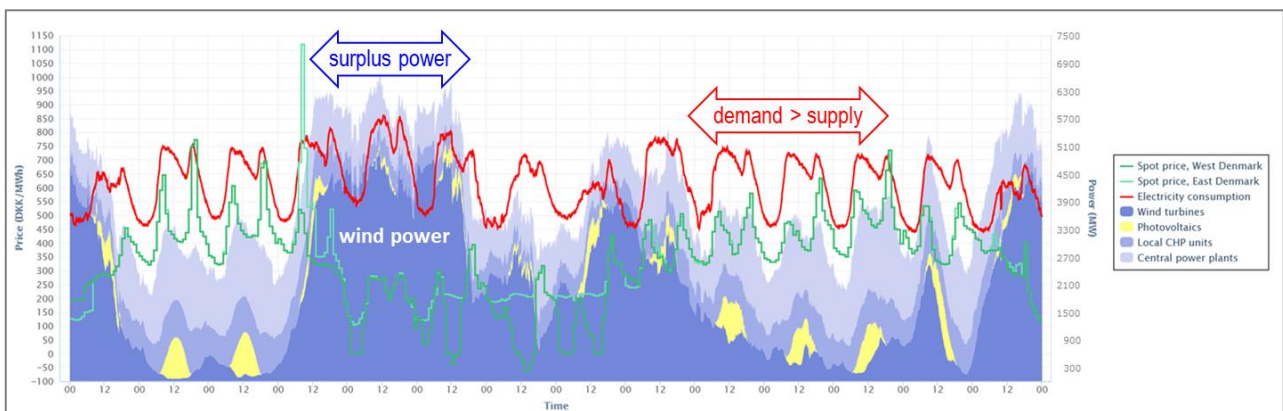


Fig. 3. Example of two weeks' electricity supply and demand in Denmark, 7-20 March 2021. Wind power (dark blue) and solar power (yellow) are intermittent and central power plants (light blue) are inflexible as they cannot be switched on and off to match variable demand (red line). Consequently, there are periods when surplus electricity is generated and periods when there is insufficient, reflected in the price on the spot market (green lines). Denmark deals with this imbalance by utilising hydro-electric schemes in Norway, exporting and importing electricity through high voltage interconnectors, a source of significant Norwegian profit. The data are from EMD International A/S.

The other issue is that the supply of energy is variable, related to weather and sunshine rather than consumer demands for electricity. This variability is known as intermittency and has two serious effects on electricity supply:

- 1) Intermittency can cause rapid fluctuations in voltage over periods of fractions of seconds to tens of seconds. This can be due to things as simple as gusting wind or temporary shielding of the sun by clouds. To avoid damage to electrical equipment, these fluctuations have to be neutralized or "stabilized" so that

consumers receive a constant 50 hertz (Hz) of alternating current. Various types of electrical equipment known as “ancillary services” are used to regulate voltage and frequency such as inertia devices, transformer taps, batteries and capacitors⁵, equipment the Isle of Man will have to invest in as renewable energy is added to the grid.

- 2) The generation of wind and solar power is related to weather and daylight, not to electricity demand (see Fig. 3). In the future, the difference between peaks and troughs may be reduced through price incentives and energy efficiencies but variable demand will remain. The scenario of no wind on a dark winter evening when electricity demand is high means that security of supply would be threatened without another way of supplying power. This is where energy storage plays its part – a way of saving surplus electricity for times when it is needed.

There has been insufficient planning for energy storage in the UK and many parts of the European Union, including Ireland. Because of daily and seasonal variability in wind and solar energy, long duration energy storage is required to meet both the demands of the consumer and the network. The electricity grids were built around the traditional means of generating electricity, where centralised fossil fuel-fired power stations supply a constant source of “baseload” power. Nowadays a combination of variable power from renewables with rather inflexible baseload power from gas- or biomass-fuelled plants and nuclear reactors makes it more difficult to balance and stabilize electricity for consumers (e.g. Fig. 3). It can be argued that the problem is made worse because the management of the grids is rather fragmented, involving different transmission and distribution operators. As a result there is an opportunity for other countries to provide energy storage services. At the moment, Norway is the key player.

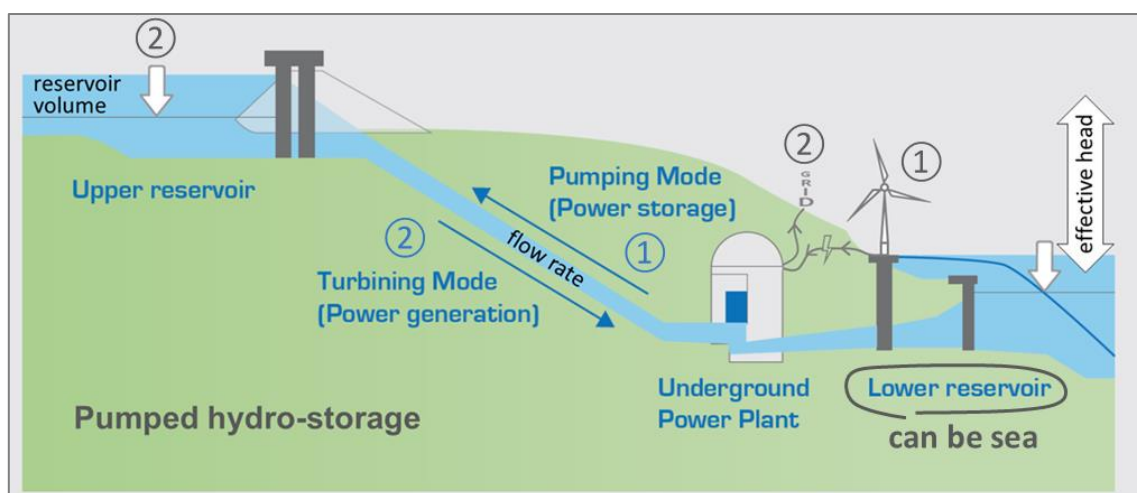


Fig. 4. Schematic illustration of a pumped hydro-storage scheme. ① Using surplus renewable power, turbines in the underground power plant pump water from the lower reservoir to the upper reservoir. ② When grid supply is insufficient to meet electricity demand, the flow is reversed so water descends under gravity to drive the turbines. Such schemes are remarkably efficient with around 75% of the energy recovered. Energy losses in other types of storage, such as lithium-ion batteries or hydrogen, are much higher. If sea-water is used for the lower reservoir, extra linings are required in the upper reservoir to prevent leakage.

The Netherlands, Germany, Denmark and Sweden rely on Norway to balance their national power supply and demand. By using high voltage undersea cables known as interconnectors to import and export electricity, Norway stores energy for these countries by taking surplus electricity – times when there is too much wind and sun – either using it themselves or storing it and then selling it back during periods of peak electricity demand,

⁵ Further information about frequency variations, alternating current and ancillary services can be found in an accompanying article *29 years to decarbonize the Isle of Man* at www.energysustainabilitycentre.im/knowledge-hub.

when otherwise there would be insufficient supply. Norway can provide this power more or less instantly through hydro-electric schemes.

Although there are many technologies to store energy – such as batteries, heat, compressed air and weights – these all have disadvantages and none of them have the scale and longevity needed to serve the grid effectively. The one that does meet all requirements is pumped hydro-storage which provides 95% of the world's energy storage capacity based on the potential energy of water between an upper and a lower reservoir (Fig. 4). Sloped underground tunnels or pipes link the two reservoirs. Using surplus electricity, turbines pump water from the lower reservoir to the upper one. When called for, electricity is generated again by flowing water from the upper reservoir to the lower one, either through the same turbines (reversible) or through a separate set of tunnels and turbines. Pumped hydro-storage also has the benefit that it provides stable electricity, without fluctuation in voltage or current.

There are several types of pumped hydro storage, including schemes where existing water bodies or the sea is used as the lower reservoir. Also tanks or underground caverns can be used for the upper reservoir. A few hundred metres of elevation is usually required between the lower and the upper reservoir ("effective head"), otherwise a very large volume of water is needed. Nonetheless, a theoretical offshore scheme using an artificial marine lagoon is currently under investigation. This would use dykes to separate the lagoon from the sea with water pumped out of the lagoon with surplus power and allowed to flow back in to the lagoon to drive turbines when the power was required**.



Fig. 5. View of Turlough Hill pumped hydro-storage scheme near Dublin. In today's money this cost £213 million to construct. This is the main energy storage scheme in Ireland, capable of supplying around 90 MW for 20 hours. In the Isle of Man there are several different options. For example, a pumped hydro-storage project might incorporate floating solar panels in either reservoir or the upper reservoir could be constructed underground or the sea could be used as the lower reservoir.

Where pumped hydro-storage is used to balance wind and solar energies, ancillary services and careful management are still required to deal with potential rapid variations in voltage and frequency. In addition, there needs to be a background supply of alternating current known as reactive power which is conserved within the grid. One way to provide reactive power with pumped storage is if a certain amount of power is continually supplied through a continuous hydro circulation system. This would mean, for example, that the upper reservoir

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would be filled more quickly when surplus renewable power was available, and emptied more quickly when demand was higher than the supply from wind and solar parks.

France produces most of its electricity from nuclear reactors but, as these cannot be easily adjusted to demand, they too utilise pumped hydro-storage plants to balance supply. There are some pumped hydro-storage schemes in UK and Ireland, such as Dinorwig and Turlough Hill (Fig. 5), but not enough to balance the increasing reliance on intermittent renewable energy. More schemes are planned, but the immediate solution for the UK has been to build a large interconnector to Norway. Ireland is also planning an interconnector to France.

If the Isle of Man can provide its own means of storing renewable energy then, not only is it possible for the Island to be self-sufficient in low-carbon power, there is also potential for significant revenue by selling electricity to UK and Ireland when they are struggling to meet demand and market prices are high. There is also the possibility of offering storage services to these countries, assuming there is sufficient capacity. The advantages the Isle of Man has for energy storage are mountains and large amounts of water – the crucial elements for pumped hydro-storage – albeit on a smaller scale to Norway. An indicative size is discussed in a later section (page 10).

Manx energy requirements and future uncertainties

The easiest way of considering the options for low-carbon power in the Isle of Man is to start with a blank sheet, as if the Island currently had no energy network. The challenge is then to develop a way of providing reliable, cost-effective, sustainable power to approximately 85,000 Manx residents and their businesses.

Most low-carbon solutions involve a switch to electricity generated from renewable sources plus related forms of “clean” or “green” energy. First it is worth considering how much power is theoretically required before dealing with the practicalities, including the fact that there is already infrastructure geared to supply traditional forms of electricity, gas and other fuels.

In 2018 the Isle of Man used approximately 2075 GWh of energy from oil and gas for electricity, heating and transport. An additional 54 GWh was used in the form of electricity supplied from the UK and a small hydro-electric power plant below the Sulby reservoir. At this stage we run into an issue in converting between different forms energy.

As an illustration, we will compare the amount of petrol used to power an internal combustion-engine car relative to the amount of electricity to drive the same distance in an electric car with a lithium-ion battery. The efficiency of a petrol engine (on average around 25%) is less than that of an electric vehicle (approximately 60% from charging point) so the simplest way of converting between the two is using the relative proportion 25/60.

By averaging data from relevant technologies – turbines, engines, boilers, heat pumps, energy recovery units, energy storage devices and electrical converters – we find that power from fossil fuels is on average 50% efficient compared to 80% efficiency for power produced directly from electricity. This reflects differences in mechanical, thermal and transmission losses. Thus, 2075 GWh from oil and gas in 2018 represents 1297 GWh in the form of electricity (2075 multiplied by 50/80). With 54 GWh of additional electricity, this sums to an annual on-Island consumption of approximately 1350 GWh/year. There is of course a wide range of uncertainty in this number, depending on assumed energy efficiencies.

The next question is whether the Isle of Man will use less or more power in the future. For example, will energy efficiencies reduce demand or will new industries increase it? This cannot be predicted with any confidence. We choose a range between 950 GWh and 1750 GWh (+/- 30% of current use), with 1350 GWh representing the median value or mid-case. The range also includes assumptions and interpretations involved in converting between different fuels, electricity and other forms of energy. Nonetheless, not all of this power has to be in the form of electricity via the grid; some could be generated or saved by the consumers themselves, for example using heat pumps, solar panels or batteries, as will be discussed later. Other uncertainties, such as the cost of technologies and future energy prices also need to be taken into account.

It is worth noting that, in terms of the amount of fuel or electricity used to generate the power, renewable technologies such as wind turbines, solar cells and heat pumps can be regarded as greater than 100% efficient. This is because the actual “fuel” - wind, sun, potential energy, environmental heat, etc. - is not included in the calculation, it being a free resource. Nonetheless, like all forms of engineering, energy is still required to manufacture and install the technologies, plus a certain amount of energy is used in keeping them running. At present, the construction and installation of the equipment and facilities depend largely on fossil fuels. The indirect emissions from these do need to be accounted for (see Appendix 1), even though the overall carbon footprint of renewable energies tends to be significantly less than that from oil and gas.

Viable energy technologies

Technologies which could feature in a Manx low-carbon energy scenario are tabulated in Appendix 1. The information includes mid-case estimates of up-front capital costs (“CAPEX”), annual operating or running costs (“OPEX”), the areas of land or sea required, attendant emissions and other considerations. A simple summary is shown in Fig. 6, with options ranked on the basis of estimated costs over a 20-year period.

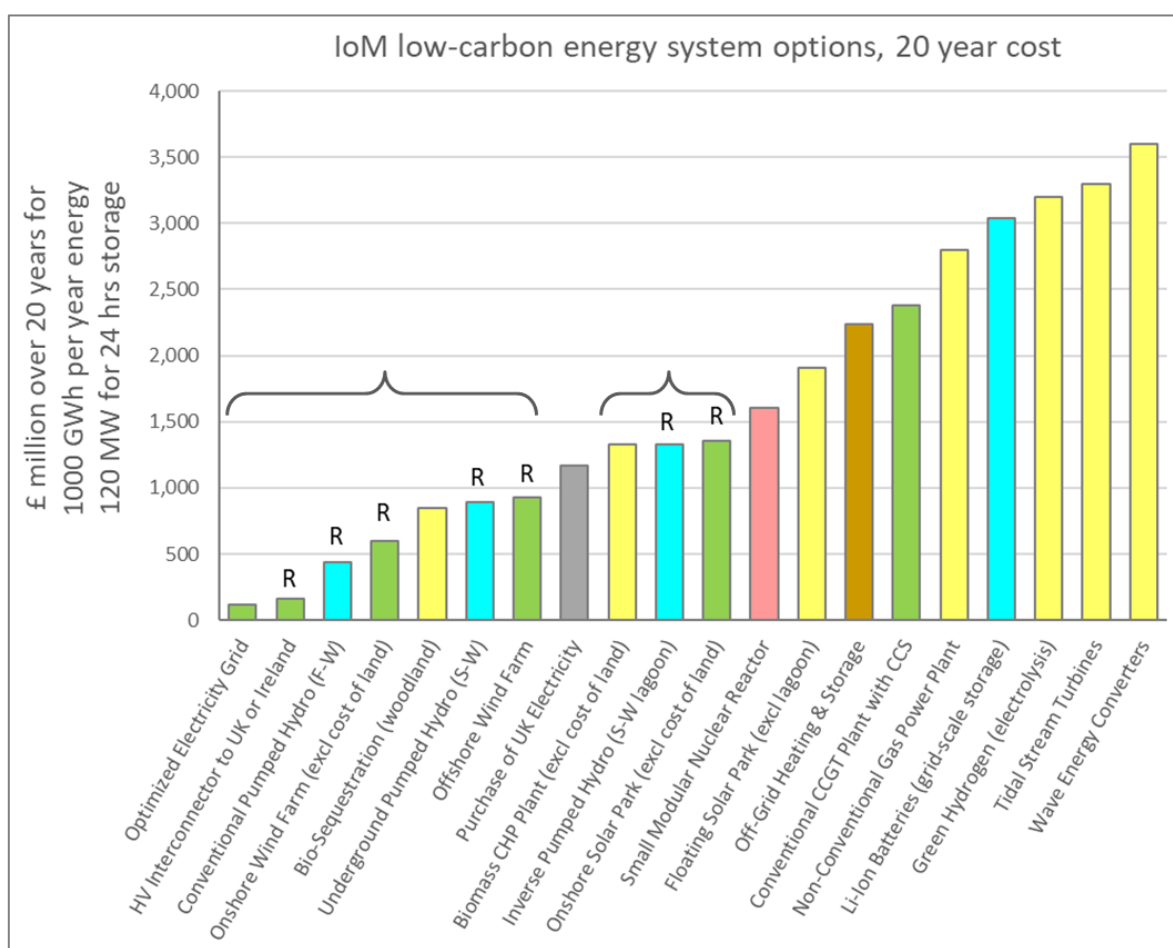


Fig. 6. Cost comparison of technologies to build an effective low-carbon energy system on the Isle of Man, based on values summarized in Appendix 1. A combination of the options encompassed by brackets provides self-sufficient power. With an appropriate statutory framework, these can generate significant income from sales of green electricity to UK and Ireland via interconnectors. Bar colours: green – viable technology for supplying 1000 GWh/year; yellow – unable to supply 1000 GWh/year or else not currently commercial; brown – power supplied or saved by consumers rather than through the grid; blue – energy storage; red – unlikely choice. R – potential revenue stream; HV – high voltage; F-W – freshwater; S-W – sea-water; CCGT – combined cycle gas turbine; CCS – carbon capture and storage.

The values shown in Appendix 1 and Fig. 6 have been levelized and normalized to what would be required to either produce 1000 GWh of electricity per year, actually at the lower end of our range of future demand, or to store 120 MW power for 24 hours, enough to power the Isle of Man by itself for more than a day. In some cases, 1000 GWh/year is impractical, either because there is insufficient area (e.g. for biomass) or because the technology is still being developed (e.g. hydrogen) but we have kept the same magnitudes throughout in order to make comparisons easier. 0% inflation has been used.

There is more than enough renewable energy to power the entire Isle of Man by integrating different technologies (Figs. 6 and 7). The existing electricity grid will almost certainly have to be upgraded and strengthened. However, choosing the best path is made difficult by large uncertainties – there are wide ranges in the projections of energy demand, the speed of technological developments and future prices. Also, none of the parts stand alone, so wind farms and solar parks need energy storage to match demand, as well as an appropriate transmission-distribution network, plus ancillary services to provide stable alternating current.

Domestic efficiencies and retrofitting

The value of off-grid energy projects is also worth considering, where individual consumers invest in low-carbon heating, energy storage, improved insulation and other efficiencies. The main effort comes in retrofitting existing buildings. Unfortunately, it is far from cheap to upgrade traditional domestic systems with heat pumps, new boilers, insulation, efficient ventilation, solar panels, batteries, etc. To save roughly 0.5 TWh/year, we estimate would take a minimum up-front investment of £22,000 per average house. Once the annual operating costs, OPEX, are included, and the figures are then scaled up to the normalized level of 1 TWh/year, it becomes clear that developing a comprehensive off-grid solution is an expensive choice (Fig. 6, brown bar).

From a collective perspective, rather than many separate investments on a per-home or per-business basis, grid-scale energy projects tend to deliver better value. One way of looking at this is through an estimate that it would take a minimum of £770 million to retrofit the Island's current housing stock (35,000 houses x £22,000). One can use the same money to build a 66 km² offshore wind farm which would generate 2-3 times more power than would be saved through retro-fitting (see Appendix 1).

Thus, considering the Island as a whole, it is difficult to make an economic argument for greatly improving the efficiencies of existing buildings, at least when compared to the costs and potential earnings of investing in large renewable energy projects. Assuming the power can be supplied cheaply through the grid, it might be more effective to upgrade properties with specific types of electric heating and heat storage than trying to make them significantly more energy efficient.

It is important that improvements made now fit with future developments – requiring a strategic vision of the type and cost of power in 5 years', 10 years', 20 years' time. Nonetheless, when it comes to new houses, it still makes sense to build them with improved energy performance, as well as with low-carbon materials (which currently does not include cement, steel or most plastics). Also, there is a desire amongst many residents to do their part. The issue is then making sure that any investment a house-owner or business might wish to make now, does not become obsolete or redundant as the new energy system is developed.

An important part of making the right decision on investments at home is having clear sight on how and when low-carbon power will be delivered in the future. It is sensible to plan improvements in domestic efficiencies which fit with the way energy system evolves. Thus, if the Isle of Man is to be entirely electrified within, 15-20 years, and the electricity is both renewably-sourced and relatively cheap, then it probably makes more sense to invest in home insulation and electric heating than to invest in generating off-grid domestic power from biomass-fuelled boilers or solar panels. Some suggestions on home improvements can be found in Appendix 2.

Another option for heating houses and offices within towns is with district heating schemes where warm water is piped to premises and then used in central heating. In addition to a network of insulated pipes, a source of warm water is required as might be supplied from a combined heat and power (CHP) biomass power plant, a solar installation or a community-scale heat pump. In the case of a heat pump, it is surprising the size of the heat extraction operation which would be required. Even using boreholes or the sea, it is difficult to provide

sufficient warm water for more than a few thousand new properties on the Isle of Man and the up-front investment for such a project is considerable. District heating could, nevertheless, represent a worthwhile add on to a larger renewable energy scheme such as biomass or solar.

Other ways of powering the Isle of Man

For completeness, we also estimate the cost of buying 1 TWh electricity per year from the UK through a new interconnector over the same 20-year period (Fig. 6, grey bar). It should perhaps come as no surprise that, based on current prices, this works out more expensive than using the Isle of Man's own sources of power. It is difficult to predict future prices but analysts expect that markets will become more volatile making it difficult to budget for a plan that depends on UK electricity. There is also a security of supply risk in that the UK is increasingly relying on intermittent sources of power, currently without sufficient energy storage. Furthermore, if the UK fails to reach its emissions goals, then there is the risk that carbon tariffs will be applied to third party consumers like the Isle of Man, whilst businesses will be unable to reduce their energy-related emissions.

Although nuclear power does not play to the Island's strengths, it has been included in the evaluation for comparative purposes (Fig. 6 & Appendix 1). Small modular fission reactors are being considered by some governments as a realistic alternative to traditional fossil fuel-fired power stations. The power produced from a nuclear plant cannot easily be adjusted so grid-scale energy storage is still required to meet variable demand. Other issues such as cost, disposal of radioactive material, safety and public acceptance make nuclear power an unlikely choice for the Isle of Man.

Costs versus benefits

Fig. 6 can be used to identify those elements which currently rank highest in terms of lowest cost. What is more difficult to quantify is the added value which comes from selling green electricity to the UK and Ireland, an aspect that needs further research, including deciding on the optimum balance of different technologies. Even before this research is completed, a crucial step is developing a legislative framework which attracts up-front private investment.

The arguments against renewable energy often include the costs and complexity but this is day to day business for the energy industry. As Figure 2 illustrates, companies are prepared to invest significant amounts of money, provided they can see a profitable route to market. On the other hand, there has to be clear benefit to residents and businesses on the Isle of Man. We therefore suggest that one overriding objective of the energy transition should be to provide cheap, low-carbon electricity, sufficient to keep houses warm and dry as well as to attract new industry to the Island. One mechanism to achieve this is if energy companies are invited to bid a minimum price for guaranteed amount of electricity to the Isle of Man, supported by the higher prices they can achieve through exports to UK and Ireland when market prices are high. This requires that the generation and storage capacity for Manx renewable energy is at a scale larger than just on-Island demand.

Energy dependency versus self-sufficiency

We have calculated the total cost to the Isle of Man of generating and storing its own renewable power – energy self-sufficiency – compared to buying electricity from the UK (Fig. 7). Although there are large uncertainties, the mid-case cost of UK-dependency is almost double the mid-case cost of Manx self-sufficiency over a 20 year period (£3.5 billion versus £1.7 billion, respectively). This does not include the additional value from renewable energy created through licence fees or by selling surplus electricity to the UK and Ireland, assuming .

The main differences in the two cases (Fig. 7) are that in the self-sufficiency model, Manx wind farms are used to produce most of the power and pumped hydro-storage is used to match supply to demand, whereas in the UK-dependence model electricity is purchased and supplied through a new interconnector. The self-sufficiency model is based on there being a second interconnector to Ireland, providing two routes to market for energy companies, assuming they generate and store significantly more power than is required by the Isle of Man

alone. The two models require different amounts of subsidiary power generation, ancillary services, battery storage and energy efficiencies.

Appendix 3 provides a more detailed analysis over a 25-year and 30-year period, including a comparison to an alternative scenario for UK-dependence modelled by Government consultants Arup. Arup forecast much less electricity use in the future by assuming a large proportion of the current power demand – that associated with heating and transport – is circumvented through retrofitting homes and generating off-grid power. Although the costs of providing these alternatives have not been calculated by Arup, we expect them to be more expensive than grid-scale solutions, as discussed earlier.

	UK-dependence scenario	IoM self-sufficient scenario
New UK Interconnector (AC)	dispatchable + resilience	for export & resilience
Pumped Hydro-Storage (various)	-	dispatchable + resilience
Existing UK Interconnector (AC)	partial baseload	partial baseload + export
Wind Turbines (onsh &/or offsh)	secondary power source	primary power source
Solar PV Arrays + inverters (onsh)	secondary power source	secondary power source
Biomass SRC & CHP plant (excl DHS)	partial baseload	partial baseload
Lithium-Ion Batteries + converters	primary storage + resilience	possibly
Thermal Storage (e.g. heat tanks)	possibly	possibly
Mechanical Storage (e.g. weights)	possibly	possibly
EFR Batteries or Flywheels	possibly	enhanced frequency response
Hydrogen Fuel (from electrolysis)	possibly in CCGT & FCs	possibly in CCGT & FCs
Retrofitting Homes	smart meters, insulation, heat pumps, biomass boilers, off-grid storage	
Low case cost[†], 20 years (excl upgrades to grid)	£1518 million	£1146 million
Mid case cost[†], 20 years (excl upgrades to grid)	£3486 million	£1728 million
High case cost[†], 20 years (excl upgrades to grid)	£7699 million	£3090 million

[†]Excluding switch to low-carbon transport (cars use 31% IoM power, produce 18% emissions)

Fig. 7. Comparison of different elements which might be required in a future, low-carbon energy system on the Isle of Man, either by buying electricity from the UK via a new interconnector (left) or by producing sufficient power from Manx renewable sources (right). The calculated range in costs are also shown. Key: AC = alternating current; onsh = onshore; offsh = offshore; PV = photovoltaic; SRC = short rotation coppice; CHP = combined heat and power; DHS = district heating schemes; EFR = enhanced frequency response; CCGT = combined cycle gas turbines; FCs = fuel cells

Which are the best choices for the Isle of Man considering technologies are still developing?

Although each low-carbon technology has certain disadvantages, combining the technologies is the way to provide a cost-effective and resilient system. At present, the grid-scale options which seem to offer the best

solutions in terms of energy self-sufficiency are wind (both onshore and offshore), pumped hydro-storage and onshore solar, possibly with some biomass (Fig. 6 and Appendix 1).

As testing and uptake of new technologies increases, the price tends to fall, as has been seen with wind turbines. Starting with government subsidies in Denmark, continued investment in wind since in the 1980's has meant that the cost of electricity generated from an offshore wind farm is nowadays cheaper than electricity from traditional gas-fired power stations (Fig. 6). Solar cells and lithium-ion batteries are currently showing the greatest decreases but it is still difficult to predict prices, even in 5 years' time, meaning investment choices for the future cannot be based solely on cost.

Certain technologies relevant to the energy transition are still under early development. In some cases, high costs may mean they are never a commercial proposition. This is the main risk for marine (tidal and wave) energies and technologies to capture and store carbon dioxide (carbon capture and storage, otherwise known as CCS). CCS potentially offers a way to continue using fossil fuels^{††} but renewable energy will almost certainly remain a cheaper option.

Biomass can be regarded as a renewable resource if the material is grown in sustainable plantations such as forests using rotational planting and minimal disturbance of soils. At present, most biomass fuel comes in solid form such as wood pellets which are burnt in power stations. Thus, the carbon dioxide produced is only that which was temporarily stored by photosynthesis – the remaining plantation continues to capture carbon as a natural product of solar energy. The use of land where agriculture is uneconomic does potentially offer a new source of income for farmers.

Significant research and investment is being made around the world into producing liquid or gaseous bio-fuels such as ethanol, bio-diesel and bio-gas, not just from trees but also from grasses and even marine algae like kelp. At present, the conversion processes involved are rather inefficient meaning they are expensive. There are also concerns about the environmental footprint of industrial-scale bio-fuel operations. Another problem is that the Isle of Man does not produce more than a small fraction of the amount of biomass which would be required. At present, there is around 35 km² of managed forest which, based on average growth rates, probably yields around 10,000 tonnes of wood each year, sufficient to provide about 8 GWh/year of electricity or an average of less than 1 MW. Even if this amount can be doubled using other sources of Manx vegetation, it is unlikely that biomass will play more than a minor role in a sustainable energy system, unless large amounts of biomass material are imported.

In the future, it is possible or even likely that the cost and efficiency of other options such as hydrogen improve to the degree that they become commercially viable. This can be used directly or by conversion to methane ("syngas") as a fuel to replace natural gas in power stations and in boilers and stoves at home. Hydrogen fuel cells also offer certain advantages over lithium-ion batteries for powering electric vehicles and it can also be used to produce liquid fuels for use in aviation and shipping. Significant research and development is being funded by the European Union and other governments in "green" hydrogen – where hydrogen is produced by electrolysis from wind or solar power. This process is currently expensive, whilst storing and transporting hydrogen is difficult. Nonetheless, electrolysis is a way of utilising surplus renewable energy and, assuming this would otherwise go to waste, it might be a viable way of providing low-carbon fuel for road transport system, as discussed later. It is still difficult to see which types of electrolyzers and fuel cells will ultimately be commercial so for now it is really a question of "watch this space".

Energy storage adds significant value to intermittent renewables

As the Isle of Man is unusually well endowed with renewable energy, there is the potential for significant revenue if electricity can be supplied via interconnectors to meet demand in the UK and Ireland when their wind resources are insufficient. It is a relatively straightforward operation to synchronize the different electricity grids

^{††}Rather burning it in a power station, natural gas can be used in high temperature solid oxide fuel cells to produce electricity directly and the by-product, carbon dioxide, is easier to capture but, at present, the technology is only applicable at relatively small-scale.

and, ultimately, this would mean the Island would become part of the wider European market. The real issue is being able to supply the market when prices are high. This requires large-scale, long duration energy storage, enough to both meet Isle of Man needs and to export surplus when renewable power supply is limited.

Just to illustrate the scale involved if pumped hydro-storage was to provide the solution, an upper reservoir of 0.1 km² (10 hectares) with an average depth of 35 m and 400 m elevation above a lower reservoir could store enough energy to power the Isle of Man for at least 24 hours. If two or more such facilities were available, then electricity could be traded through two interconnectors, allowing Manx offshore wind power to be sold to the British and Irish grids. Weather forecasts would be used to predict when stored power should be kept for the Isle of Man and when it could be sold at profit. Of course, it is possible that all the stored energy would be used up before it could be resupplied with more renewable power. It is a fairly rare situation that there is no wind and no sun for several days in the Irish Sea region but, nonetheless, two interconnectors would mean the Isle of Man would be in the position to buy electricity from the greater European market during off-peak periods, and store it to meet domestic demand. In fact, with sufficient capacity, the Isle of Man could also provide a storage service for the UK and Ireland. In essence, this would mean the Island would become an electricity import-export hub.

A number of suitable sites are present on the Island for pumped hydro-storage, including options to use underground reservoirs and/or the sea as the lower reservoir. In fact, another innovative concept is to build a marine lagoon where sea-water is pumped out of the lagoon using surplus power; electricity is then produced on demand by flowing sea-water back through tidal turbines. Although it would be relatively expensive to build the enclosing dykes of the lagoon, there are other potential benefits including the possibility of developing floating solar panels, aquaculture such as shellfish and water-based leisure activities (e.g. Fig. 8). Wind turbines could also be sited on the dykes themselves. In addition, the entire structure would offer coastal protection by diverting strong offshore currents.

The costs of any hydro project are specific to each site meaning there is large uncertainty at this stage. Nonetheless, historical data are a good source of empirical information which have largely been used to compile the numbers in Figure 6 and Appendix 1.

Most pumped hydro-storage schemes, whether proven or conceptual, have an environmental and visual impact. Although these can be lessened using excavated reservoirs or entirely sealed systems, there may be better options not involving water. Existing technologies such as batteries, compressed air, weights and thermal storage are commercially viable on relatively small projects. However, these are difficult to scale up to what the grid would require for an energy system dominated by renewable power. For example, it would take around 200 mine passages to provide a medium-scale energy storage facility using compressed air. Lithium-ion batteries have several problems including limited duration, modest lifetime and expense plus ethical and environmental concerns on the source of component elements such as cobalt. A perhaps more feasible idea is to use “railway energy storage” where reversible engines are used to raise and lower heavy train carriages along reinforced tracks on a mountain slope. The size of the system needed on the Isle of Man is quite challenging but a smaller-scale project is already being built in Nevada.

In summary, the value of energy storage is hard to overestimate when it comes to utilising renewable energy, and it is the key component to building a low-carbon energy system for the Isle of Man. At present, pumped hydro-storage appears to offer the best grid-scale solution. However, further work is required before deciding which option or options offer the most benefit.

Transport solutions

One significant challenge in the energy transition is how to transition road vehicles, ships and air transport to non-fossil fuels. These are all particular problems on the Isle of Man which has 75,000 private cars, hilly topography and a stretch of sea separating travellers and various goods from their destinations.

Considering road transport, the assumption is that future vehicles will be electric but not necessarily powered by lithium-ion batteries. Hydrogen fuel cells have several advantages over batteries, including the speed of

refuelling, their low weight, their distance range, their length of life and the fact that significantly less metals and chemicals are used in their manufacture. In this regard, it may make sense to install one large electrolyser or several small electrolyzers to produce hydrogen on the Island. Private vehicles, trucks and buses can all be powered efficiently by hydrogen fuel cells. In fact, a new train or tram system could be developed, perhaps following the old lines between Douglas, Peel and Ramsey.

At present, the main disadvantage of hydrogen is the cost. However, the price of electrolyzers is falling and the operating costs can be significantly reduced if only surplus electricity is used, when renewable power generation outstrips demand and other storage schemes have reached capacity. The other major cost is the construction of leak-proof containers to store the hydrogen at pressure, although the vehicles and fuel cells themselves can provide some of the storage.

If the Isle of Man converted its transport networks to hydrogen, it would serve as a demonstration to other nations. Hydrogen or a derivative such as ammonia can also be used to power ships. Alternatively, hydrogen can be combined with carbon dioxide to produce synthetic methane ("syn-gas") as well as other fuels such as aviation fuel. The process can be regarded as carbon neutral if the carbon dioxide is captured from a biomass plant, releasing back to the atmosphere the carbon temporarily fixed by photosynthesis. The advantage of using syn-gas rather than hydrogen is that the existing gas network already uses methane and therefore no conversion of pipelines or appliances would be required. In addition, storage of the gas would be no different than is already used for natural gas.

The manufacture of electric cars involves significant emissions, the lithium-ion battery alone accounting for around 10 tonnes CO₂e. There is also insufficient supply of certain component materials ("critical metals") such as cobalt. Therefore, rather than encouraging a wholesale shift to electric cars, there are greater environmental benefits if individuals use public transport instead of private vehicles. The scope of public transport could be expanded to include electric taxis. In addition, a scheme where loan vehicles could be booked with a telephone app would allow people in towns to move away from personal car ownership, a considerable saving in expenditure.

Also, if cycling and walking were adopted for a greater proportion of journeys, there are clearly health benefits. As Manx roads are relatively narrow, cycling lanes and footpaths could be sited on the field sides of hedges, farmers being paid for the set-aside land. If these strips of land were allowed to grow wild, such a scheme would be a simple way of sequestering carbon, as well as providing corridors for biodiversity.

Other benefits of a home-grown solution to climate change

The onus is on companies to reduce their own emissions of greenhouse gases. Most are now looking to reduce what are called Scope 2 emissions – those related to their use of power. Assuming the Isle of Man were ahead of other jurisdictions in offering green electricity and other clean tech activities, new companies would be attracted here, including energy-intensive data industries.

In the meantime, many companies are trying to offset their current emissions through carbon sequestration schemes. The majority of these are of questionable benefit to climate change, with few if any demonstrating the scale of tree planting or rewilding required to remove the claimed amount of carbon dioxide from the atmosphere. In the future, these schemes will have to meet agreed standards of accountability, resulting in an increasing number of companies looking to relocate somewhere that can genuinely decarbonize their activities.

From the point of view of existing consumers on the Isle of Man, a key goal is providing significantly cheaper electricity so that houses can be kept warmer and drier. One option is to supply surplus electricity at cost price for storage at home in thermal devices and batteries. The process would be controlled by smart meters which balance renewable power generation and consumer demand. Although per-customer solutions tend to be more expensive when considering the Island as a whole, the advantage with home storage of energy is that the required size of grid storage projects can be reduced.

Experience on Scottish islands suggests there will be a strong drive from local residents to support community-funded renewable energy projects. Support for such enterprises can come through legislation and regulations related to the sale of electricity to the grid.

Training will be required for local professions to ensure they possess the skills needed to build and install low-carbon technologies, from large engineering projects down to domestic installations as fossil fuels are phased out. The number of new jobs is also likely to be significant – in the order of 500-1000 based on a pro rata of UK figures.

Assuming the Isle of Man is at the forefront of some innovative projects such as energy storage using sea-water, there is potential to develop marketable expertise. All countries are struggling with how to deal with the intermittency of renewable power and there are elements of weather, topography and sea in other islands and coastal nations with analogies to the Isle of Man. Therefore, the lessons learnt on the Island may be applied elsewhere. In other words, low-carbon initiatives on the Isle of Man can help other parts of the world, providing favourable publicity and a sense of national pride.

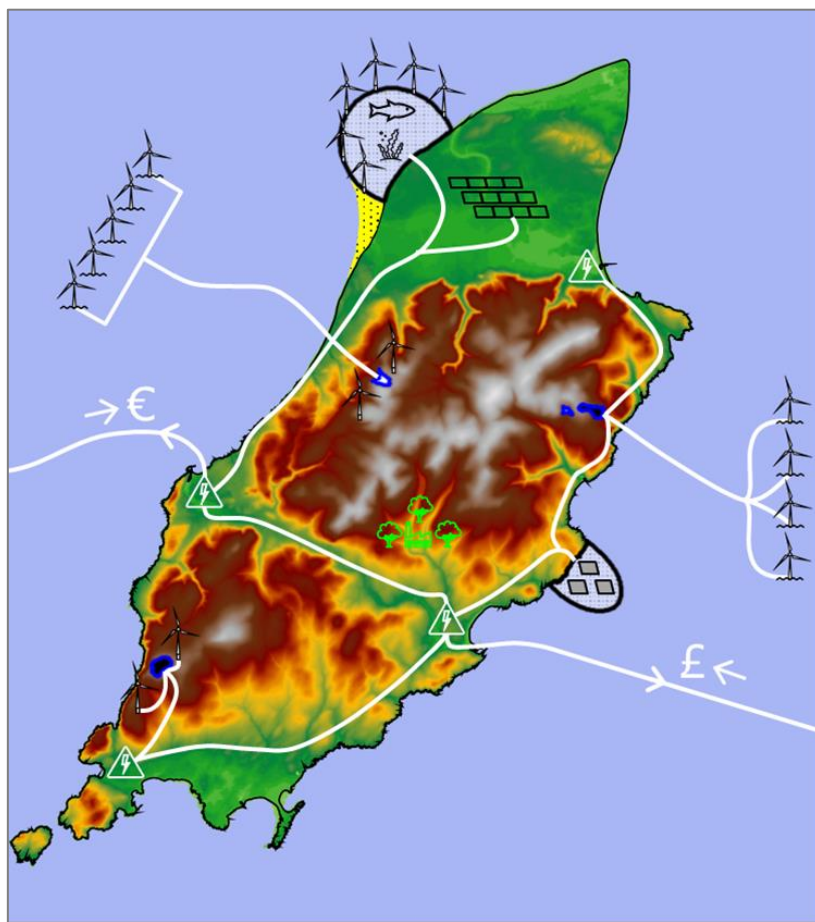


Fig. 8. Conceptual vision of a Manx Green Energy Hub. The location and size of the different elements are purely illustrative. Certain elements, such as offshore lagoons, are speculative whereas others are crucial, such as wind farms, onshore storage and transmission and export routes to UK and Ireland.

Financing the transition through private-public partnership

There are numerous uncertainties in evaluating options for low-carbon power on the Isle of Man and there are significant cost implications if the wrong decisions are made. In contrast, the energy industry has been dealing with these types of technological and financial uncertainties for years. Their method is to use a broad range of predictions to make “probabilistic” comparisons of value and risk. By taking an appropriate share of equity in

different projects, companies can deal with the fact that not all projects are profitable. Provided they take part in sufficient high-ranking ventures, the outcome tends to be positive over the medium- to long-term.

Governments do not have the luxury of rolling the dice more than once and cannot afford to lose large amounts of money at any stage. Nor do they have the experience to manage large engineering projects. Instead, Governments can take advantage of the industry model by being a partner. This has been a successful model for all countries with oil and gas. Thus, participating companies within a consortium pay the national stake of the up-front investment in return for a larger share of projected future revenues. The Government not only provides access to national resources but also enables the process by ensuring the appropriate fiscal legislation is in place and by issuing licenses and permits. In return, industry pays for virtually all investments, including the necessary installations, plants and infrastructure, including oil and gas platforms, processing facilities and pipelines. As the world turns away from fossil fuels, the private sector is now looking to invest in green power which, by analogy not only includes wind farms and solar parks but also energy storage and transmission. It is sometimes forgotten that to make use of the highly pressured and flammable fluid in an offshore oil or gas field is a technologically complex and cost-intensive process involving seismic, drilling, production, transport and processing operations. In comparison, the generation of electricity from wind or sun is a rather simple and benign process.

The other role Government can play is in guiding industry and bringing potential partners together. The old model of competition between companies and sectors is unlikely to work in the future where many parts of the low-carbon energy system do not make profit by themselves. To produce a fully integrated system – where renewable power is generated, surplus is stored and electricity is supplied to meet demand – requires a collaborative approach. Although the funding and project management will come from industry, the direction and governance has to come from Government.

Public engagement

The measures required to move from our current fossil fuel-based society to one producing net zero emissions imply there will be a total transformation in both our way of life and the economy. Nevertheless, there are numerous choices to be made and it is important that all views and ideas are taken on board. In particular, the pluses and minuses of different large-scale energy projects need to be fully discussed.

The advantages of renewable power can be regarded as local supply, low emissions and sales revenue and the disadvantages are significant up-front investments, large footprint areas and intermittency of supply. However, environmental considerations as well as personal preferences and human emotions play a major role when it comes to decisions. For example, there may be a preference that hydro-storage schemes are hidden from view, for example underground, even though this is more expensive than traditional reservoirs. People can also object to the sight of wind turbines and electricity pylons.

There is no doubt to move from the way modern society produces and utilizes power based on fossil fuels to sustainable sources of energy represents a major transformation. In fact, not one country has got close to achieving net zero emissions. It will therefore take a “can do” attitude and a proactive approach if the Isle of Man is to benefit from the energy transition rather than be dragged along.

One of the reasons for writing this paper is that we believe that the benefits of a home-grown, low-carbon energy system far outweighs the alternative of buying electricity from the UK. The disadvantages of choosing the latter are price volatility, security of supply from a grid with its own problems and reliance on someone else to meet emissions targets. An independent approach is not only responsible but also offers a new economic future for the Isle of Man.

Way forward

Industry and investors are looking for green energy projects where a route to market is available, especially those that can guarantee a price for a proportion of sales. The Isle of Man in turn needs a guaranteed supply of inexpensive electricity.

To develop a Manx Green Energy Hub, one where the Island can be entirely self-sufficient in renewable power as well as benefiting from revenue through the export of surplus electricity to the UK and Ireland, we envisage the following steps:

- 1) Complete the research and modelling summarized in this paper and discuss options with stakeholders (*4 months*). The goal would be to establish a baseline scenario with an appropriate mix of technologies, providing the scale and private investment which would maximize benefit to the Isle of Man. We envisage that renewable power projects, including storage, will be paid for and built by industry, provided there is a route to an export market and, possibly, also a guaranteed price for supplying electricity to the Manx grid. Part of the discussion will be whether the private or public sector or both pays for i) the facilities to transmit, balance and stabilize the electricity on-Island; ii) two new interconnectors to the UK and Ireland.
- 2) Engage with industry to develop an economic model which incentivizes energy companies to accept all technical and financial risk and also pay for an equity stake for the Manx State (*3 months*).
- 3) Engage with the public to collect views on the advantages and disadvantages of different options for a future energy system (*concurrent with Steps 1 & 2*).
- 4) Develop draft legislation and regulations to facilitate i) public-private partnerships in the energy sector; ii) a streamlined permitting procedure to licence land and offshore acreage for power projects (*6 months*). The statutory framework would allow the Manx State in the form of a Government-owned company to have a controlling equity share in all grid-scale projects, funded by participating companies, i.e. the State is “carried” by partners. The legislation might include the option for companies to bid on a fixed price to supply electricity to the Isle of Man, in part subsidized by the higher prices obtained through sales of stored electricity to UK and Ireland when market prices are high.
- 5) Issue a call to industry for public-private partnerships in the form of one or more groups of companies (consortia) contracted to build sections of a Manx Green Energy Hub (*concurrent with Steps 2 & 4*). An example section could be an offshore wind farm combined with onshore long-duration energy storage and electricity transmission.
- 6) Develop additional mechanisms to integrate renewable power production with net zero emissions goals such as electric heating systems, electric or hydrogen-fuelled transport networks, environmental farming and bio-sequestration projects and Manx low-carbon building materials.

Timescale and reality checks

The proposition of using Manx renewable energy resources to reach net zero emissions is ambitious but achievable. Nowadays wind and solar power projects are profitable without subsidies and the Isle of Man has the natural asset of a large and windy territorial sea ideal for siting fixed-base wind turbines. However, it is worth considering phasing and which types of projects might be easiest to start and complete first. The Manx Government has the goal that 75% of its electricity will be supplied from renewable sources by 2035 – less than 14 years from now. This also happens to be when the main power plant on the Isle of Man, the combined cycle gas turbine station at Pulrose, is due to be decommissioned. Most of the potential projects discussed here can be completed in this timeframe assuming they are started within the next year or two.

Offshore wind farms typically take 6-12 years from leasing round to first electricity. Provided permitting is streamlined, then onshore wind and solar projects can take less than 6 years, although meteorological measurements, environmental data collection and public enquiries can prolong the process. Onshore wind farms and solar parks are generally smaller and less expensive than offshore projects meaning that planning and

funding can be expedited. The construction phase of a traditional pumped hydro-storage scheme is typically 5 or more years, preceded by 4 years or so of planning and procurement, adding up to around 9 years in an optimum scenario. In other words, in terms of timelines, pumped hydro-storage projects are not too dissimilar to offshore windfarms. Extra time will be needed if more innovative technologies are used, as would be the case with sea-water pumped hydro-storage.

The commissioning, manufacturing and laying of two high voltage interconnectors to UK and Ireland, the strengthening of the electricity grid on the Island and the construction of ancillary service equipment would need to be in place before significant amounts of renewable power were generated. However, this is probably the most straightforward of the steps, easily achievable before 2030 provided long lead items are ordered in a timely manner.

Commercial energy projects are driven by a strong financial motive to stay on schedule and within budget. Therefore, assuming economic modelling and discussions with industry are positive, we would suggest having Manx legislation and regulations in place by end 2022, in order to build the components of a sustainable energy system over the period 2023-2035, including storage and export facilities.

CONCLUSIONS

Although it is governments that are making net zero commitments, the energy transition is now driven by investors and lenders who in turn are strongly influenced by public sentiment. Concerns about climate change mean that support for fossil fuels is waning.

The Isle of Man has tremendous resources of renewable energy that are currently unused. Traditionally, it has been the private sector which has developed oil and gas fields, not only building the entire production facilities and infrastructure but paying the Government for a share of the national resource. Nowadays the value is in clean energy such as wind, sun and water. Renewable power benefits both the nation and industry with the right economic model.

Although the costs of generating wind and solar power is relatively low, there is some inertia in moving from the traditional way we generate and utilize power to an entirely sustainable system. The typical concerns are large up-front costs, visual impact and “keeping the lights on”. Concerning costs, given the right legislation and a route to market, the energy industry will pay for most of it. Concerning the visual impact, experience on Scottish islands shows that the prospect of reduced energy bills tends to change the way the community view of renewable energy projects. Nonetheless, it is essential to engage the public in discussing the different options. It may be that the most cost-effective solution is not necessarily the one that is preferred by the majority such, for example, concealed facilities may be more acceptable than cheaper options. Concerning energy security, this is best provided with a set of alternative sources of power such as wind and solar, grid-scale energy storage and interconnection to two countries.

At the moment, the Isle of Man is wholly dependent on oil and gas for electricity, heating and transport. The current emissions of an average Manx person has a disproportionate impact on the climate compared to the majority of people on the Earth. The Isle of Man has a tremendous opportunity to turn things around by developing a self-sufficient, low-carbon energy system. The vision includes a new source of income generated by exporting green electricity to the UK and Ireland, whereby the investments are financed and managed by industry.

A key objective is improving the warmth and dryness of Manx homes. Another is attracting new businesses to the Island with the offer of clean, inexpensive power. These opportunities are enabled with appropriate legislation and private capital. Also, with a proactive approach, the Isle of Man will be able to demonstrate to the world how innovative technologies in energy storage and hydrogen fuels can help achieve net zero emissions.

Suggested reference for this paper:

Quirk, D., Peake, R. and Boucher, J., 2021. *Can the Isle of Man power itself with renewable energy?*

Report by Energy & Sustainability Centre Isle of Man, 21 p, www.energysustainabilitycentre.im/knowledge-hub.

Other references are available on request to dave.quirk@energysustainabilitycentre.im.

APPENDIX 1: OPTIONS FOR LOW-CARBON POWER ON THE ISLE OF MAN

	Costs & footprint for 1000 GWh/year energy or for 24 hours storage of 120 MW						Advantages & Disadvantages					Comments
	Up-front cost (CAPEX), £ million	Annual operating cost, £ million/yr	20 Year cost, total, £ million	LCOE, £/MWh	Total area of facilities, km ²	Avg emissions, '000 t CO ₂ e/yr	Fit of supply to demand	Cost to Manx consumers	IoM revenue (fees & exports)	Government investment	Commercial maturity	
Offshore Wind Farm	700	11	926	46	60	15	Intermittent	Low	High	None	High	Combine with energy storage; intra-turbine area has value
Onshore Wind Farm (excl cost of land)	325	14	598	30	40	11	Intermittent	Low	Moderate	None	High	Combine with energy storage; intra-turbine area has value
Onshore Solar Park (excl cost of land)	1,200	8	1,353	68	15	25	Intermittent	Low	Moderate	None	High	Combine with energy storage & agriculture at smaller scale
Floating Solar Park (excl marine lagoon)	1,600	15	1,906	95	30	35	Intermittent	Moderate	Low	Subsidy	Moderate	Combine with marine lagoon; marine solar is not mature
Tidal Stream Turbines	2,800	25	3,300	165	50	8	Intermittent	High	None	Pilot plant	Low	Currently expensive & difficult to scale up
Wave Energy Converters	2,400	60	3,600	180	40	15	Intermittent	High	None	Pilot plant	Low	Currently expensive but could fit between wind turbines
Biomass CHP Plant (excl cost of land)	228	55	1,326	66	280	63	Dispatchable	Moderate	None	Biomass & entire plant?	High	Down-scale for IoM biomass; combine with district heating
Combined Cycle Gas Turbine Plant with CCS	1,500	44	2,381	119	<1	44	Dispatchable	High	Low	Entire plant?	Moderate	Possible Pulrose conversion but CCS viability is uncertain
Non-Conventional Gas Power Plant	1,200	80	2,800	140	<2	160	Dispatchable	High	None	Biomass & entire plant?	Moderate	Down-scale for IoM biomass; combine with district heating
Small Modular Nuclear Reactor	1,000	30	1,608	80	<1	19	Inflexible	High	High	Entire plant?	Moderate	Issues of safety, fuel supply & decommissioning costs
Off-Grid Heating & Storage	1,540	35	2,240	112	>1	21	Reduces peak demand	High	None	Grants & other support	High	Grid-scale power projects may be more effective
Conventional Pumped Hydro Storage (F-W)	424	1	435	na	0.2 km ² upper reservoir	6	Dispatchable	Low	High	None?	High	Key enabler to low-C energy; needs public acceptance
Underground Pumped Hydro Storage (S-W)	880	1	895	na	5 million m ³ upp reservoir	6	Dispatchable	Moderate	High	None?	Low-Mod	Viability of excavation & SW pumping are uncertain
Inverse Pumped Hydro Storage (S-W lagoon)	1,300	2	1,330	na	8 km ² marine lagoon	11	Dispatchable	Moderate	High	Partial	Low	New tech for coastal regions; needs risk-inclined investors
Lithium-Ion Batteries (for grid-scale storage)	1,800	2	3,040	na	<1	14	Dispatchable	High	Moderate	Entire plant?	Moderate	Renew after 12 years; ethical & environmental concerns
Optimized Electricity Grid (resilient, low-C)	80	2	120	na	c.1	7	Provides stability	Moderate	If AC interconnector	Infrastructure strengthening	High	Requires smart tech, energy storage & ancillary services
HV Interconnector to UK or Ireland	150	1	164	na	2x 100 km length	1	Dispatchable to markets	Moderate	High	Entire cable?	High	High value to UK & Iri from 2 140 MW + storage; AC or DC?
Purchase of Electricity (via UK interconnector)	0	58	1,166	58	0	responsibility relinquished	Dispatchable but at cost	Volatile	None	Requires interconn.	High	Insecure; dependent on UK emissions, prices & unity
Green Hydrogen (electrolysis)	1,800	70	3,200	160	<2	15	Dispatchable in gas plant	High	Low	Entire system?	Low	Electrolysis to produce fuel; storage & transport is difficult
Bio-Sequestration (e.g. trees as carbon sink)	750	5	843	42	934	-484	80 year time frame	Low	Possibly from offset schemes	Support schemes	Moderate	Rewilding & restoration of land & sea; insufficient area

Key to table: green cells – good; yellow cells – not optimum; orange cells – problematic; red font – uncertain values; CHP – combined heat and power; CCS – carbon capture and storage; FW – fresh-water; SW sea-water; LCOE – levelized cost of energy over 20 year period, t CO₂e/yr – tonnes carbon dioxide equivalent per year, na – not applicable.

APPENDIX 2: DOMESTIC IMPROVEMENTS IN ENERGY USE FOR HEATING?

What can home-owners do in the short-term to reduce their carbon emissions? Working on the assumption that future electricity is supplied from renewable sources and is relatively cheap, choices to lower the environmental impact of home heating can be ranked as follows.

Emissions-friendly investments in an existing property:

- 1) Heat recovery unit with 2), 3) and/or 4).
- 2) Draught-proofing of windows and doors.
- 3) External wall insulation and roof insulation with 1) to avoid damp.
- 4) Double or triple glazing with 1) to avoid damp.
- 5) Electric thermal storage heaters (controlled by grid-linked smart meter)
or electric radiators + battery storage (ditto)
or air-sourced heat pump to feed existing central heating system + electric immersion heater.
- 6) Thermal solar panels for hot water + electric immersion heater (controlled by grid-linked smart meter).
- 7) Electric cooker

Emissions-friendly new constructions:

- 1) Energy-efficient timber houses built with local wood and using Manx stone foundations^{††}
or passivhaus, avoiding the use of concrete and steel.
- 2) Air-sourced heat pumps with underfloor heating.
- 3) Electric radiators
or electric thermal storage heaters (controlled by grid-linked smart meter).
- 4) Electric cooker.
- 5) Hot water storage units (controlled by grid-linked smart meter)
&/or thermal solar panels for hot water.
- 6) Photovoltaic solar panels for electricity generation + battery storage.
- 7) Rainwater harvesting system.
- 8) In dense residential areas, district heating schemes possibly supplied by community-scale water- or ground-sourced heat pump.

If desirable, the Government could support such investments through a supplementary mortgage scheme.

^{††}Cement and steel account for approximately 15% of global emissions of greenhouse gases so limiting their use reduces the impact of construction on climate change.

APPENDIX 3: COMPARISON OF DIFFERENT FUTURE LOW-CARBON ENERGY SCENARIOS – UK-DEPENDENCY VERSUS ISLE OF MAN SELF-SUFFICIENCY

	Arup - PLEXOS models			ESC - UK-Dependence model			ESC - IoM Self-Sufficiency model			
	Scenario 1 / CT demand	Scenario 2 / ST demand	Scenario 3 / LtW demand	Low Case	Mid Case	High Case	Low Case	Mid Case	High Case	
main aim:	NZE on-Island electricity, low CAPEX			NZE on-Island power			NZE surplus power, export revenue (UK or Ireland)			
2050 annual electricity use, GWh	636	553	514	876	1,270	1,664	876	1,270	1,664	narrow range in Arup models
proportion of 2018 energy use	38%	33%	31%	53%	77%	100%	53%	77%	100%	energy missing in Arup models?
30 yr total cost, £ million, undisc	1,639	1,361	1,114	1,647	3,794	8,366	1,275	2,036	3,757	narrow range in Arup models
25 yr total cost, £ million, undisc	1,311	1,057	852	1,518	3,486	7,699	1,146	1,728	3,090	estimates from Arup models
avg total cost normalised to Mid Case ESC IoM Self-Sufficiency model	2,945	2,776	2,429	2,294	3,640	6,130	1,755	1,882	2,613	low case costs are similar
up-front CAPEX, £ million, undisc	659-844	530-567	415-489	909	1,998	4,432	1,104	1,648	2,960	narrow range in Arup models
annual OPEX, £ million, 2020-30	22	18	16	26	62	133	2.2	3.2	4.2	large range from uncertainty in future GWh & elec import prices
annual OPEX, £ million, 2030-50	22	21	16	24	59	130	1.5	3.2	5.5	
cost of electricity imports:	£54/MWh			£39/MWh	£58/MWh	£87/MWh	not applicable (no elec imports)			no range in Arup models?
main components of energy system model:	new DC IC (UK customer), 28 MW biomass & EfW +/- wind & solar			new UK IC (UK customer), LIB, 20 MW biomass, refitting houses			offshore wind + solar, PHS, EFR, new IC for export to UK/Ireland			high UK-Dep costs are from LIB, elec imports & refitting
not included in models:	electricity-LIB losses, refitting homes, public transport, biomass land cost, NZE responsibility, air & sea travel			UK sales revenue, licence fees, biomass land cost, air & sea travel			export revenue from green power, 2nd IC, value to new industry, air & sea travel, licence fees			next step is to add value of earnings from IoM Self-Suff
source of data:	MUA, IoM CCTT, UK BEIS, National Grid, standard PLEXOS selections			DTU, DK-NO-NL-UK-IR companies, multiple EU & UK sources noted in Quirk et al. 2021 - <i>The North Sea through the energy transition</i>						Arup rely on public UK sources
other comments:	insufficient IoM biomass, variable treatment of efficiency losses, 20,000 km/EV > twice current cars			difference in costs to Arup models is 2050 electricity use GWh/yr & inclusion of LIB & refitting houses			250-400 MW offshore wind farm + costs include 20 MW biomass & modest building efficiencies			missing energy will need accounting for in NZE plan

Abbreviations used in table: CT = consumer transformation model; ST = system transformation model; LtW = leading the way model; NZE = net zero emissions; CAPEX = equipment and construction costs; OPEX = operating cost, including imports; undisc = undiscounted; IC = interconnector; EfW = energy from waste; LIB = lithium-ion batteries; PHS = pumped hydro-storage; EFR = enhanced frequency response (an ancillary service); EV = electric vehicle.

APPENDIX 4: WHY NET ZERO EMISSIONS?

Background on climate change

A basic question is whether comprehensive action on emissions is worthwhile. The average person on the Isle of Man has a relatively comfortable life and there may be the risk that the transformation to a low-carbon society will have negative economic effects. Therefore, it is worth summarizing the global situation in terms of emissions and climate change to give a perspective of what happens if we do not act^{§§}.

An accelerating rise in global temperatures is paralleled by increasing human emissions of greenhouse gases (Fig. 9), mainly carbon dioxide, methane and nitrous oxides. Greenhouse gases act like the windows of a greenhouse in that they prevent the sun's heat from escaping back to space causing the atmosphere to get warmer. This was already known in the 19th century and in 1896 Svante Arrhenius correctly predicted the rise in temperatures we are seeing today.

In 2019, emissions of greenhouse gases were equivalent to the amount of carbon dioxide which would be produced by burning 13% of the Amazon or an area of 700,000 km² of rainforest each year. 2.2 trillion tonnes of carbon dioxide and equivalent greenhouse gases have been added to the atmosphere since the start of the industrial revolution, around 1850, largely from using fossil fuels (oil, gas and coal) to provide power for industry, heating, transport and electricity. To date this has caused global warming of around 1.2°C (Fig. 9). Never in Earth's history have temperatures risen so rapidly.

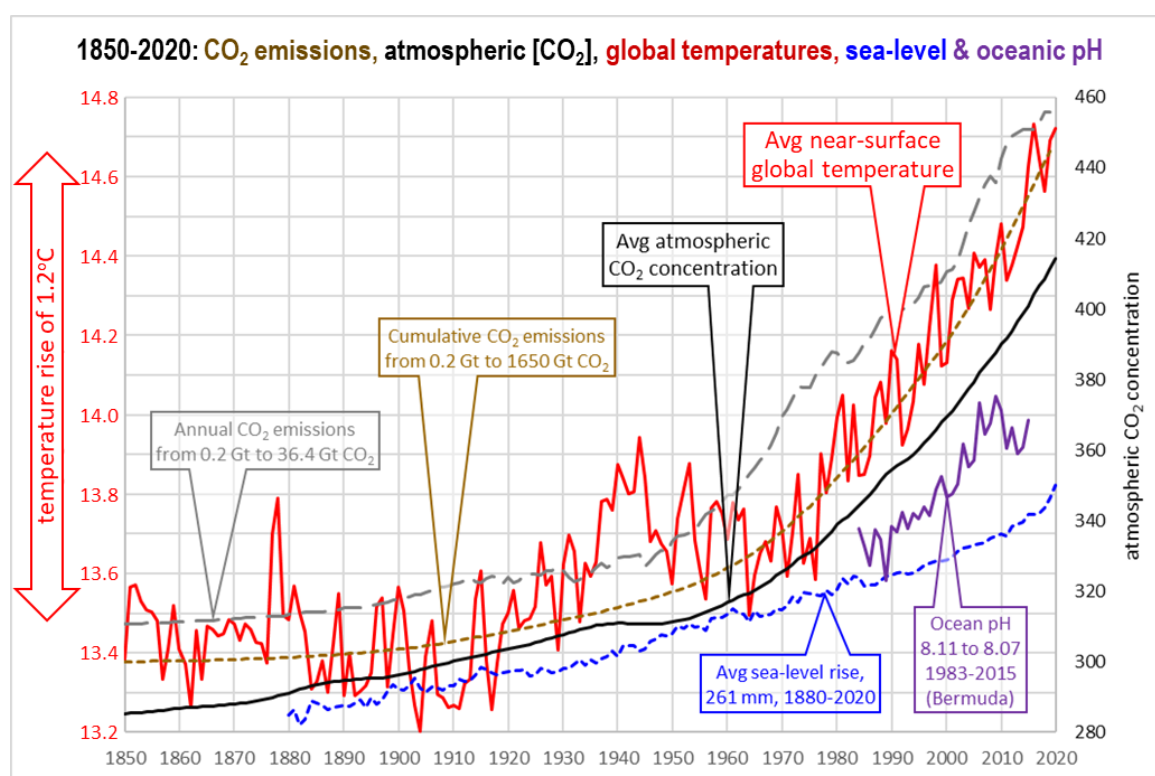


Fig. 9a. Graph showing fossil fuel-derived emissions of carbon dioxide, the rise in global temperatures and related effects since the start of the Industrial Revolution. The sources of the data are listed in Quirk (2021).

^{§§} Further information can be found in a separate document entitled *Facts about climate change and greenhouse gas emissions relevant to the Isle of Man* at www.energysustainabilitycentre.im/knowledge-hub.

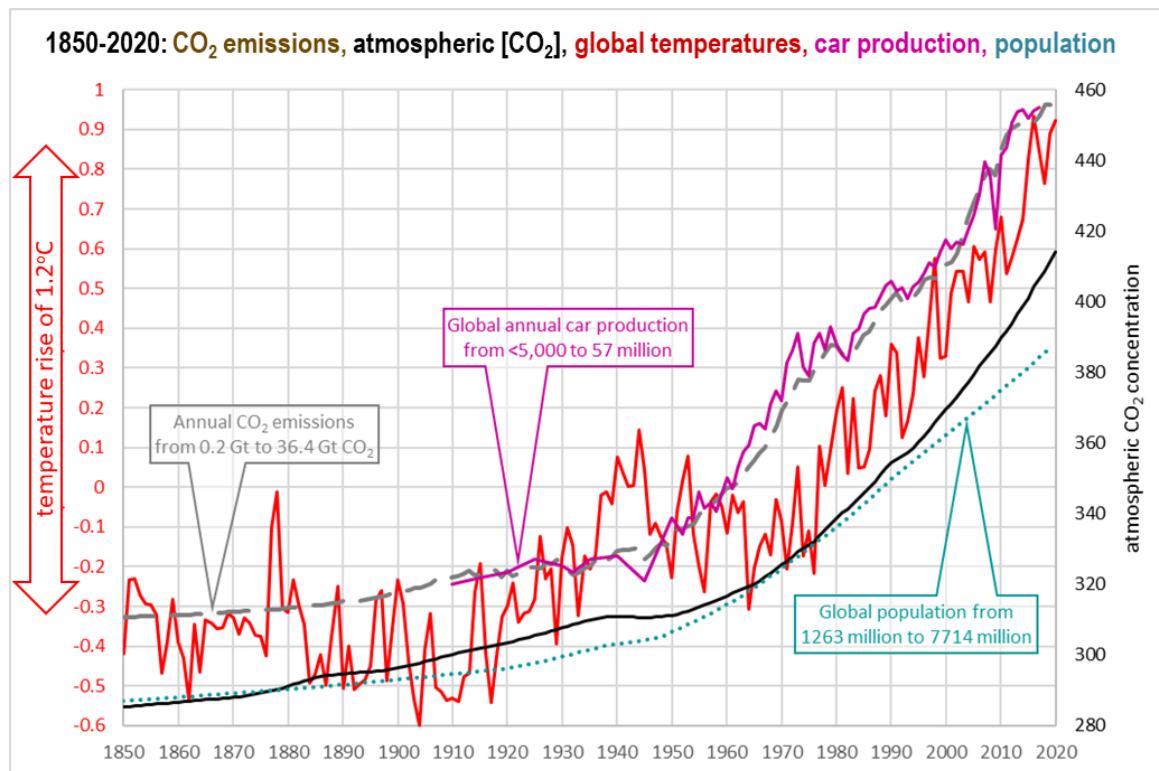


Fig. 9b. The rise in global emissions, atmospheric carbon dioxide concentrations (black line), global temperatures (red line), annual car production and world population. There is a strong correlation between emissions, temperature rise and a high-consumption lifestyle (in this case represented by cars). Since around 1975, emissions and temperatures have risen more quickly than the growth in global population, largely because consumption in developed countries has grown disproportionately to the rest of the world reflected, for example, in widespread car ownership.

Rising temperatures will affect the Earth's climate in different ways. There are obvious effects, such as melting ice sheets and rising sea-level, and there are less obvious effects such as changing weather and acidification of oceans. Most of the Earth's ecosystems are under threat. If global warming continues, many of the tropical regions will become uninhabitable as they will be too hot and dry for humans. The Isle of Man will probably become colder as it is likely that the Gulf Stream will stop as a result of increasing amounts of meltwater flowing from Greenland. Many other areas will suffer from violent storms.

An additional worry is that there is a delay in the full effect of rising temperatures. This means, if we stopped all emissions now, it may still take many years before climate change is mitigated. The scale of this lag is difficult to predict.

The impact of the Isle of Man on global emissions

Taking all activities into account, the average person on the Isle of Man is responsible for emissions equating to 16 tonnes of carbon dioxide, a volume of gas the size of 50 average houses. These emissions come from driving cars, heating homes, using electricity, working and making purchases of food and other goods. Even manufacturing an electric car produces the equivalent of 25-40 tonnes of carbon dioxide, with roughly 8 tonnes of carbon dioxide to produce the lithium-ion battery.

67% of the greenhouse gases which the Isle of Man is responsible for are so-called direct emissions – those that originate on-Island. These direct emissions are equivalent to an annual 11 tonnes of carbon dioxide per Manx resident, representing the same amount produced from burning 25 barrels of crude oil or from burning 15 large trees each year. The Climate Change Bill is a legal commitment to reduce these to zero by 2050. Unfortunately, this is not an easy task as society is currently wholly dependent on fossil fuels.

Capturing or sequestering carbon dioxide has a surprisingly small effect. For example, 85,000 trees at Meary Veg will soak up the average emissions of 53 Manx residents on an annual basis, and only after the trees have become relatively large. So, although re-establishing forests, wetlands and other carbon-rich environments is important, this will not save us from having to drastically curb our output of greenhouse gases. In other words, we will have to transform how we produce and utilise energy, food and materials.

Nonetheless, as it is unlikely we will stop traveling, using heat and electricity and working in the office, factory or farm, it is worth asking whether net zero emissions is really possible? The main article aims to show that it is but there is a collective responsibility for us all to work together to achieve it within 29 years.

How much time do we have?

Climate experts at the United Nations and most scientists around the world agree, that if global warming rises another 0.3°C from present day (a total of 1.5°C since the start of the Industrial Revolution), the consequences will be extremely severe. The international community has therefore set this as the goal: to limit the rise in temperature to 1.5°C. It is calculated that this temperature limit will be reached by adding another 560 billion tonnes of carbon dioxide to the atmosphere, based on theoretical considerations and historical data. This is regarded as a point of no return.

Although climate change is already happening, the view is that it will be catastrophic if we continue to add greenhouse gases beyond the equivalent of 560 billion tonnes of carbon dioxide. This is the threshold that the world's nations are working towards through the United Nations' Conference of Parties.

560 billion tonnes of carbon dioxide contains the same amount of carbon as half of the world's oil and gas reserves or just 20% of the world's coal reserves. In other words, most of the world's fossil fuels will have to be left in the ground, requiring alternative methods to produce power, materials and goods.

avg citizen of:	CO ₂ e emissions per avg citizen in tonnes/year	CO ₂ e emissions per avg citizen relative to World	Years equivalent to 1.5°C global temperature rise based on IPCC mid-case: 560 Gt CO ₂ e	
Isle of Man	16.1	240%	4.5	assuming World's 7.7 billion people have the same carbon footprint as avg citizen of country or region
China	5.6	83%	13.1	
India	1.4	22%	50.3	
World	6.7	100%	10.9	

Fig. 10. The environmental footprint of people around the world is very unequal. This table shows the greenhouse gas emissions of an average person in carbon dioxide equivalent (CO₂e) tonnes per year for three countries compared to the world average. The data are from Tukker et al. (2014) and Quirk et al. (2021). Also shown are how many years it would take to reach the United Nation's Intergovernmental Panel on Climate Change (IPCC) suggested limit of 560 billion tonnes (Gt) of CO₂e assuming the world's population had the same emissions as the average person in the selected countries.

Based on current rates of global emissions we have around eleven years left before reaching the threshold of 560 billion tonnes of carbon dioxide. However, people on the Isle of Man have a significantly larger impact than the average. Thus, if the rest of the world had the same emissions as we do, there would only be 4½ years before reaching the 560 billion tonnes threshold (Fig. 10).

Other countries are often given the blame for emissions, even though a large proportion come from producing goods for consumers in developed countries. Nonetheless, just for comparison to the Manx 4½-year footprint, if the entire world had emissions equivalent to an average Chinese person it would take 13 years before reaching the 560 billion tonnes threshold and 50 years based on an average Indian person's emissions (Fig. 10). In other

words, in countries like the Isle of Man, we can have a far greater impact on lowering emissions than most of the world. The biggest step we can now take is replacing fossil fuels with low-carbon sources of power.