Technical note: emissions displacement from additional renewable energy

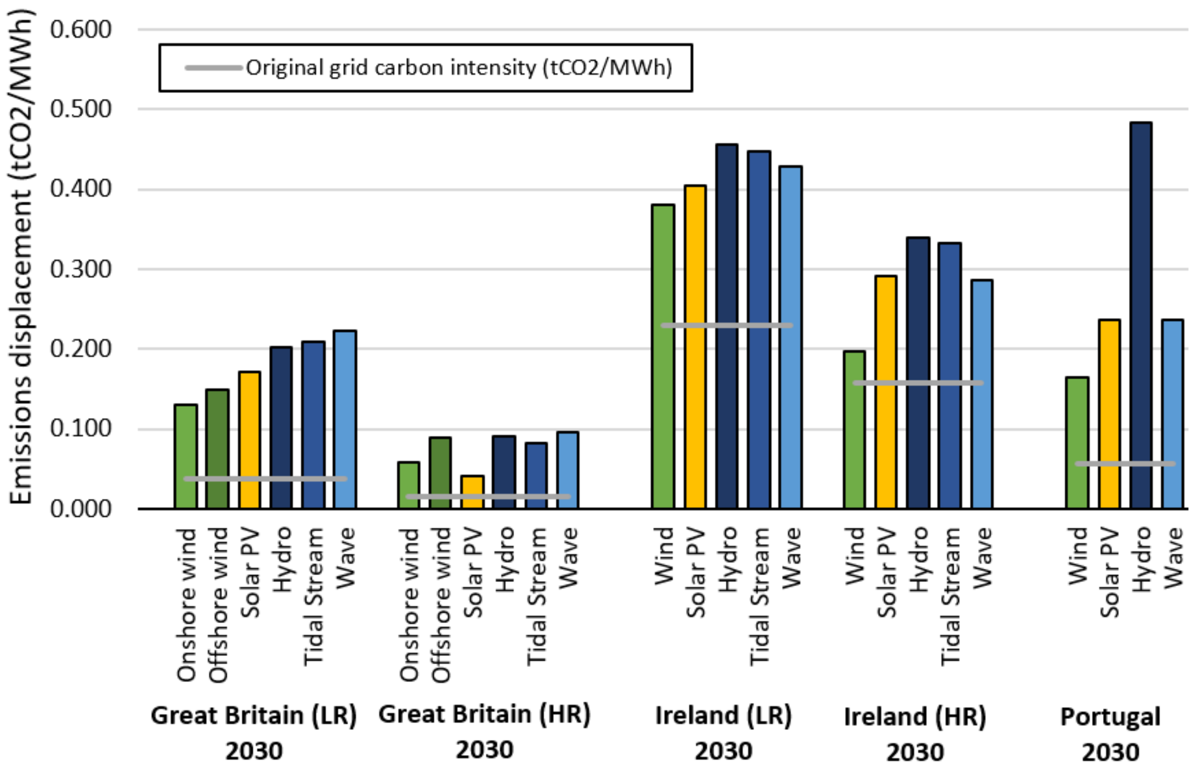
September 2022

EXECUTIVE SUMMARY

This technical note summarises analysis on emissions displacement performed through the OCEANERA-NET EVOLVE project. Twenty-six cases have been modelled representing three regions: Great Britain, Ireland, and Portugal, based on established future energy scenarios for 2030. Low Renewable (LR) and High Renewable (HR) scenarios are included for Great Britain and Ireland.

Specially developed economic dispatch models of each region are used to compare a base case and a number of sensitivity cases for each scenario, in which 1TWh of additional renewable generation (either wind, solar photovoltaic, hydroelectric, wave or tidal stream) is included. The resultant carbon emissions displacement due to the additional 1TWh of renewable generation is quantified in terms of tCO_2 reduction per MWh of additional generation.

It has been found that **all forms of renewable energy displace higher emissions than the grid carbon intensity**. This result is consistent in every sensitivity case. This result is not surprising, as the economic dispatch model has a cost reduction objective function and –like the merit order process within European electricity markets- will prioritise generation that does not incur a fuel or carbon cost and can bid lower in wholesale electricity markets. As renewable energy bids in to electricity markets as a low cost (acting as a price-taker), it is able to displace more expensive fossil fuel generation.



1. BACKGROUND

The EVOLVE (Economic Value of Ocean Energy) project is funded through the OCEANERA-NET Co-fund, with project partners from Scotland, Sweden, and Portugal. The key objective of EVOLVE is to analyse the overall system benefits possible from installing ocean energy (both tidal stream and wave energy) in the European energy mix. This analysis takes place through use of economic metrics such as wholesale market prices, and environmental metrics such as carbon emissions. The project aims to develop an understanding of the market value of ocean energy within future high-renewable power systems, using the analysis of production, supply and demand profiles and credible economic energy supply scenarios. The EVOLVE project considers three country-scale case studies, covering the electricity grids of Great Britain (GB), Ireland (IE), and Portugal (PT), and is supported by an external stakeholder group consisting of energy systems experts from each of these regions.

This analysis examines the potential for carbon emissions displacement from renewable generation, including wave and tidal stream, over the three EVOLVE modelling regions. The key output for comparison is the tonnes of carbon dioxide displaced per megawatt-hour of additional renewable generation (tCO_2/MWh).

2. METHODOLOGY

Electricity dispatch models have been created by the EVOLVE project partners, in consultation with regional experts, to represent the current and future power systems of Great Britain, Ireland, and Portugal. Python for Power Systems Analysis (PyPSA) software is used to compute hourly optimal dispatch for each of these regions, minimising the total cost of dispatch whilst maintaining supply-demand matching on an hourly basis. This represents a perfectly competitive wholesale market, where generation bids based on short-term (fuel and carbon) costs, and the market clears at the price of the marginal generator in every hourly time-step.

The electricity mix for each of the three regions has been modelled using historical data from 2019, and future projected energy scenarios for 2030 (see section 3). Hourly profiles for variable renewable generation (wind, solar PV, wave, tidal stream) have been generated based on historical resource availability from 2019, illustrated for Great Britain in Figure 1. 2019 has been found to be an average year for renewable energy availability.

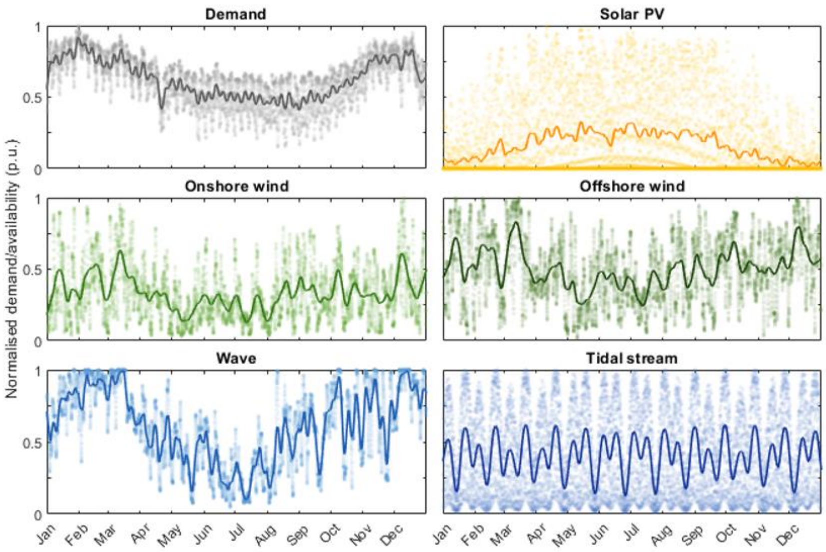


Figure 1. Great Britain demand and variable renewable generation capacity factor profiles from 2019 resource data, normalised to annual peak power, with hourly data as individual points and weekly moving average in bold.

It can be seen in Figure 1 that the generation availability profiles for the different sources of variable renewable energy display very different profiles, at both hourly and seasonal scales. Solar and Tidal stream are particularly variable intraday due to their well understood daily and 6-hourly generation cycles, respectively. Wind and wave generation show a strong seasonal pattern, with higher availability in the winter and lower availability in the summer, whereas solar generation shows the opposite seasonal pattern, with higher availability in the summer. There are periods of offsetting between all of the different forms of variable renewable generation, and it can be inferred that a combination of generation profiles will result in a more consistently available renewable mix.

The methodology used to calculate emissions displacement in this study is illustrated in Figure 2. Scenario comparison is used, with carbon emissions results compared between a base scenario (**step 1**) and a sensitivity scenario including an additional 1,000,000 MWh, i.e. 1TWh, of each renewable generation technology (**step 2**). The carbon emissions from each scenario run are calculated based on the fossil fuel dispatch and assuming an emissions factor of 0.504 tCO_2/MWh for gas generation (**step 3**). It should be noted that the economic dispatch models minimise cost, without any constraints applied to carbon emissions. The carbon emissions resultant from the optimised dispatch is therefore calculated in post-processing of the results. The carbon emissions displacement is also calculated in post processing, by comparing the emissions (in tonnes of CO_2) between the base and sensitivity scenarios and dividing by the additional 1TWh dispatch (**step 4**) to produce the emissions displaced per MWh of additional generation.

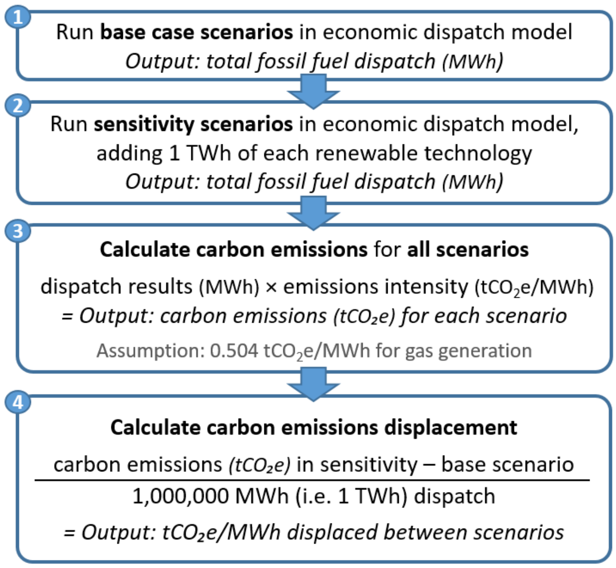


Figure 2. Calculation methodology

3. SCENARIOS

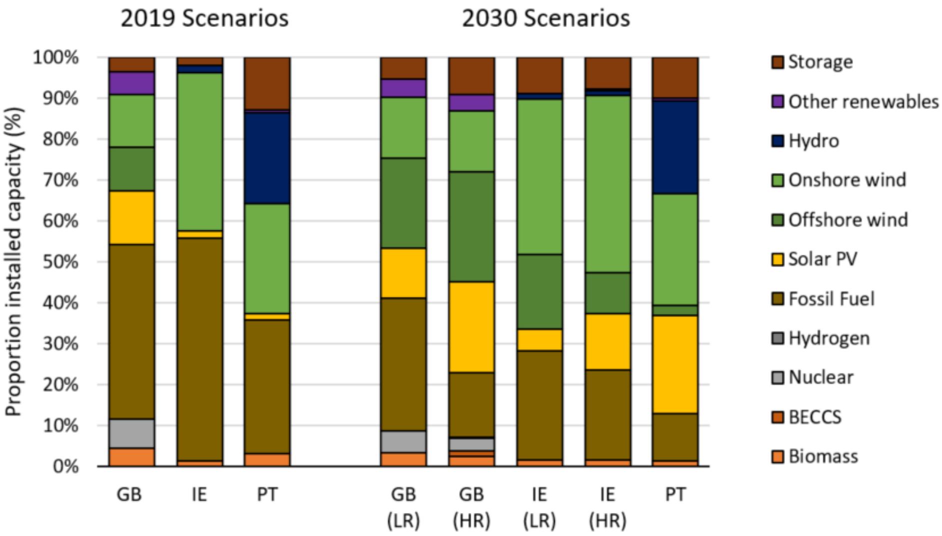
Five scenarios have been selected over the three regions as future energy scenarios for 2030, with the electricity mixes illustrated in Figure 3, alongside the 2019 historical electricity mixes[1] for each region for comparison. The 2030 electricity mix data has been taken from established future energy scenarios developed within each of the three regions, from National Grid[2] in Great Britain, SONI[3] and Eirgrid[4] in Ireland and from the National Hydrogen Strategy[5] in Portugal. Multiple future energy scenarios are available from these sources for Great Britain and Ireland and so both a Low Renewable (LR) and High Renewable (HR) scenario is modelled for these regions, to explore the range of possible results. The low and high renewable scenarios selected are: Steady Progression and Leading the Way (Great Britain); and Delayed Transition and Coordinated Action (Ireland).

It can be seen in Figure 3 that the 2030 energy scenarios all have higher proportions of renewables and lower proportions of fossil fuels than the 2019 electricity mixes. It should also be noted that the total installed capacity

[1] Historical electricity mix data sourced from ENTSO-E: https://transparency.entsoe.eu/
[2] https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021
[3] https://www.soni.ltd.uk/customer-and-industry/energy-future/
[4] https://www.eirgridgroup.com/customer-and-industry/energy-future/
[5] https://kig.pl/wp-content/uploads/2020/07/EN_H2_ENG.pdf

of all the future scenarios is higher than the corresponding 2019 total installed capacity for each region. Although some scenarios are labelled ‘low renewable’, this is by comparison to the ‘high renewable’ cases - all 2030 scenarios have more than half of their installed capacity from renewable energy.

The sensitivity cases applied to the future scenarios are shown in Table 1. Wind, solar photovoltaic, hydroelectric (with reservoir), and wave energy are included in every region. For GB offshore wind and tidal stream are also included.



	GB	IE	PT	GB (LR)	GB (HR)	IE (LR)	IE (HR)	PT
Total installed capacity (GW)	100	15	20	143	177	19	23	25
Proportion from Renewables	47%	44%	54%	57%	72%	65%	70%	78%
Proportion from Fossil Fuels	43%	54%	33%	32%	16%	27%	22%	12%

Figure 3. Proportional installed electricity generation capacity for all scenarios modelled. LR/HR indicates low/high renewable 2030 scenarios

4. RESULTS

Table 1 shows the emissions displacement results from each of the sensitivity cases from the 2030 scenarios. It can be seen that the grid carbon intensities in all regions vary considerably, from 0.016 tCO_2/MWh in the high renewable scenario for Great Britain, to 0.229 tCO_2/MWh in the low renewable scenario for Ireland. It has been found that adding 1TWh of any form of renewable energy always displaces higher emissions than the average grid intensity, as signified by each of the ratios of emissions displacement to grid intensity being greater than 1. In fact these ratios vary from 1.26 (wind, Ireland High Renewable) to 8.62 (hydro, Portugal).

The greatest variation in displaced emissions is between countries and scenarios. There is also some lesser variation between different renewable technologies:

- Hydro displaces the highest emissions in the Irish and Portuguese scenarios (0.339 – 0.483 tCO_2/MWh).[6]
- Solar PV and wave both displace the highest emissions for Portugal – up to 0.236 tCO_2/MWh.
- Wave displaces the highest emissions in Great Britain and tidal stream in Ireland – up to 0.447 tCO_2/MWh.

[6] It should be noted that hydroelectric generation in these models is assumed to be fully dispatchable through use of a reservoir, with no seasonal limits on generation, which is a simplification of the available water resource

- While wind does not have the highest emissions displacement in any of the examined scenarios, this is likely because of the substantial deployment (and corresponding absolute emissions displacement) already modelled for wind by 2030 in all scenarios, as shown in Figure 3.

Table 1. 2030 scenarios emissions displacement results

1 TWh of additional ...	Emissions displaced by this additional generation (tCO2e/MWh)	Original grid carbon intensity (tCO2/MWh)	Ratio
Portugal 2030			
Solar	0.236	0.056	4.21
Wind	0.165	0.056	2.95
Wave	0.236	0.056	4.21
Hydro	0.483	0.056	8.62
Great Britain 2030 – 'High Renewable' scenario			
Solar	0.040	0.016	2.54
Offshore wind	0.090	0.016	5.65
Onshore wind	0.059	0.016	3.69
Wave	0.097	0.016	6.09
Tidal Stream	0.082	0.016	5.15
Hydro	0.090	0.016	5.66
Great Britain 2030 – 'Low Renewable' scenario			
Solar	0.172	0.038	4.57
Offshore wind	0.149	0.038	3.98
Onshore wind	0.130	0.038	3.46
Wave	0.222	0.038	5.92
Tidal Stream	0.210	0.038	5.59
Hydro	0.202	0.038	5.38
Ireland 2030 – 'High Renewable' scenario			
Solar	0.291	0.157	1.85
Wind	0.198	0.157	1.26
Wave	0.287	0.157	1.83
Tidal Stream	0.332	0.157	2.12
Hydro	0.339	0.157	2.16
Ireland 2030 – 'Low Renewable' scenario			
Solar	0.405	0.229	1.77
Wind	0.380	0.229	1.66
Wave	0.428	0.229	1.87
Tidal Stream	0.447	0.229	1.95
Hydro	0.455	0.229	1.99

5. CONCLUSIONS

Scenario analysis has been used to compare the emissions displacement potential of renewable technologies in 26 model runs scenarios representing the future electricity mixes of Great Britain, Ireland and Portugal in established 2030 future energy scenarios. It has been found that all forms of renewable energy displace higher emissions than the grid carbon intensity in every sensitivity case – in some cases a high multiple of the grid carbon intensity.

These results are consistent with the normal operation of European electricity markets. Renewable energy typically has negligible marginal costs and can therefore bid in to electricity markets at a low price (acting as a price-taker). Electricity markets clear at a marginal price, based on the merit order of available generation (stacked from least expensive to most expensive), and the cheapest solution to meet demand, subject to technical grid and system constraints. This makes renewable energy capable of displacing fossil fuel generation – which has much higher marginal costs - rather than displacing other renewables, which will also have very low marginal costs.

The ratio of displaced emissions relative to the average grid carbon intensity appears to increase as the grid becomes more decarbonised. Average technology ratios are higher in ‘high renewables’ scenarios. This means that renewables continued to disproportionately displace fossil fuel generation, even as renewables take up a higher and higher percentage of the total power generation.

This is likely to be related to the deployment of complementary renewable sources – i.e. renewables which generate at different times (see Figure 1). For example wind and solar are complementary on a seasonal basis, and wave & wind complement each other on an hourly and daily basis. Such complementary renewables have a greater collective tendency to displace fossil fuels.

The ratios associated with each technology in the results table also reflect the assumed prevalence of other complementary renewable sources in the various scenarios. Ratios will also reflect the individual characteristics of the technology and resource – for example hydropower’s assumed dispatchability.

In terms of next steps, it is recommended that authorities and planners should undertake their own modelling of the carbon displacement of additional renewable energy sources, including heating & cooling, using their own baseline scenarios. The results of this analysis will strengthen decisions in multiple climate & energy policy fields – for example, the ambition & timeline of renewable deployment targets, investments into renewables versus supporting infrastructure, RD & I priorities, etc.

ACKNOWLEDGEMENTS

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Place, Time and Value study for Blue Energy across Europe