AN ASSESSMENT OF 100% RENEWABLES IN ELECTRICITY AND HEAT IN ARAN ISLANDS BY 2030

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Abstract: Decarbonisation of geographical islands are gaining more attention within the European climate and energy targets. The islands are either depended on mainland through grid or they face high dependency on fossil fuels. In this respect the Project React [1] focuses on the achievement of island energy independency by joining renewable energy sources (RES) and storages, a demand response platform and promote user engagement in a local energy community for the three pilot and five follower islands. This paper presents a long-term techno-economic assessment of covering 100% of total electricity and heat demand from RES by 2030 for the Irish Aran Islands. The main goal is to find suitable renewable energy mix for the year 2030 by considering local circumstances.

Keywords: Decarbonisation, geographical islands, techno-economic system modelling

1 Methodology

The Aran Islands are a group of three limestone islands with around 1,226 inhabitants, located in Galway Bay. Currently generation from RES is very limited accounting only few PV and heat pumps (HP) installations. The target of 100% energy autonomy for the islands means an ambitious uptake of RES. We assumed for the energy autonomy, electricity generation from local renewables shall cover 100% of total electricity and heat consumption and partially the transport energy demand in an annual balance.

1.1 Estimation of electricity and heat demand in 2030

The future demand projections for electricity, heat and fossil fuel for road transport are estimated up to 2030.

In 2017, the electricity demand is accounted about 2993 MWh. The electricity future demand is estimated based on population forecast and variation of demand per capita. The Aran Islands are faced with threats of depopulation, ageing population and over usage of energy mainly due to their position in the sea and their heavy dependence on tourism business [2]. However, public authorities planning on the increase of population through different measures such as job creation or changes of working mode more oriented to the teleworking. Therefore, for the future projection, a total increase of 1% is estimated for Aran´s population from 2017 to 2030. This implies an increase from 1226 inhabitants in 2017 to 1238 inhabitants in 2030. In parallel, the variation of the electricity per capita is based on the projection of Irish population [3] and the future electricity consumption of Ireland [4]. The projections foresee a decrease of the electricity per capita during the first years due to efficiency improvement of the appliances. However, for further years, this trend is compensated by the increase of the number of electronic devices used.

Currently there are 3 electric vehicles (EV) in Aran Islands, which represents less than 1% of the total vehicles. EV projection follows the recommendation from the Energy Master Plan 2018 [5], that aims at least 7% EV share in 2030. This will account 34 EV of the total, estimated in 481.

In Aran islands, there is no natural gas network. Heat demand is in residential and public buildings covered primarily through the burning of heating oil or kerosene. Open fire places are a common feature [2]. The high increase of electricity consumption in the projection is because of the use of heat pumps to cover 100% of the heat demand by 2030. The Coefficient of Performance (COP) of the heat pumps in this use case is estimated as 3 to have a balance between the COPs of the air and the ground heat-pumps estimated based on range 2.5 and 4.5 [6]. A COP 3 implies that for 1 unit of electricity consumed the heat-pump provide 3 units of heat.

The total annual electricity demand is assumed to be at 4712 MWh by 2030, including 1585 MWh demanded by the heat pumps and 104 MWh by EV (7% of total vehicle stock). Table 1 summarizes the specific values of the current (2017) and future demand projections (2030) for electricity, heating and fossil fuel driven road transport for the Aran Islands.

Table 1 Current (2017) and future estimation (2030) for electricity, heating and fossil fuel for road transport demand of Aran Island (in MWh)

	Electricity demand				**Heat demand**			**Transport**
	Elect.	**HP**	**EV**	**Total**	**Fossil**	**HP**	**Total**	**Fossil**
2017	2915	68	9	2933	5811	205	6016	2931
2030	2934	1585	104	4623	0	5548	5548	2771

There is an increase of around 64% of the electricity consumption between both years mainly because of 100% heat pump usage for the heating demand. This implies additionally: the total reduction of fossil imports for heating, the increase of the electricity peak demand and increase of the overall efficiency of the system. In the transport sector, there is a reduction of around 5% in the fossil fuel imports because of the increase of the e-mobility despite overall increase of the vehicle stocks.

1.2 Assessment of future generation mix in 2030

For the assessment the open source energy system modelling tool Balmorel [7] has been used. Balmorel is optimizing the generation investments in different scenarios that minimizes the total investment and operational costs of the energy systems. It considers the balance of supply and demand of electricity and heat reserve power demand, possible investment in new generation and transmission capacity, power plant and transmission line capacity restrictions and efficiencies. For this work, the model has been calibrated to and adapted for the electricity and heat system for Aran Islands. Furthermore, following assumptions have been made based on local conditions.

- For the generation wind on-shore, solar PV, air and ground source heat pumps (ASHP and GSHP) and solar thermal are taken into consideration
- Because of the expected significant uptake of volatile renewables, flexibility requirements may grow at island level, although the islands are connected to mainland

through a 3 MW transmission line. Two flexibility options are included into the model: Li-ion batteries for electricity and small heat water tanks for heat.

- Electricity exchange has been included between Aran islands and the mainland by considering 3 MW connection (assumed also as maximal transmission limit) and 7% transmission losses [8] Exchange occurs price dependently based on the electricity day-ahead prices for Ireland in 2030. It is assumed that the electricity prices in Ireland will be about 10 % higher in 2030 [9] in comparison to 2016 level [10].
- PV and batteries installation: It is assumed that Aran island will have at least 300 kWh batteries (30 houses each with a 10 kWh capacity) and 120 kW_p building integrated PV (60 houses each with an 2 kW_p capacity) in 2030, based on the activities ongoing for the use of these technologies.
- Wind turbine installation: The possibility to install on-shore wind turbines was included following existing local plans.

1.2.1 Techno-economic characteristics of technologies

In the simulation following supply technologies for the local energy production are considered: Solar PV and Wind energy for electricity production and thermal solar panels and heat pumps for heat production. Table 2 presents the techno-economic characteristics of these technologies considered in the simulation in terms of lifetime, costs, annual full operational hours and efficiency for 2017 and 2030.

Table 2: Technology characteristics of generation technologies for 2017 and 2030 [11],[12] ,[8]

	Economic Lifetime [a]	**Investment Costs [€/kW]**	**Fixed O&M Costs [€/kW]**	**Variable O&M Costs [€/MWh]**	**Annual full load [h]**	**Efficiency**
Wind 2017	20	1397	13	0.15	2947	
Wind 2030	20	1261	13	0.15	2947	
PV decentral 2017	20	1453	24	0	850	
PV decentral 2030	20	930	17	0	850	
PV central 2017	20	721	22	0	850	
PV central 2030	20	690	15	0	990	
Solar thermal[1] 2017	20	860	14	0	850	
Solar thermal 2030	20	810	14	0	990	
ASHP 2017	20	940[2]	16			3 (COP)
ASHP 2030	20	850	15			3.5 (COP)
GSHP 2017	20	1500	27			3 (COP)
GSHP 2030	20	1400	24			3.7 (COP)

Although the islands are connected to mainland through a 3 MW transmission line, Li-ion batterie for electricity and small heat water tanks for the heat generation are included into the simulation to estimate additional flexibility needs for an energy system dominated by variable renewable sources in Aran. Table 3 shows the techno-economic characteristics of these energy storages in the energy simulation for 2017 and 2030.

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[1] Thermal solar systems include 8 hours thermal storage.

[2] Typical investment cost for 10 kW system based on (DEA, 2016)

Table 3: Technology characteristics of storage technologies for 2017 and 2030 [13]

	Econ. Lifetime [a]	Efficiency per cycle	Inv. costs [€/kW]	Inv. costs [€/kWh]	O&M costs [%/year of Inv. Costs]	Max. number of cycles	Charge/ discharge (for batteries C-Rate 1) [hours]
Li-Ion 2017	15	0.80	90	475	2%	5000	1
Li-Ion 2030	15	0.83	75	229	2%	7000	1
Thermal Storage (small scale hot water tank) (2017 and 2030)	20	0.92		410	4%	-	0.6

1.2.2 Hourly wind and solar profiles

In the model, the wind turbine Enercon E-70 with a capacity of 2,3 MW rated power [14] and a hub-height of 64 m is taken as reference to characterize the electricity production from wind energy. This wind turbine indicates about 2947 h full load hours for the stand Aran Island. The wind generation profile bases on the SEAI (Sustainable Energy Authority of Ireland) wind mapping system for the place south-west coast of Galway [15]. This hourly generation profile is normalized to 1 kW Enercon E-70 install capacity to derive the hourly wind profile for Aran islands. Hourly electricity generation profile for PV panels bases on the PVGIS tool [16] taking as reference a crystalline silicon PV panel with a nominal power of 1 kW_p.

2 Results

2.1 Electricity

Table 4 shows the modelling results on annual balance for generation and consumption of electricity for the 100% autonomy scenario. In this scenario Aran islands are net exporter thanks to a 2010 MWh surplus in renewable electricity supply.

Table 4: Electricity generation and consumption in 2030

Generation Technologies	Generation [MWh]	Consumption categories	Consumption [MWh]
Wind	6552	Load	4712
Solar PV	102	From Heat Pump	1585
Battery	69	From Battery	83
Import	1306	Export	3317
Total	8029	Total	8029

Figure 1 illustrates the modelling results on installed electricity generation capacity by 2030. Accordingly, the largest installed is wind energy with about 2.2 MW followed by solar PV and batteries where capacity figures for 2030 are predefined exogenously.

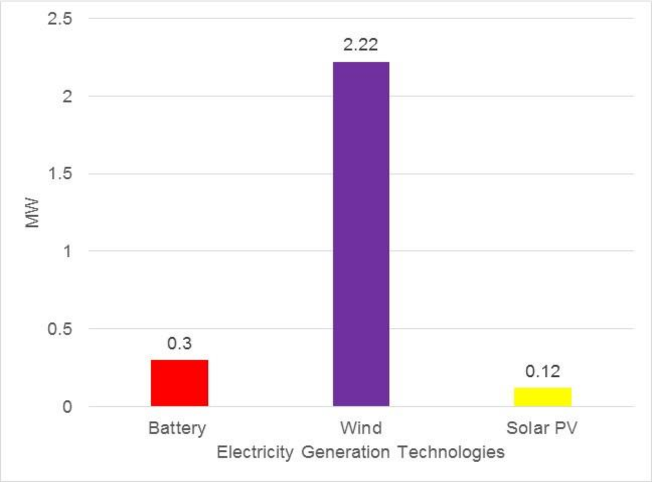

Figure 1: Generation capacity in MW, Battery is in MWh

The figures below illustrate hourly electricity generation profiles and electricity prices for the Aran islands representatively for the months January 2030 (Figure 2) and July 2030 (Figure 3). Indicated electricity prices are representing the estimated prices for the Irish mainland by 2030. They are considered as an input to modelling for this scenario.

In January electricity generation from wind is higher in comparison to July, which fits well to increased demand that comes along with the stronger use of heat pumps to cover heat demand during winter times. Thus, the represented load includes also electricity demanded by heat pumps.

In modelling the operation of batteries appears sensitive to price signals in the overall electricity market but is hardly driven by system needs from a local perspective. They are in operation where electricity prices are high.

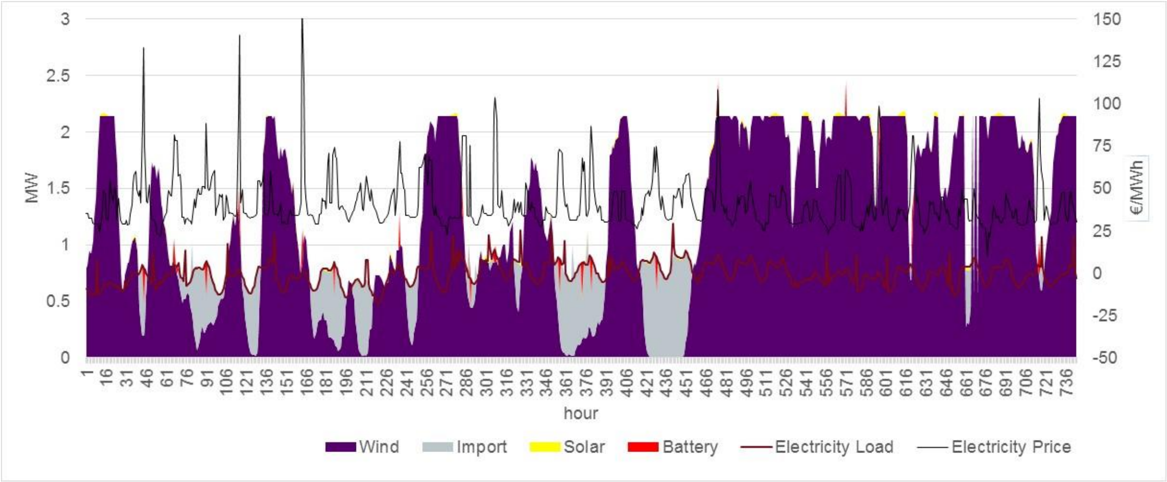

Figure 2: Hourly electricity generation in January 2030

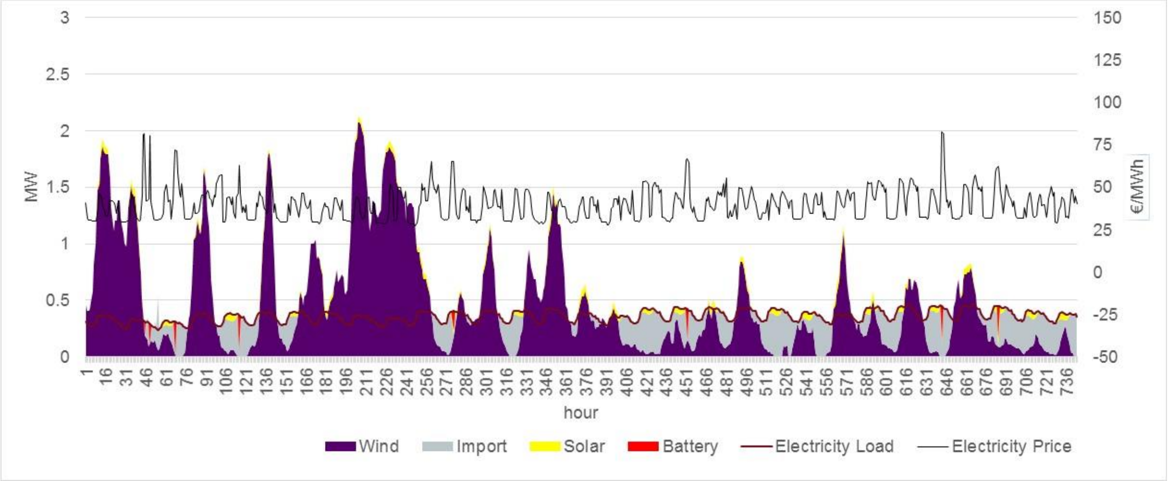

Figure 3: Hourly electricity generation in July 2030

2.2 Heat

Table 5 shows the annual balance for heat generation and consumption by 2030. Accordingly, heat demand is covered almost 100% by heat pumps. The installed heat pump capacity is about 1.77 MW. Although the solar thermal is allowed in the system, it seems that from the system perspective it is not economic and there is no installation of this technology.

Table 5: Heat generation and consumption in 2030

Generation technologies	**Generation [MWh]**	**Capacity [MW], (storage [MWh])**	**Consumption categories**	**Consumption [MWh]**
Heat Pumps (air to water)	5543	1.77	Heat demand	5548
Thermal storage (small water tanks)	5	0.09	From thermal storage	5

The results also show the need for thermal storage capacity (water tanks) is very low with about 0.09 MWh. However, this does not reflect the realistic thermal storages utilisation as our long-term system model is conducted in hourly resolution and it doesn't reflect the future need for technologies correctly that are utilised in minutes level such as thermal storages (i.e. water tank). In most applications heat pumps are operated with a heat storage tank. Storage tanks decouple heat generation from heat consumption as they can store the generated heat at that time it is not demanded. It allows that the heat pump heating can work consistently and reduce switching on and off, which protects the technology and ensures a longer system life [17]. Therefore, the low storage capacity of modelling results should not be interpreted that these technologies will not be needed in the future electricity and heat system of Aran islands.

Figure 4 shows hourly heat generation for January 2030 and July 2030. As heat demand is increasing during winter time heat generation and consumption in January are much higher than in July. Like electric batteries thermal storages are also sensitive to the high heat prices. In general heat prices correlate well to electricity prices as in case of heat pumps electricity is the fuel and defines the variable costs.

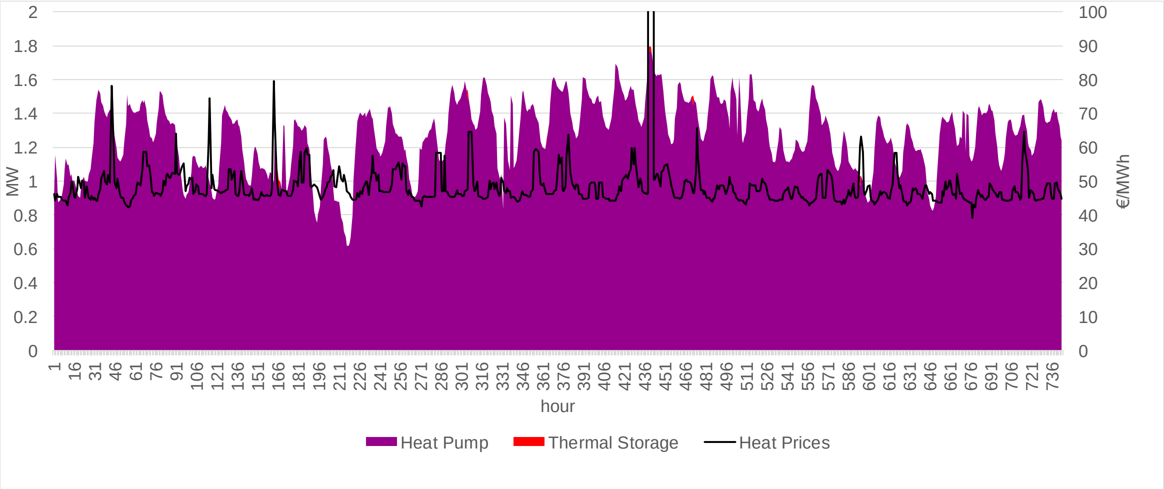

Figure 4 - Hourly heat generation in January

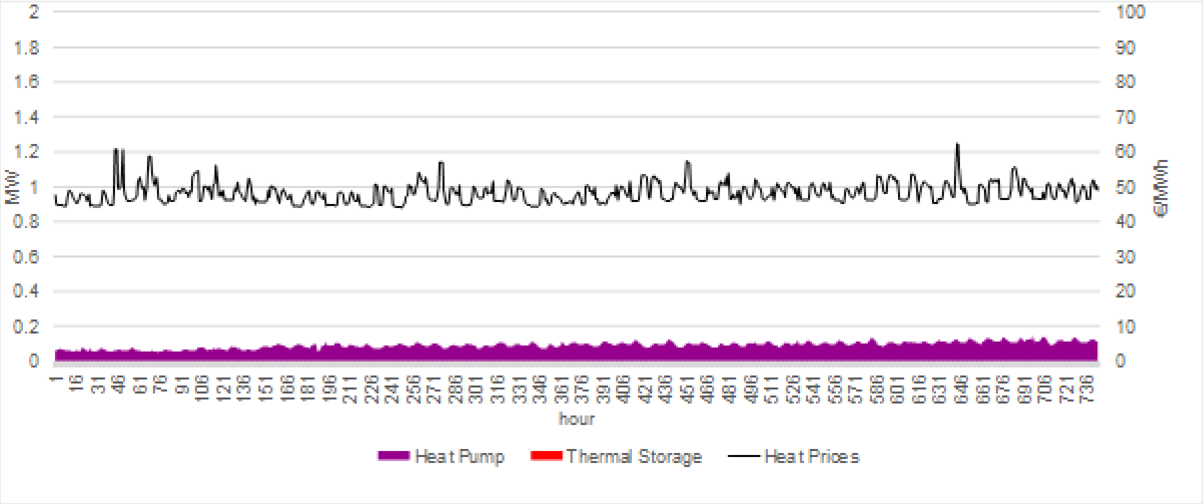

Figure 5 - Hourly heat generation in July

3 Conclusions

The results of the model-based analysis show that a wind turbine of 2.2 MW, with an average yearly electricity generation at 6562 MWh, may cover 100% of the domestic electricity demand. This includes also the demand driven by the presumed heat pump that, in turn, meets 100% of the domestic heat demand. The total annual electricity demand is assumed to be at 4712 MWh by 2030, including 1585 MWh demanded by the heat pump system. The generation surplus from wind power can then be exported and, in the hours, when local generation lies below local demand, import from the mainland seems to be necessary as a backup.

With this result we can claim that a full decarbonisation of the Aran Islands by 2030 can be achieved for the electricity sector, and, additionally, also for the heat sector (by using electric heat pumps). Furthermore, Aran islands will act as a net exporter thanks to a 2010 MWh surplus in electricity supply. If a wind turbine with about 2.2 MW rated capacity is installed, this surplus may also the overall local passenger transport demand. In modelling the assumption is taken that EV achieve 7% (or 104 MWh) of that only (i.e. 34 vehicles compared to in total 481) – thus, if the whole fleet would be electrified corresponding electricity demand would be roughly 1470 MWh. This is still smaller than the surplus in power supply. However, the main condition in this regard is that the EV are charged in the surplus hours so that they do not cause additional import from the mainland.

As mentioned above, connection to mainland acts as key flexibility option. Besides pre-given battery installation there is no additional battery capacity required according to modelling results. Batteries provide from today`s perspective combined with assumptions for the expansion towards 2030 only a limited contribution to overall system balance. In modelling their operation appears sensitive to price signals in the overall electricity market but is hardly driven by system needs from a local perspective. This argument holds also for solar PV which is modelled at 0.12 MWp pre-given capacity in this analysis.

Today small-scale battery systems applied at end user level cannot benefit from price fluctuations at the wholesale market since end users generally face flat tariffs for their consumed or produced electricity. Thus, to be able to operate these systems in an economic manner (as modelled) a change in end user tariff design appears necessary, so that end users have the possibility to react to price signals also in reality.

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