Towards the energy transition to renewables

Cape Clear Island

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The Clean Energy for EU Islands Secretariat

Who we are

The launch of the Clean Energy for EU Islands Initiative in May 2017 underlines the European Union's intent to accelerate the clean energy transition on Europe's more than 1,400 inhabited islands. The initiative aims to reduce the dependency of European islands on energy imports by making better use of their own renewable energy sources and embracing modern and innovative energy systems. As a support to the launch of the initiative, the Clean Energy for EU Islands Secretariat was set up to act as a platform of exchange for island stakeholders and to provide dedicated capacity building and technical advisory services.

The Clean Energy for EU Islands Secretariat supports islands in their clean energy transition in the following ways:

- It provides technical and methodological support to islands to develop clean energy strategies and individual clean energy projects.
- It co-organises workshops and webinars to build capacity in island communities on financing, renewable technologies, community engagement, etc. to empower them in their transition process.
- It creates a network at a European level in which islands can share their stories, learn from each other, and build a European island movement.

The Clean Energy for EU Islands Secretariat provides a link between the clean energy transition stories of EU islands and the wider European community, in particular the European Commission.

Acknowledgments

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- to 3E (http://www.3e.eu/), Partner of the Secretariat, for the supply of the wind and the ambient temperature data.

Preface

Scope of this report

This report has been accomplished within the frame of the first open call announced by the European Commission's Secretariat on "Clean Energy for E.U. Islands" (Secretariat) for the support of insular communities – initiatives in the European Continent on specific projects regarding their energy transition from fossil fuels to renewable energy sources and rational use of energy. This report has been developed following the application submitted by the Comharchumann Chléire Teoranta, together with MaREI Centre for Marine and Renewable Energy and the Sustainable Energy Authority of Ireland (SEAI), and approved by the Secretariat, for the Cape Clear island, Ireland. According to the submitted application, the requested support should be focused on:

- the estimation of the required electricity for the full transition from fossil fuels to renewables for the onshore transportation needs on the island
- the estimation of the required power plants for achievement of full energy transition in the island
- the coverage of these electricity needs with renewable energy sources (R.E.S.) technologies.

For the above different approaches, alternative scenarios will be studied regarding the required R.E.S. technologies.

1. The Cape Clear Island

Location

The Cape Clear Island is the southernmost island of Ireland, as shown in Figure 1. It has a total area of 6.7 km^2. Its permanent population in 2011 was 124 inhabitants [1]. Yet, according to the submitted application, recalculating the impact of summer residents and visitors, the human pressure on the island is equivalent to 278 all-year inhabitants.

Figure 1: *The Cape Clear island and its location with regard to Ireland.*

Existing situation regarding energy consumption

The existing energy consumption in the Cape Clear Island is classified in the following forms:

- electricity, for the following uses:
  - municipal buildings
  - tertiary sector (essentially tourism and services)
  - residential sector
  - public lighting
  - primary and secondary sector
- LPG, for cooking purposes in
  - residential buildings
  - restaurants
- diesel oil, with the following discrete uses:
  - primary and secondary sector (agriculture, fishing)
  - indoor space heating
  - transportation on the island
  - transportation from and to the island
- gasoline (petrol), exclusively for the transportation sector
- kerosene, exclusively for indoor space heating
- polish and smokeless coal for indoor space heating
- peat briquettes for indoor space heating
- timber (woods) for indoor space heating.

The annual energy consumption in Cape Clear Island is analysed in Table 1.

Table 1*: Annual energy consumption analysis in Cape Clear Island.*

Energy source		Residential buildings	Public buildings	Primary and secondary sector (agriculture, fishing, service supply, industry)	Tertiary sector (including tourism)	Transportation on island	Final or primary energy consumption on island
Electricity	Final (kWh)	200,200	35,000	25,000	44,500		304,700
	Primary (kWh)	580,580	101,500	72,500	129,050		883,630
LPG	Final (kg)	3,600			1,200		4,800
	Primary (kWh)	47,779			15,926		63,706
Diesel oil	Final (L)					60,546	60,546
	Primary (kWh)					682,656	682,656
Gasoline (petrol)	Final (L)					8,000	8,000
	Primary (kWh)					81,788	81,788
Kerosene	Final (L)	40,000					40,000
	Primary (kWh)	407,358					407,358
Coal	Final (kg)	26,400					26,400
	Primary (kWh)	263,102					263,102
Wood (timber)	Final (kg)	15,000					15,000
	Primary (kWh)	61,500					61,500
Peat briquettes	Final (kg)	4,800					4,800
	Primary (kWh)	22,656					22,656
	Total Primary (kWh)	**1,382,976**	**101,500**	**72,500**	**144,976**	**764,444**	**2,466,396**

As seen in Table 1, the current annual electricity consumption in the island is **304,700 kWh**.

In a future approach, the energy needs for the indoor space heating and the transportation sector are going to be transferred to the electrical grid too, substituting the current fossil fuels and biomass consumption with electricity. Additionally, in an effort to eliminate the fossil fuels consumption onshore, the current LPG consumption in residential buildings and in restaurants for cooking can be also substituted with electricity. In order to proceed to an estimation of these future additional electricity consumptions, the following assumptions – parameters are introduced [2]:

- lower calorific value of diesel oil H_{ud}: 10.25 kWh/L
- lower calorific value of gasoline H_{ug}: 8.90 kWh/L
- lower calorific value of LPG H_{uLPG}: 12.64 kWh/kg
- lower calorific value of coal H_{ucoal}: 9.05 kWh/kg
- lower calorific value of kerosene H_{uker}: 9.70 kWh/L
- lower calorific value of peat briquettes H_{upb}: 4.72 kWh/kg
- lower calorific value of timber H_{ut}: 4.10 kWh/kg
- average total efficiency of central burners for heating, including distribution network η_{heat}: 0.80
- average total efficiency of LPG cooking devices η_{LPG}: 0.90
- average total efficiency of electrical cooking devices η_{el}: 0.95
- seasonal Coefficient of Performance (COP_s) for heat pumps operation in heating mode for the climate conditions in Cape Clear Island: 3.5
- average diesel oil or gasoline specific consumption for transportation v: 7 L/100 km
- average electricity specific consumption for transportation e: 20 kWh/100 km

Having the coal, kerosene, peat, timber and LPG annual consumptions, we work as presented below for the calculation of the corresponding final thermal energy for indoor space heating and cooking and the estimating additional electricity consumption in the island due to the energy transition from the above energy sources to electricity:

Indoor space heating:

Indoor space heating in the current state in Cape Clear Island is covered by kerosene, coal, peat briquettes and timber. The corresponding total final thermal energy production from all these energy sources is calculated as shown below:

$$E_{heat}=\left(V_{ker}\cdot H_{uker}+m_{coal}\cdot H_{ucoal}+m_{pb}\cdot H_{upb}+m_t\cdot H_{ut}\right)\cdot\eta_{heat}\Rightarrow$$

$$E_{heat}=\left(40{,}000\text{L}\cdot 9.70\frac{\text{kWh}}{\text{L}}+26{,}400\text{kg}\cdot 9.05\frac{\text{kWh}}{\text{kg}}+4{,}800\text{kg}\cdot 4.72\frac{\text{kWh}}{\text{kg}}+15{,}000\text{kg}\cdot 4.10\frac{\text{kWh}}{\text{kg}}\right)\cdot 0.80 \qquad (1)$$

$$\Leftrightarrow E_{heat}=569{,}040\text{ kWh}$$

where:

V_{ker} :	40,000 L, the kerosene annual consumption in the island for indoor space heating
m_{coal} :	26,400 kg, the coal total annual consumption (polish and smokeless) in the island for indoor space heating
m_{pb} :	4,800 kg, the peat briquettes annual consumption in the island for indoor space heating
m_t :	15.000 kg, the timber annual consumption in the island for indoor space heating.

Assuming that the current heating needs, as calculated above, will be totally transferred to the electricity grid, the expected additional annual electricity consumption $E_{el\text{-}heat}$ will be given by the following relationship:

$$E_{el\text{-}heat}=\frac{E_{heat}}{COP_s}\Rightarrow E_{el\text{-}heat}=\frac{569{,}040\ \text{kWh}}{3.5}\Leftrightarrow E_{el\text{-}heat}=162{,}583\ \text{kWh} \tag{2}$$

where E_{heat} is the total annual thermal energy coverage by kerosene, coal, peat briquettes and timber, calculated previously at 569,040 kWh. The seasonal COP_s for air-to-air heat pumps operation in heating mode under the climate conditions met in Cape Clear Island has been assumed at 3.5.

It is, so, calculated, that the additional electricity consumption due to the heating needs coverage by heat pumps, currently covered by coal, kerosene, peat and timber, will be equal to **162,583 kWh**.

Cooking:

The corresponding electricity consumption E_c substituting the current LPG consumption m_{LPG} for the cooking needs in the island is calculated with the following relationship:

$$E_c=\frac{m_{LPG}\cdot H_{uLPG}\cdot \eta_{LPG}}{\eta_{el}}\Rightarrow E_c=\frac{4{,}800\ \text{kg}\cdot 12{,}64\frac{\text{kWh}}{\text{kg}}\cdot 0.90}{0.95}\Leftrightarrow E_c=57{,}479\ \text{kWh} \tag{3}$$

Hence, the additional electricity consumption from the transition of the cooking needs, currently covered with LPG, to electricity is calculated at **57,479 kWh**.

Transportation:

Finally, the corresponding total additional electricity consumption E_{tr} from the substitution of the current diesel oil and gasoline consumption V_d and V_g respectively in the transportation sector, can be calculated with the following relationship:

$$E_{tr}=\frac{V_d+V_g}{v}\cdot e\Rightarrow E_{tr}=\frac{(60{,}546+8{,}000)\text{L}}{7\ \text{L}/100\ \text{km}}\cdot 20\ \text{kWh}/100\ \text{km}\Leftrightarrow E_{tr}=195{,}846\ \text{kWh} \tag{4}$$

Hence, the electricity consumption from electrical vehicles, due to the total energy transition in transportation sector from diesel oil and gasoline to electricity is calculated at **195,846 kWh**.

The data and the results of the above executed calculations are summarized in Table 2.

***Table 2**: Estimation of the additional electricity consumption, substituting the fossil fuels and biomass consumption for heating, transportation and cooking needs.*

Energy usage	Currently consumed energy source	Current consumption	Final thermal energy (kWh)	Corresponding electricity consumption (kWh)
Heating	Coal	26,400 kg	310,368	88,677
	Kerosene	40,000 L	191,347	54,671
	Peat briquettes	4,800 kg	18,125	5,179
	Timber	15,000 kg	49,200	14,057
	Total		569,040	162,583
Cooking	LPG	4,800 kg	54,605	57,479
Energy usage	Currently consumed energy source	Current consumption	Covered distance (km)	Corresponding electricity consumption (kWh)
Transportation	Diesel oil	60,546 L	864,943	172,989
	Gasoline	8,000 L	114,286	22,857
	Total		979,229	195,846
Total electricity consumption				**415,907**

From the above analysis it is concluded that the transition of the heating, the transportation and the cooking needs coverage from fossil fuels and biomass to electricity is calculated at 415,907 kWh. This corresponds to 136% increase of the current electricity annual consumption (304.700 kWh). The total new annual electricity consumption is formulated at **720,607 kWh**.

2. The available wind potential

The available wind potential

The available wind potential in the under consideration area was estimated on the basis of wind potential data retrieved by the ERA-5 database of the European Centre for Medium-Range Weather Forecasts (ECMWF) for the period 2000 – 2018 [3]. The employed wind potential measurements were downloaded from four measurement points with the following geographical coordinates:

- measurement point 1: 51° 17' 16.9''N, 9° 35' 0'' W
- measurement point 2: 51° 34' 8.6''N, 9° 35' 0'' W
- measurement point 3: 51° 34' 8.6''N, 9° 10' 0'' W
- measurement point 4: 51° 17' 16.9''N, 9° 10' 0'' W

The locations of these points with regard to the Cape Clear Island are depicted in Figure 2. As shown in this figure, the measurement points are around the Cape Clear Island.

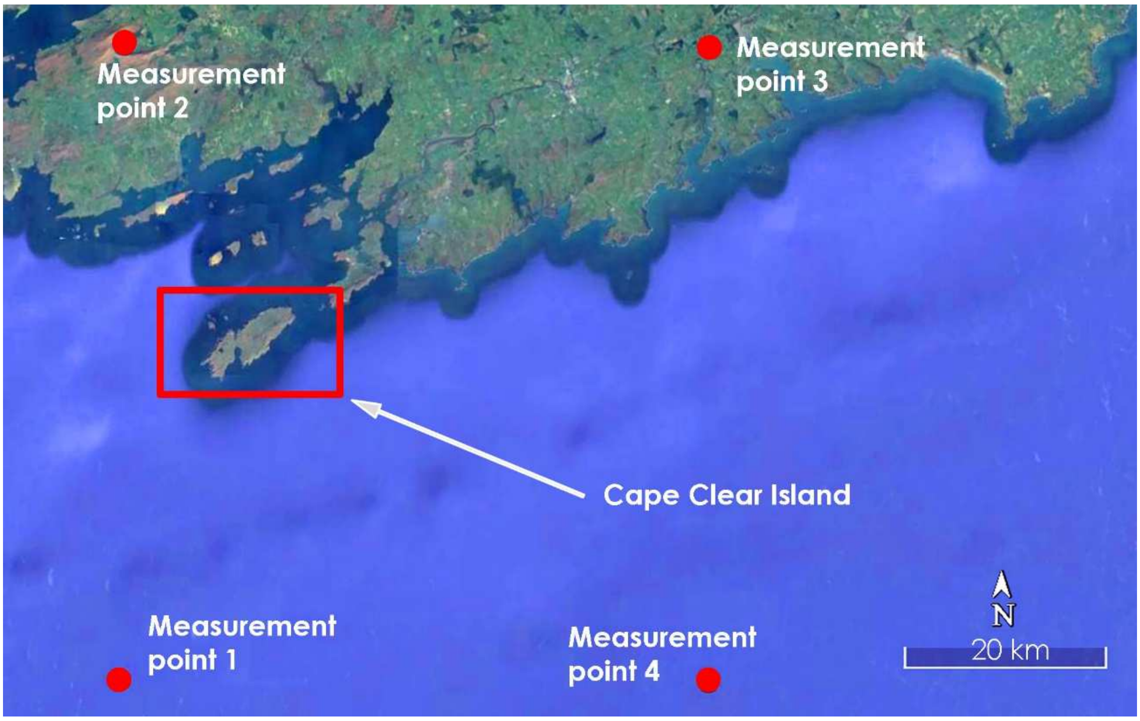


***Figure 2**: Location of the ERA-5 wind potential measurement points with regard to the Cape Clear Island.*

According to the available long-term wind measurements (19-year period), the fluctuation versus time of the annual average wind velocity at the height of 100 m above ground level are presented in Figure 3 for each one of the four measurement points.

As seen in Figure 3, the annual average wind velocity ranges between roughly 6.82 m/s, in 2010 for the measurement point 2, and 10.27 m/s, in 2015 for the measurement point 1, at 100 m height above sea or ground level (depending on the location of the measurement point). Hence, at a first glance, it can be concluded that the specific geographical area has very high wind potential. Another observation that comes from Figure 3 is that the annual average wind velocity fluctuations over the years follow the same pattern for all the four measurement points. This practically means that there are windier years, such as 2008 and 2015, and calmer years, with regard to the wind potential intensity, such as 2001 and 2010.

Finally, the obvious "topological" remark is that the measurement points 1 and 4, located offshore, exhibit higher wind potential than the onshore points 2 and 3 for the whole measurement period.

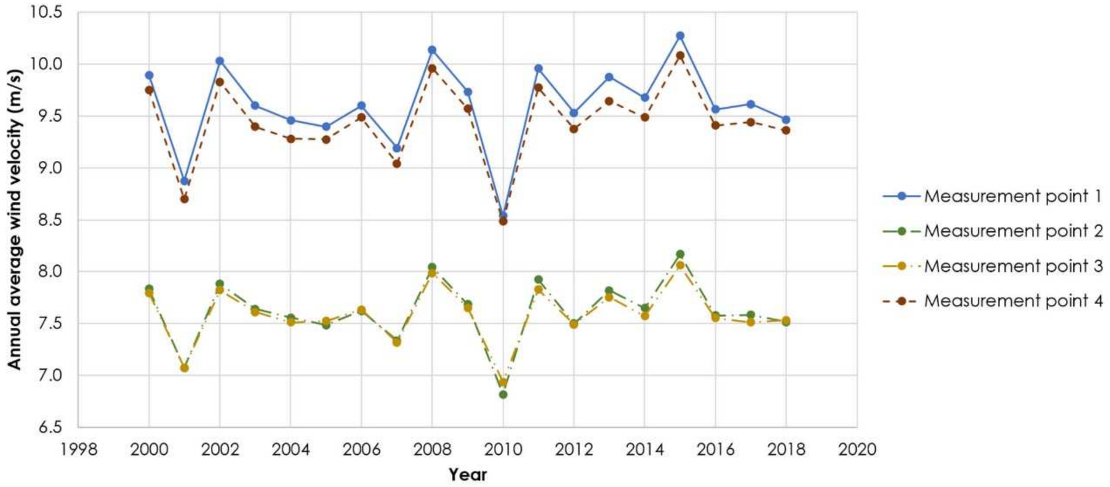


***Figure 3**: Fluctuation versus time of the annual average wind velocity at the wind potential measurement points and at 100 m height above sea or ground level.*

A closer look at the available wind potential is provided in Figure 4, where the annual fluctuation of the monthly average wind velocity is presented for three characteristic years of the available measurement period (2000 – 2018), specifically based on the available wind potential measurements from point 1. Point 1, located offshore, was chosen as the most characteristic point for the prevailing wind conditions at Cape Clear island, given that the island is totally exposed in the open sea weather conditions, while the available absolute altitudes on the island are respectively low (lower than 150 m at the southern ridge), hence the influence of the land morphology on the open sea wind potential should be rather of minor importance. Additionally, point 1 is closer to the island than point 2. The years 2006, 2010 and 2015 were selected, namely the years with annual average wind velocity close to the moderate value for the overall measurement period (2006) and equal to the minimum (2010) and the maximum (2015) annual average wind velocity for the whole measurement period. The annual average wind velocity for these particular years, based on the received measurements from point 1,are 9.6 m/s, 8.5 m/s and 10.3 m/s respectively.

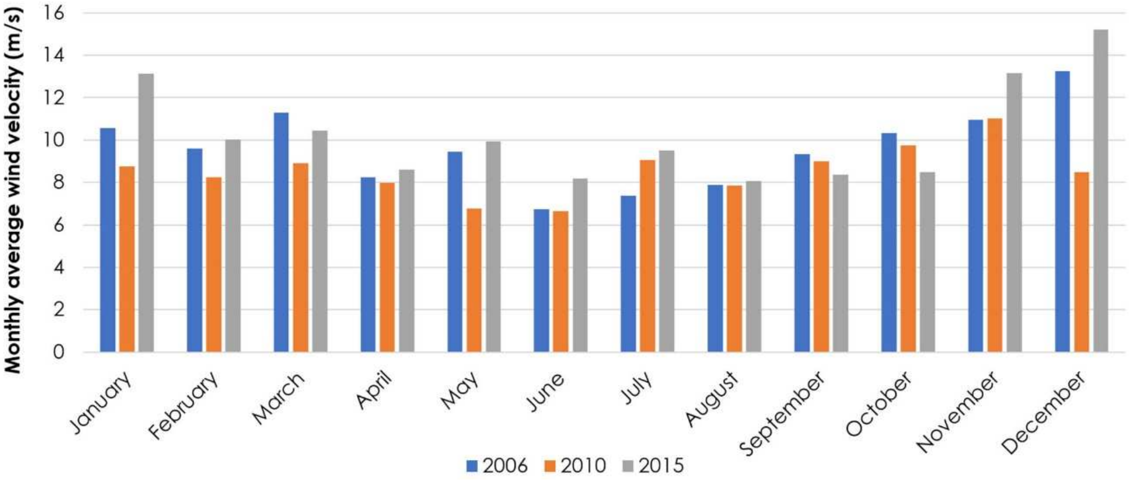


***Figure 4**: Annual fluctuation of the monthly average wind velocity for the years 2006, 2010 and 2015, based on the wind potential data captured from the measurement point 1.*

By observing Figure 4, we may conclude to the following remarks:

- The wind potential in the under interest area is maximized in winter and minimized in summer, while in spring and autumn it remains in moderate levels.
- All the examined years appear approximately the same annual fluctuation pattern for the monthly average wind velocity.
- The season which mainly affects and determines the level of the annual average wind velocity, and consequently the intensity of the available wind potential, is winter.

Another closer insight at the available wind potential is provided in Figure 5, where the fluctuation of the wind velocity hourly average values for the two most recent integrated consecutive years, namely for 2017 and 2018, is plotted. As seen in this figure, the highest values are found mainly from December to March, namely during the winter period. During summer, due to the milder climate conditions, the wind velocity remains rather in low levels. Finally, certain similarities are seen between the two years depicted in Figure 5, revealing the periodical attribute of wind potential in the under consideration area.

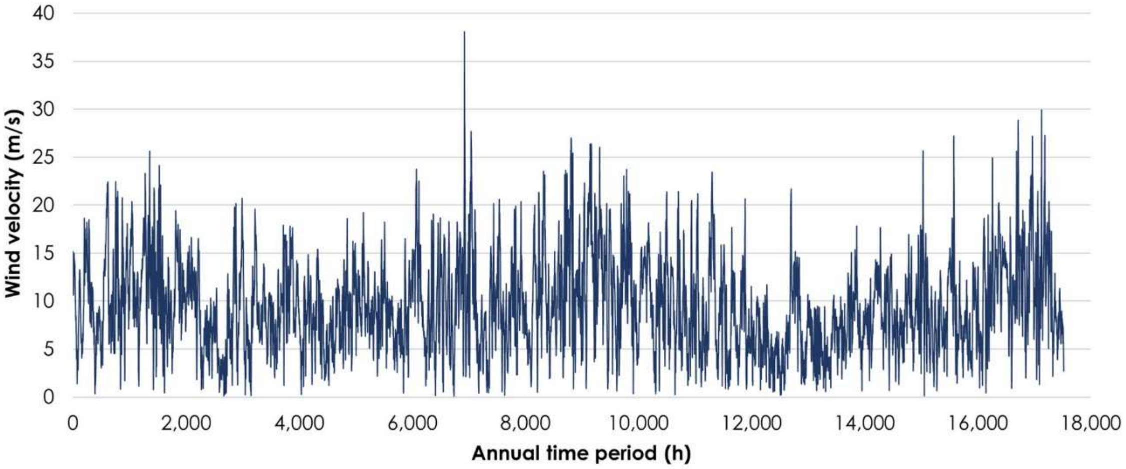
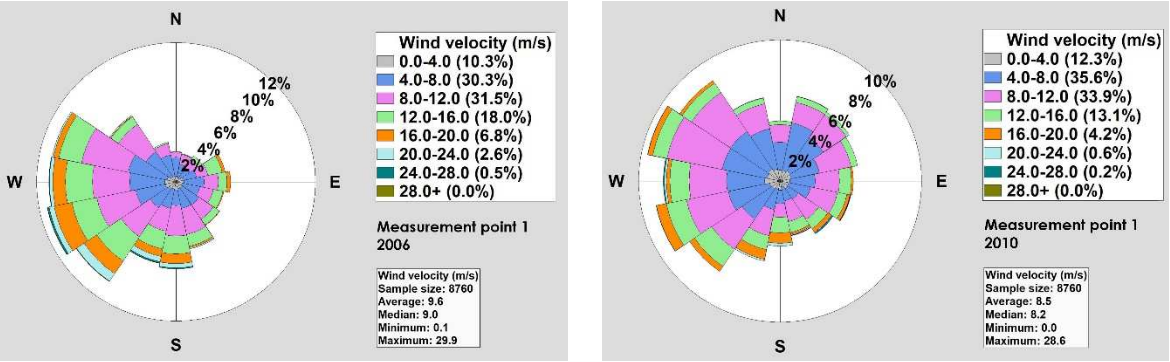


***Figure 5**: Fluctuation of hourly average wind velocity values versus time for the years 2017 and 2018 [3] for the Cape Clear island, according to the wind potential data from the measurement point 1.*

In Figure 6, the annual wind roses are depicted for the years 2006, 2010, 2015 and 2018, based on the wind potential data from the measurement point 1. With the exception of 2010, the similarities of the wind roses for the different years are obvious. The prevailing wind directions are between South-Southwest to West and West-Northwest.



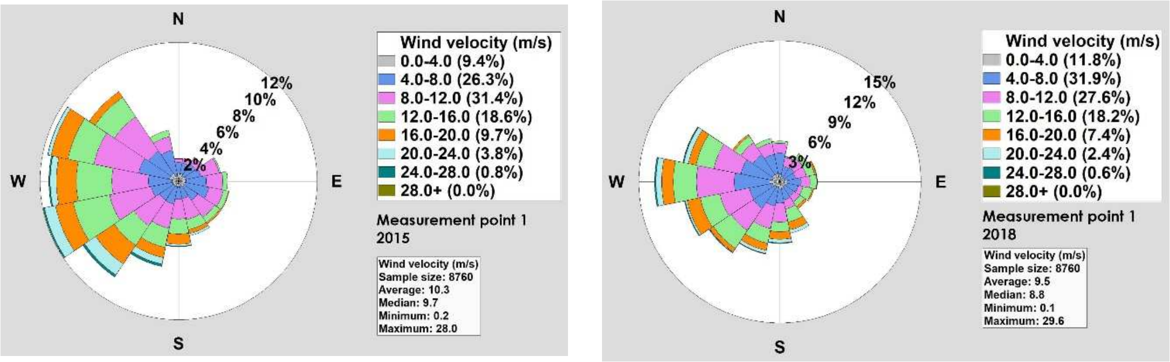


***Figure 6**: Annual wind roses graphs for the years 2006, 2010, 2015 and 2018 [3], based on the wind potential data from the measurement point 1.*

For integrity reasons, corresponding wind roses graphs for the same years are presented in Figure 7, this time based on the wind potential data captured at the measurement point 2. By observing the wind roses in Figure 7, we come to the same remarks as with Figure 6, regarding the prevailing wind directions. In Figure 7 wind roses, we also see the lower wind velocity values, compared to the data from the offshore measurement point 1.

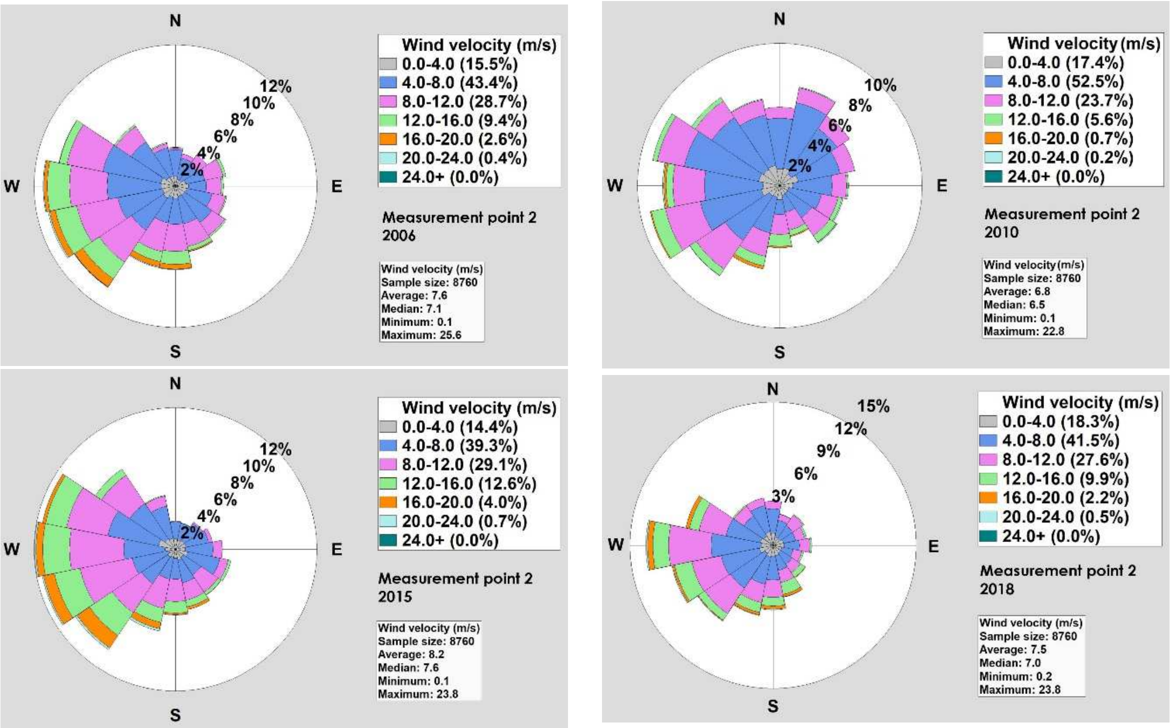


***Figure 7**: Annual wind roses graphs for the years 2006, 2010, 2015 and 2018 [3], based on the wind potential data from the measurement point 2.*

Finally, in Figure 8, the seasonal wind roses are presented, for the year 2018 and for the wind potential data captured from the measurement point 1. From these seasonal wind roses we conclude that the windiest season is winter, with spring and autumn coming next. In summer, the wind velocity reduces. Also, in summer and winter the prevailing wind blowing directions are clearly from the west, while in spring and autumn, there are considerable time periods with wind blowing directions from the south and southwest.

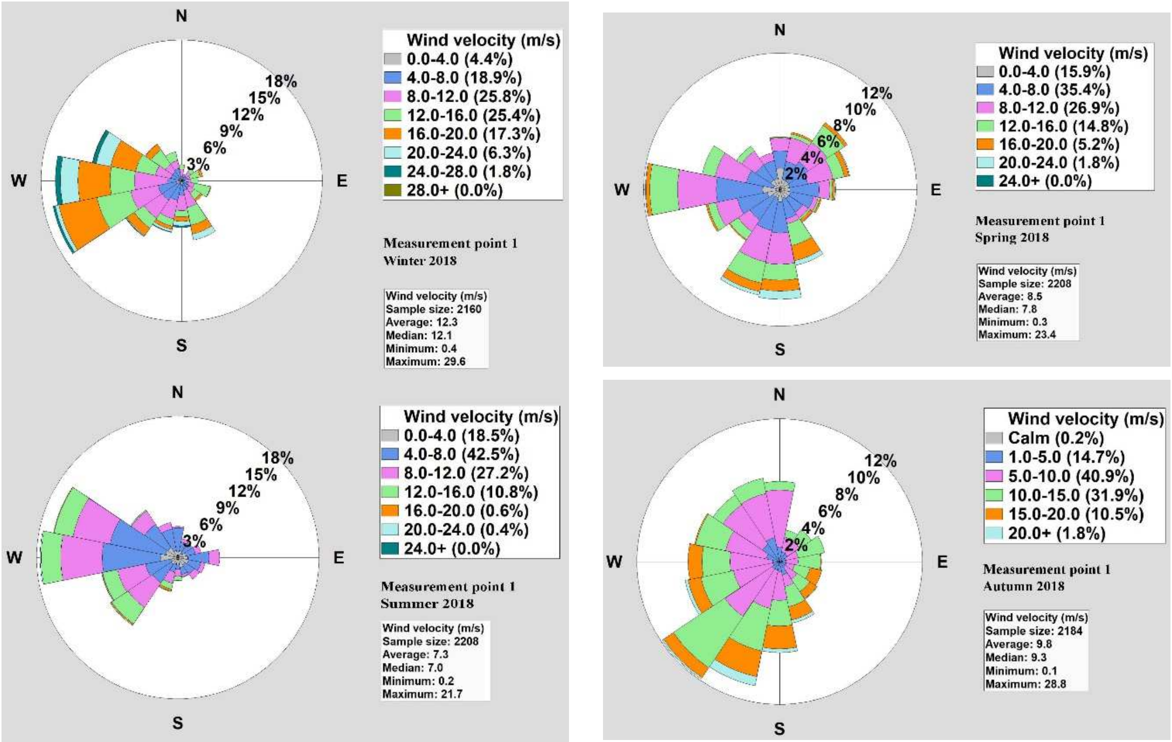


Figure 8: *Seasonal wind roses graphs for the year 2018 [3], based on the wind potential data from the measurement point 1.*

Dimensioning and siting of an onshore wind park

For the purpose of this work, two indicative dimensioning and siting scenarios for an onshore wind park are presented in this section. The wind park is sited at the highest mountain ridge on the island, found at the southern coast. Given the size of the island and the available wind potential, two different wind turbine models of 50 kW and 100 kW nominal power will be alternatively introduced. The rotor diameter for these wind turbines is 17 m and 25 m respectively, while the hub height for both of them is 25 m. The goal of the investigated wind park scenarios is the siting and the dimensioning of the wind park, so as the current and the future expecting annual electricity consumption in the island will be covered. The partial coverage solely of the required electricity consumption for the full transition in the transportation sector from the fossil fuels to the electrical vehicles will be also investigated.

The available wind potential data and the digitized map of the island were introduced in WAsP software application for the development of the wind potential map at the height of 25 m above ground level, namely the hub height of the introduced wind turbine models. In the investigated scenarios, four wind turbines of 50 kW nominal power each or, alternatively, two wind turbines of 100 kW nominal power each were sited, as shown in Figures 9a and 9b respectively, on an annual average wind velocity background. The annual average available wind power density for these alternative siting scenarios is presented in Figures 10a and 10b.

The wind roses at the wind turbines installation positions are shown in Figures 11a and 11b for the two alternative siting scenarios.

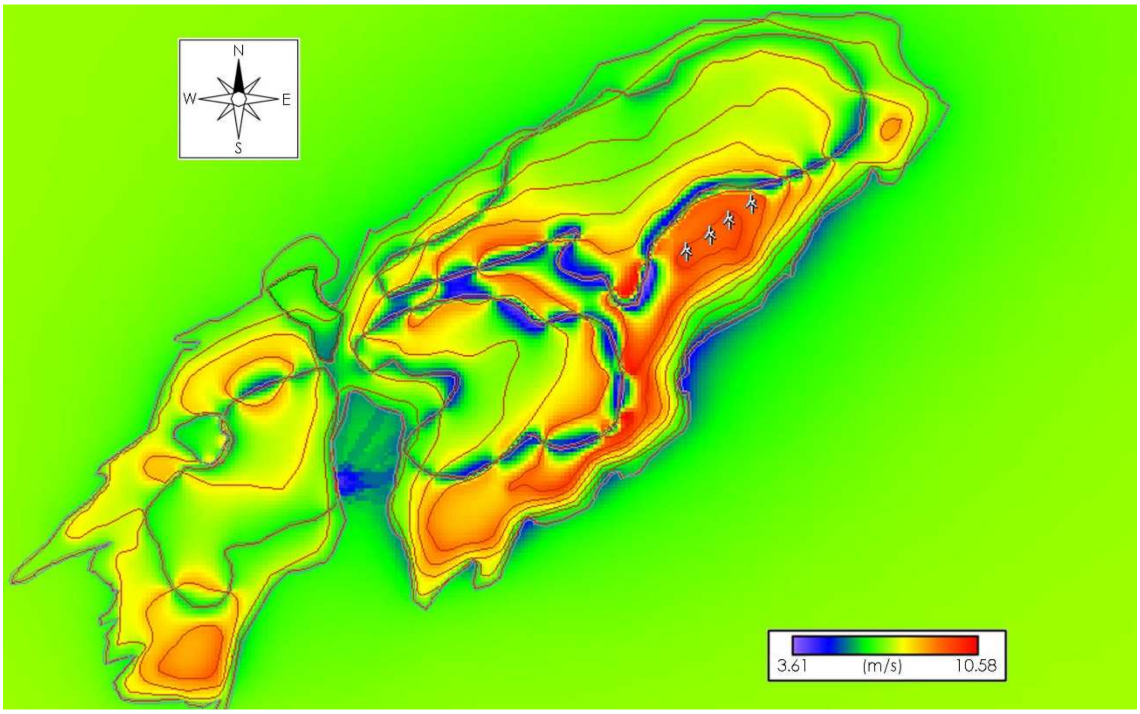


Figure 9a: *Annual average wind velocity map and siting of 4 wind turbines of 50 kW nominal power each at the southern mountain ridge of the Cape Clear Island at hub height (25 m above ground level).*

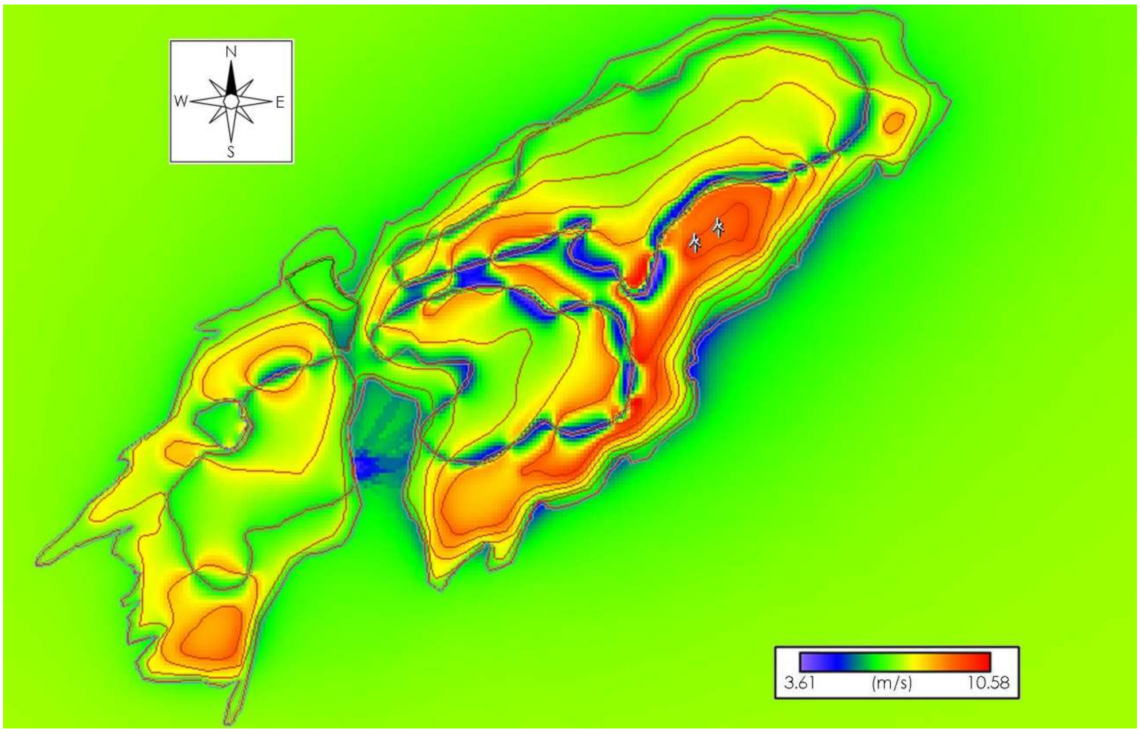


Figure 9b: *Annual average wind velocity map and siting of 2 wind turbines of 100 kW nominal power each at the southern mountain ridge of the Cape Clear Island at hub height (25 m above ground level).*

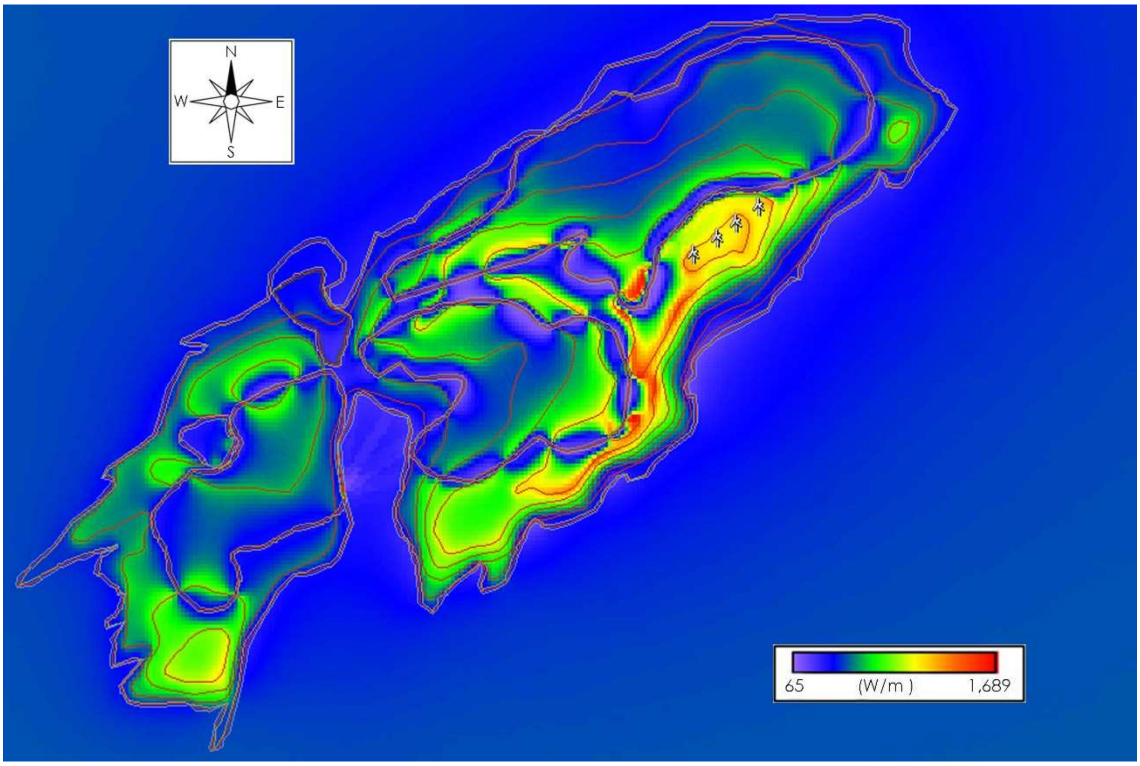


Figure 10a: *Annual average wind power density map and siting of 4 wind turbines of 50 kW nominal power each at the southern mountain ridge of the Cape Clear Island, at hub height (25 m above ground level).*

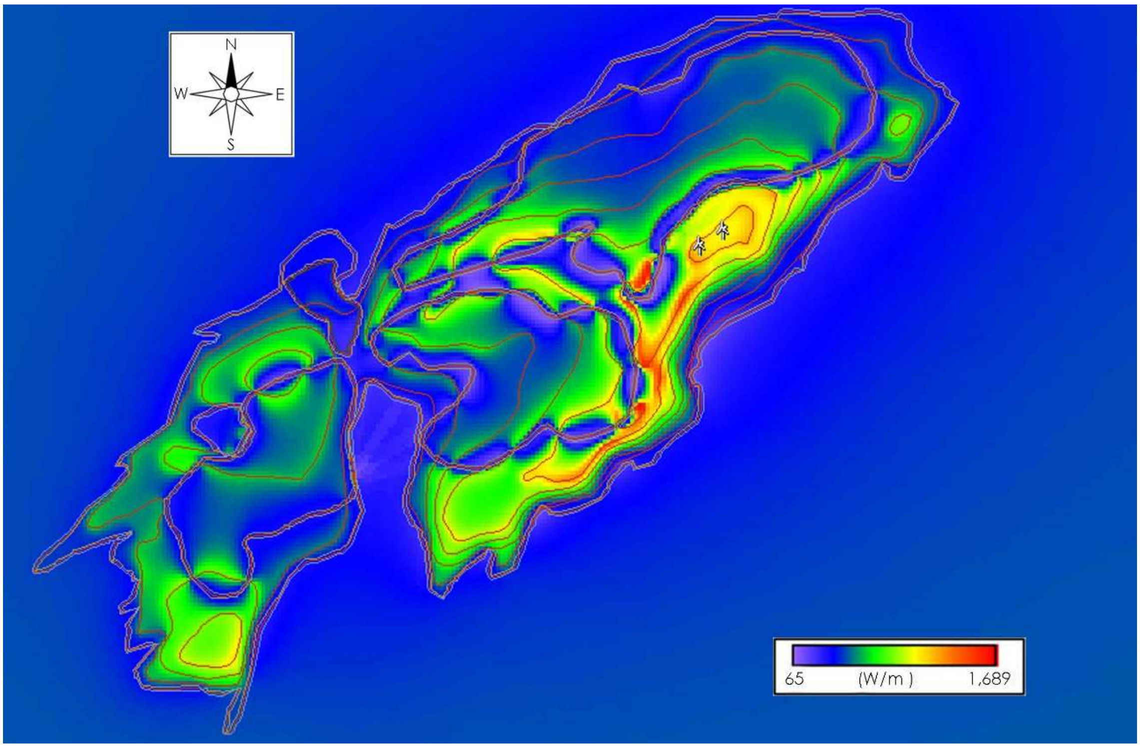


Figure 10b: *Annual average wind power density map and siting of 2 wind turbines of 100 kW nominal power each at the southern mountain ridge of the Cape Clear Island at hub height (25 m above ground level)*

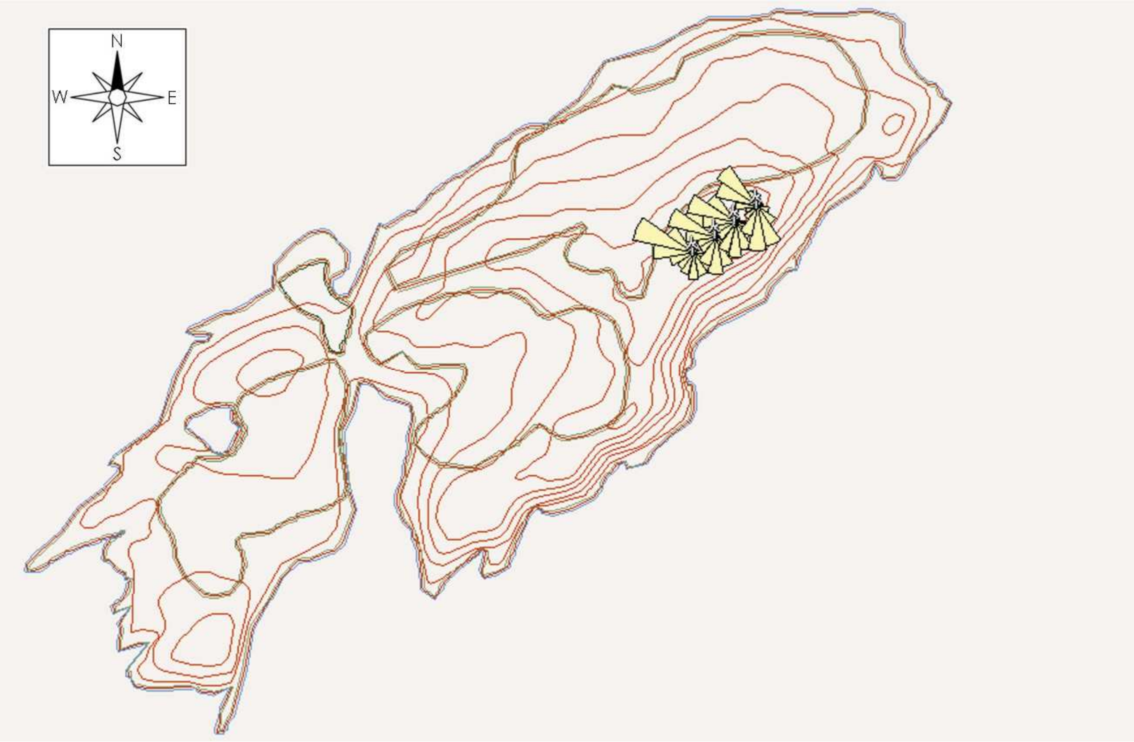


Figure 11a*: Wind-roses at the installation positions of 4 wind turbines of 50 kW nominal power each at the southern mountain ridge of the Cape Clear Island.*

Figure 11b*: Wind-roses at the installation positions of 2 wind turbines of 100 kW nominal power each at the southern mountain ridge of the Cape Clear Island.*

The electricity production from the alternatively examined wind parks is calculated with the introduction of the employed wind turbines power curves, presented in Figures 12a and 12b. In Figure 12c, the power curve of a third wind turbine with nominal power 1 kW is also presented. This one will be used for another dimensioning scenario, focused on the coverage of the electricity production of a small number for two electrical vehicles, as a first and more direct step towards energy transition in Cape Clear.

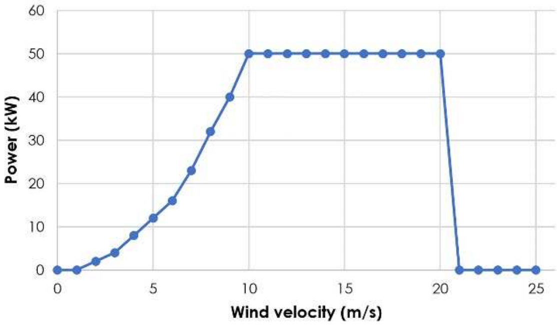


***Figure 12a**: Wind turbine power curve with nominal power 50 kW.*

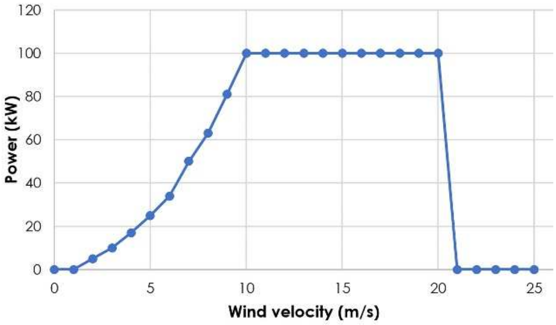


***Figure 12b**: Wind turbine power curve with nominal power 100 kW.*

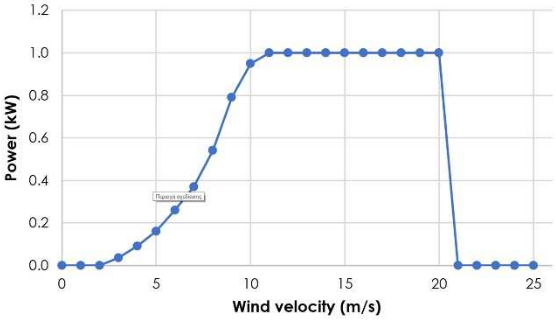


***Figure 12c**: Wind turbine power curve with nominal power 1 kW.*

The results regarding the siting positions and the annual electricity production from the two dimensioning scenarios are presented in Table 3. The results have been calculated for the wind turbines' hub height, namely at 25 m above ground for the 50 kW and 100 kW wind turbines and for 5 m height above ground level for the 1 kW small wind turbine.

***Table 3**: Annual electricity production analysis for the proposed onshore wind park.*

Wind turbine	Coordinates (WGS84)	Altitude height Above Sea Level (ASL)	Hub height Aove ground level (AGL)	Annual average wind velocity (m/s)	Annual average power density (W/m^2)	Net annual production (MWh)	Wake loss (%)	Capacity factor (%)
1st investigated scenario: 4 wind turbines x 50 kW								
Wind turbine 1	51° 26' 30.66'' N 9° 28' 45.78'' W	140	25	10.18	1,142	243,627	0.21	55.6
Wind turbine 2	51° 26' 33.28'' N 9° 28' 39.83'' W	140	25	9.87	1,044	234,084	0.72	53.4
Wind turbine 3	51° 26' 35.71'' N 9° 28' 34.80'' W	140	25	10.00	1,083	236,851	0.80	54.1
Wind turbine 4	51° 26' 38.37'' N 9° 28' 29.24'' W	124	25	9.77	1,043	231,149	0.69	52.8
					Totals / average:	**945,711**	**0.60**	**54.0**
2nd investigated scenario: 2 wind turbines x 100 kW								
Wind turbine 1	51° 26' 30.66'' N 9° 28' 45.78''	140	25	10.18	1,142	494,360	0.29	56.4
Wind turbine 2	51° 26' 33.28'' N 9° 28' 39.83'' W	140	25	9.87	1,044	475,222	0.86	54.2
					Totals / average:	**969,582**	**0.57**	**55.3**

As seen in Table 3, the annual average total wake loss is kept below 1.0% with regard to the gross electricity production. Additionally, the high wind potential is clearly revealed by the calculated annual capacity factors.

Also, the annual electricity production from the 1 kW wind turbine with a wind velocity time series at 5 m height above ground and annual wind velocity at 6.17 m/s, is calculated at 3,086 kWh, giving a final, annual capacity factor 35.2%. This small wind turbine will not be installed at the same area indicated in Figures 9 – 11, but, most probably, somewhere else in the island, certainly in lower absolute altitude, so as to be closer to the grid.

In Figures 13 the annual wind velocity wind roses and Weibull distributions are shown for the installation positions of the wind turbines and for the height of 25 m above ground level.

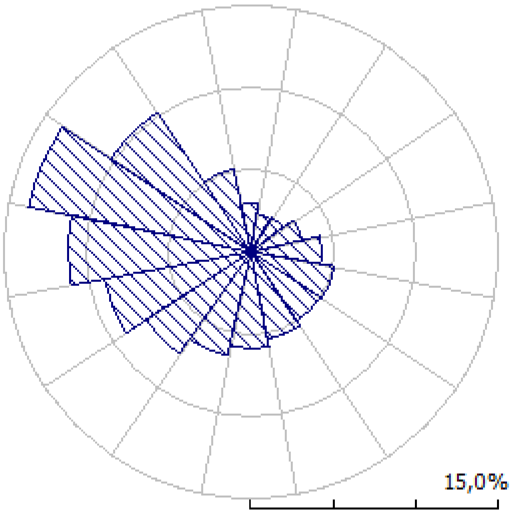


Figure 13a: *Annual wind rose for the installation position of the first wind turbine.*

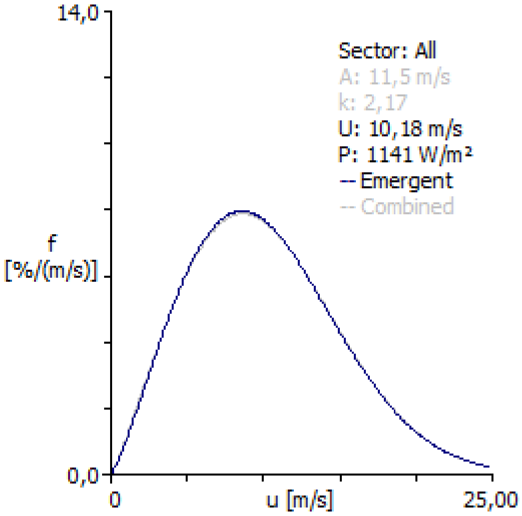


Figure 13b: *Annual Weibull wind velocity distribution of the first wind turbine.*

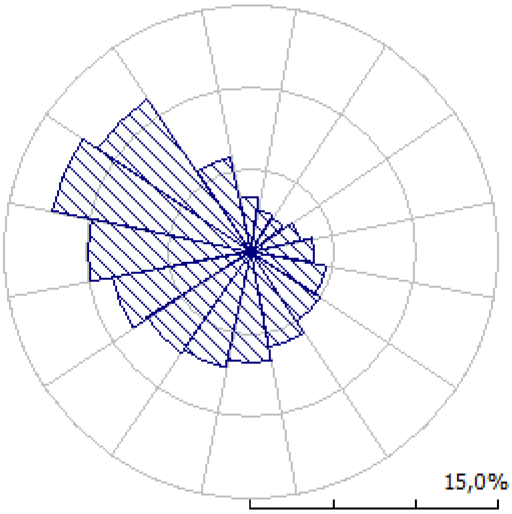


Figure 13c: *Annual wind rose for the installation position of the second wind turbine.*

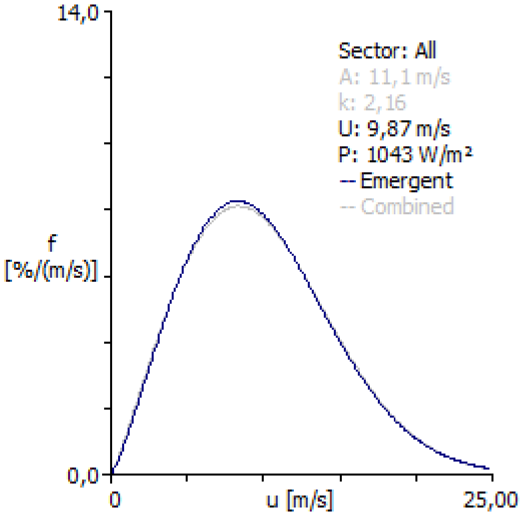


Figure 13d: *Annual Weibull wind velocity distribution of the second wind turbine.*

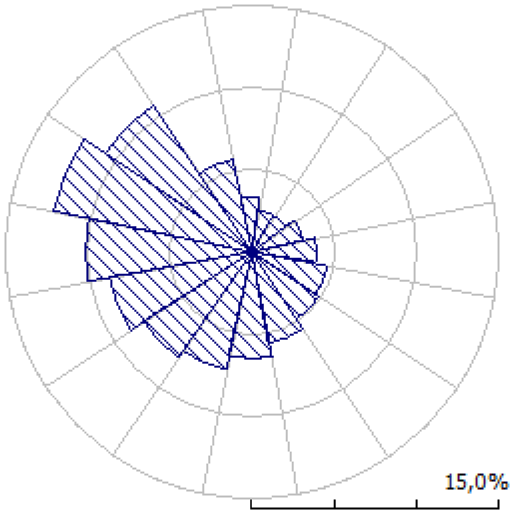


***Figure 13e**: Annual wind rose for the installation position of the third wind turbine.*

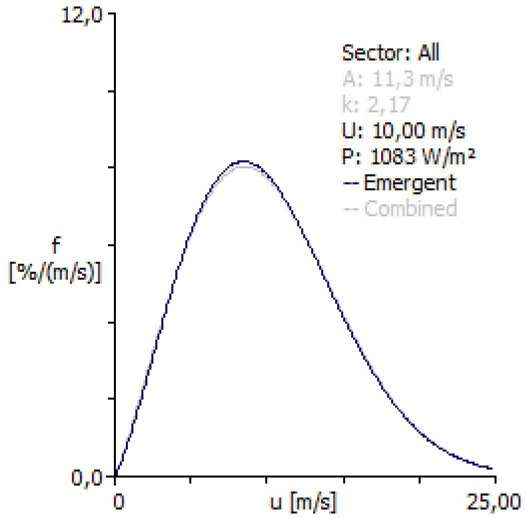


***Figure 13f**: Annual Weibull wind velocity distribution of the third wind turbine.*

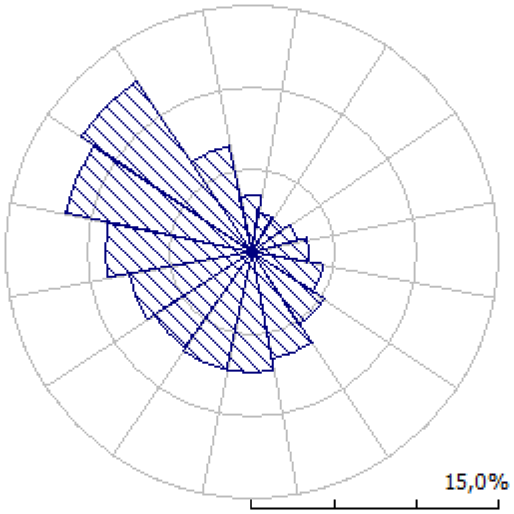


***Figure 13g**: Annual wind rose for the installation position of the fourth wind turbine.*

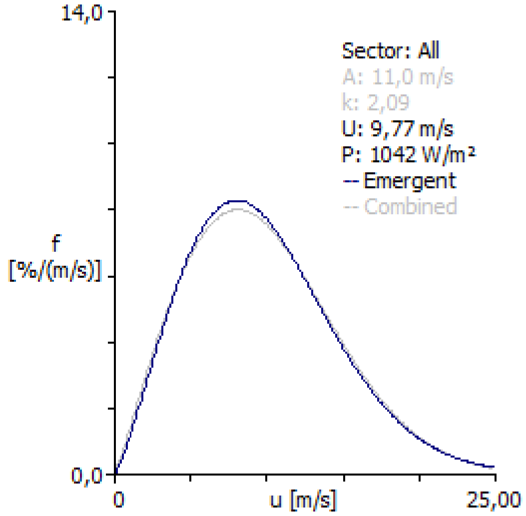


***Figure 13h**: Annual Weibull wind velocity distribution of the fourth wind turbine.*

Finally, two photorealistic representations of the wind park with the four 50 kW wind turbines in the Cape Clear Island from northwest and southeast are provided in Figure 14.

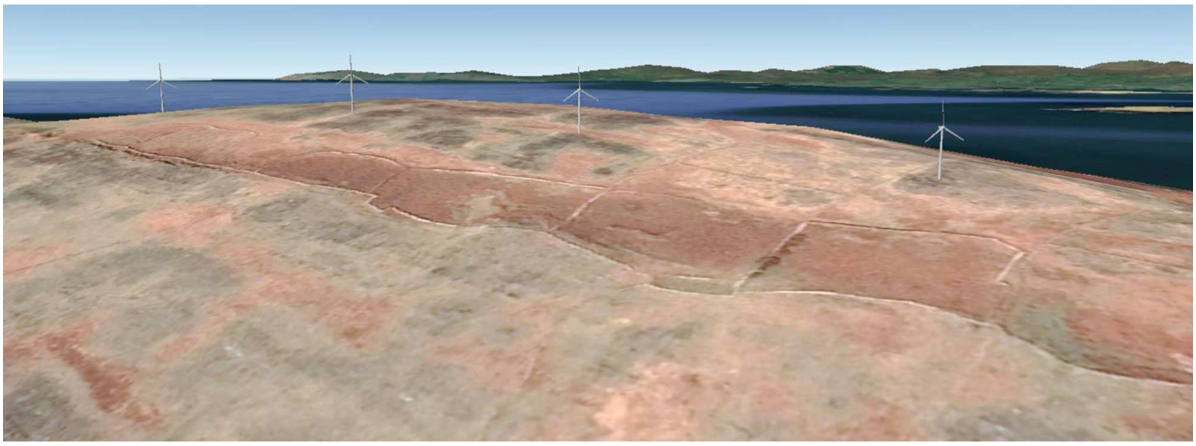


***Figure 14**: Photorealistic representation of the wind park at the Cape Clear Island from the northwest (upper figure) and the southeast (lower figure).*

3. Solar radiation

Solar radiation measurements

The estimation of the available solar potential on Cape Clear is based on the availability of solar radiation measurements from the ERA Interim database of the European Centre for Medium-Range Weather Forecasts (ECMWF) for the period 2000 – 2018 [4]. Given the, in general, low variability of the incident solar radiation on a specific geographical point from year to year, one year measurements were considered adequate for the purpose of the specific study. The geographical point's location of the available solar radiation measurements is depicted in Figure 15. It is seen that it is located on the offshore area at the north of the island, so the retrieved solar radiation measurements can be considered as characteristic for the under interest area.

***Figure 15**: Location of the ERA-5 solar radiation measurement point with regard to the Cape Clear Island.*

For the specific point, the annual time series of average hourly values for the Global Horizontal Irradiance (GHI) in W/m^2 was retrieved. It is presented in Figure 16.

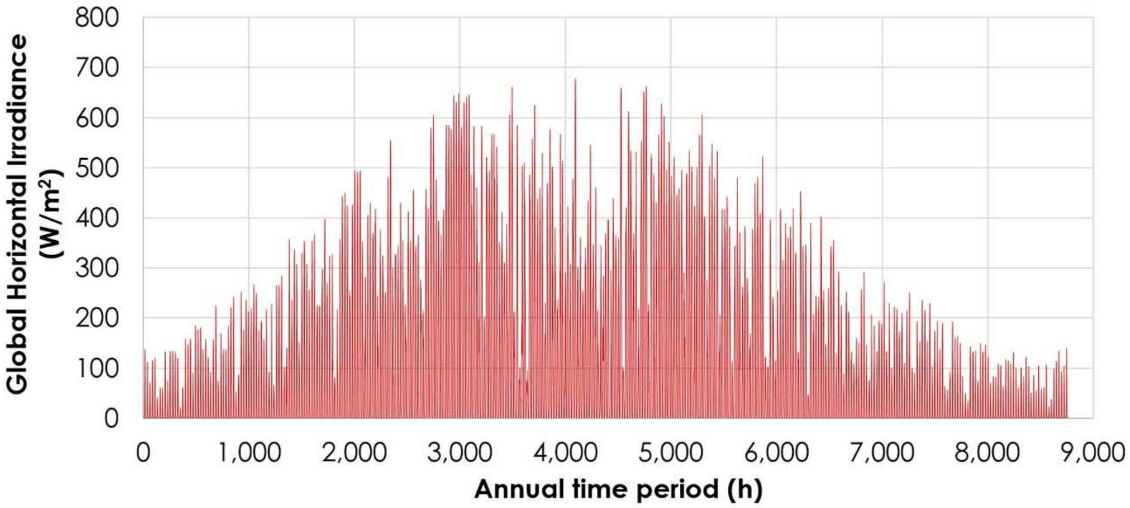


***Figure 16**: Annual Global Horizontal Irradiance fluctuation at the Cape Clear Island [4].*

Additionally, the annual time series of the ambient temperature was retrieved from the measurement point 2, presented in wind potential section, from the ERA-5 database. It is presented in Figure 17.

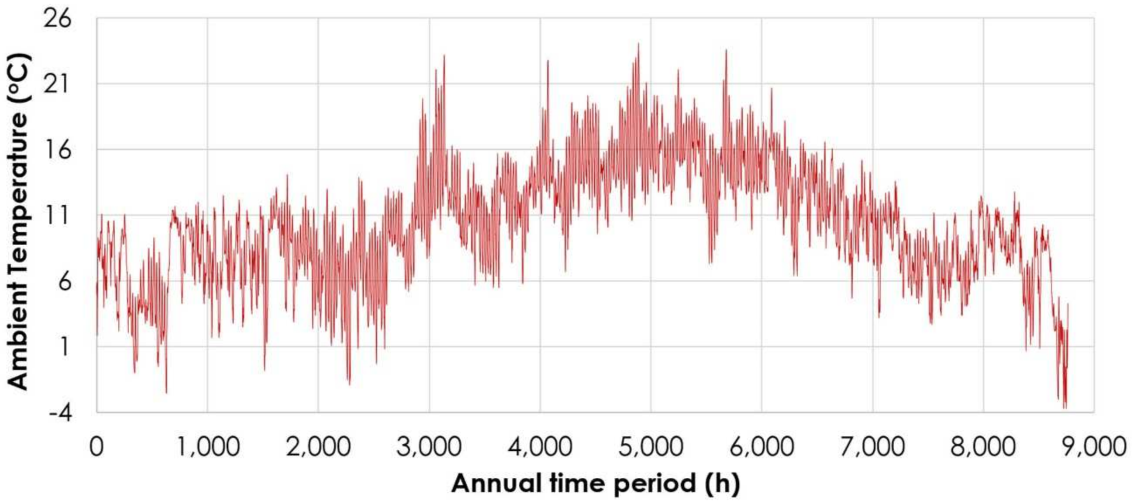


***Figure 17**: Annual fluctuation of the ambient temperature at the Cape Clear Island [3].*

By integrating the annual GHI time series, the annual solar irradiation is calculated at 769.8 kWh/m^2, with 84.8% of it (653.1 kWh/m^2) being available during the spring and summer period (from 15/3 to 15/10).

Optimum installation angle of photovoltaic panels

The estimation of the optimum installation angle of photovoltaic panels in the Cape Clear Island is based on the fundamental principles and theory of solar geometry and solar radiation [5]. Given the installation geographical position and the incident solar irradiance according to the available measurements, the annual fluctuation of the direct, the diffuse and the reflected solar radiation on a flat surface is calculated, versus several alternative installation angles of the surface with regard to the horizontal plane. These fluctuations are calculated in the form of annual time series of average hourly values. On a second stage, these annual time series are integrated, so the annual incident solar radiation is calculated, firstly for each one of the discrete three components of the incident solar radiation (direct, diffuse and reflected) and then for the overall incident solar radiation. Additionally, aiming at a deeper insight on the available incident solar radiation on a flat inclined surface, the above described process is further applied seasonally, namely for the period from 16/10 to 15/3, defined as the winter period, and for the period from 16/3 to 15/10, defined as the summer period. In this way, we obtain more detailed analysis of the total incident solar radiation during the above mentioned seasons, so as the selection of the photovoltaic panels' installation angle could be based on the maximisation of the incident solar radiation during a specific season and not during the annual period. The results from the aforementioned analysis are presented in Table 4.

By observing Table 4, we may conclude that the overall incident solar radiation on a flat surface is maximized:

- on annual basis for installation angle equal to 25° (776.61 kWh/m^2)
- during the summer period (16/3 to 15/10) for installation angle at 20° (654.76 kWh/m^2 which corresponds to 84.3% of the corresponding figure for 25° installation angle)
- during the winter period (16/10 to 16/10) for installation angle at 40° (126.45 kWh/m^2).

***Table 4**: Calculation and analysis of the overall incident solar radiation in W/m^2 on a flat inclined surface in Cape Clear Island versus the installation angle.*

Period	Solar radiation component	Photovoltaic panels installation angle (°)											
		10	15	20	25	30	35	40	45	50	55	60	65
		Incident solar radiation on a flat inclined surface (kWh/m^2)											
Annual	Direct	208.01	217.55	225.43	231.60	236.00	238.61	239.40	238.40	235.53	230.89	224.50	216.39
	Diffuse	557.70	552.40	545.02	535.64	524.32	511.15	496.23	479.67	461.60	442.15	421.48	399.73
	Reflected	1.52	3.42	6.04	9.37	13.41	18.10	23.41	29.31	35.75	42.68	50.04	57.78
	Total	**767.23**	**773.37**	**776.49**	**776.61**	**773.73**	**767.86**	**759.04**	**747.38**	**732.88**	**715.72**	**696.02**	**673.90**
Winter 16/10-15/3	Direct	24.08	27.46	30.64	33.58	36.27	38.68	40.80	42.61	44.09	45.24	46.04	46.49
	Diffuse	92.27	91.39	90.17	88.62	86.75	84.57	82.10	79.36	76.37	73.15	69.73	66.14
	Refflected	0.23	0.52	0.92	1.42	2.03	2.75	3.55	4.45	5.42	6.47	7.59	8.76
	Total	**116.58**	**119.37**	**121.73**	**123.62**	**125.05**	**126.00**	**126.45**	**126.42**	**125.88**	**124.86**	**123.36**	**121.39**
Summer 16/3-15/10	Direct	183.93	190.09	194.79	198.02	199.73	199.93	198.60	195.79	191.44	185.65	178.46	169.90
	Diffuse	465.43	461.01	454.85	447.02	437.57	426.58	414.13	400.31	385.23	369.00	351.75	333.59
	Refflected	1.29	2.90	5.12	7.95	11.38	15.35	19.86	24.86	30.33	36.21	42.45	49.02
	Total	**650.65**	**654.00**	**654.76**	**652.99**	**648.68**	**641.86**	**632.59**	**620.96**	**607.00**	**590.86**	**572.66**	**552.51**

In Figures 18a, 18b and 18c the annual fluctuation of the direct, diffuse and reflected solar radiation on the inclined flat surface for installation angle 20o, 25o and 40o is presented respectively.

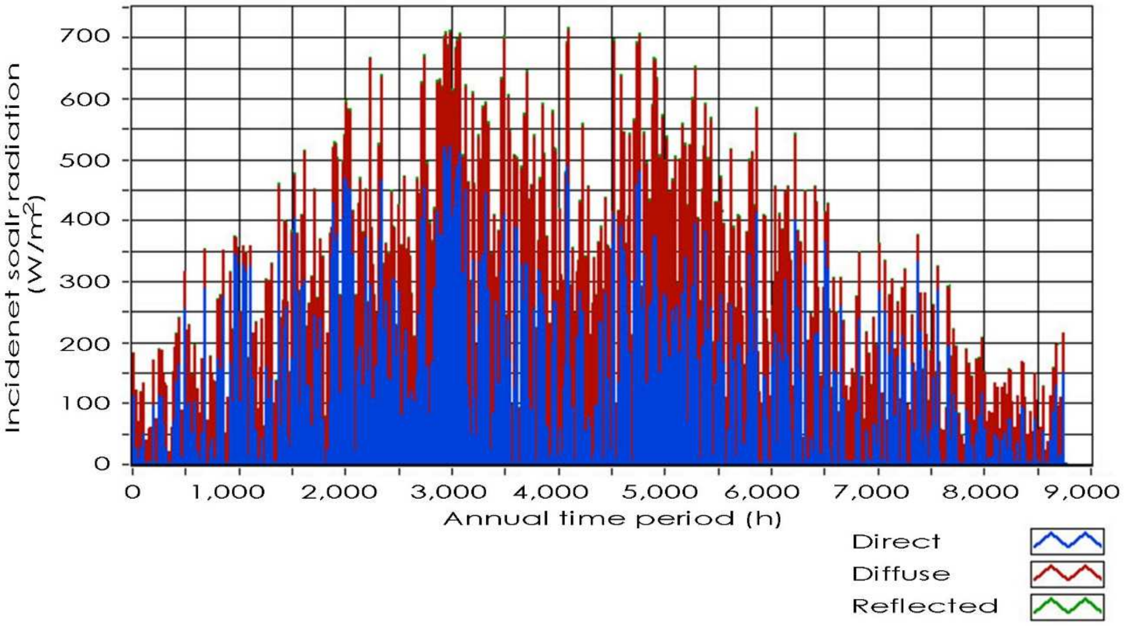


***Figure 18a**: Annual fluctuation and analysis of the incident solar radiation on an inclined surface with 20o installation angle with regard to the horizontal plane.*

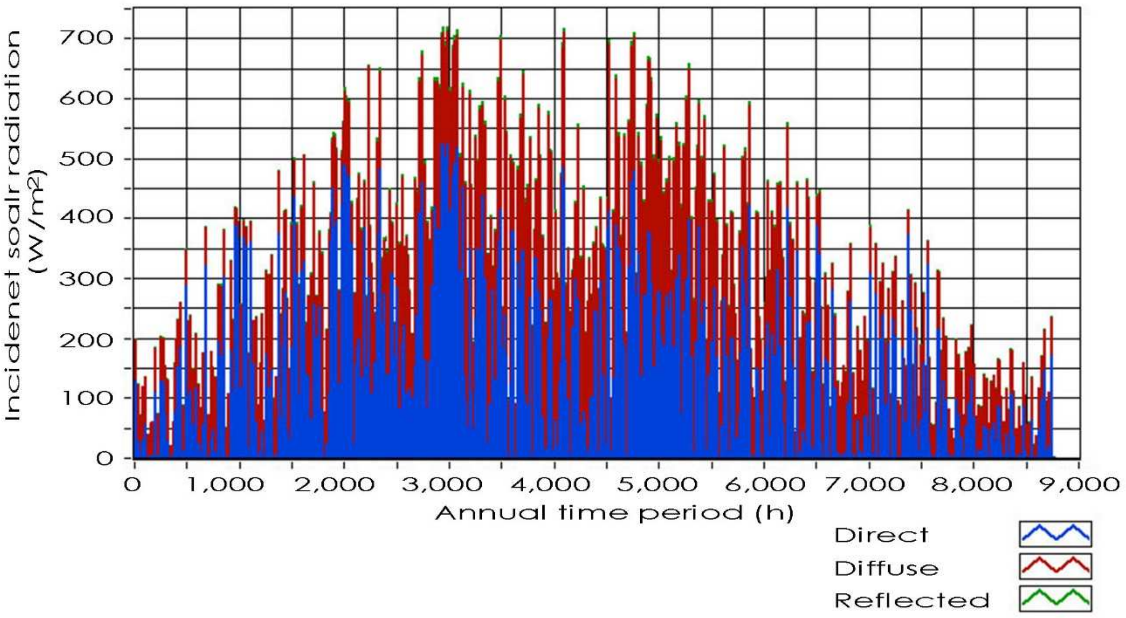


***Figure 18b**: Annual fluctuation and analysis of the incident solar radiation on an inclined surface with 25o installation angle with regard to the horizontal plane.*

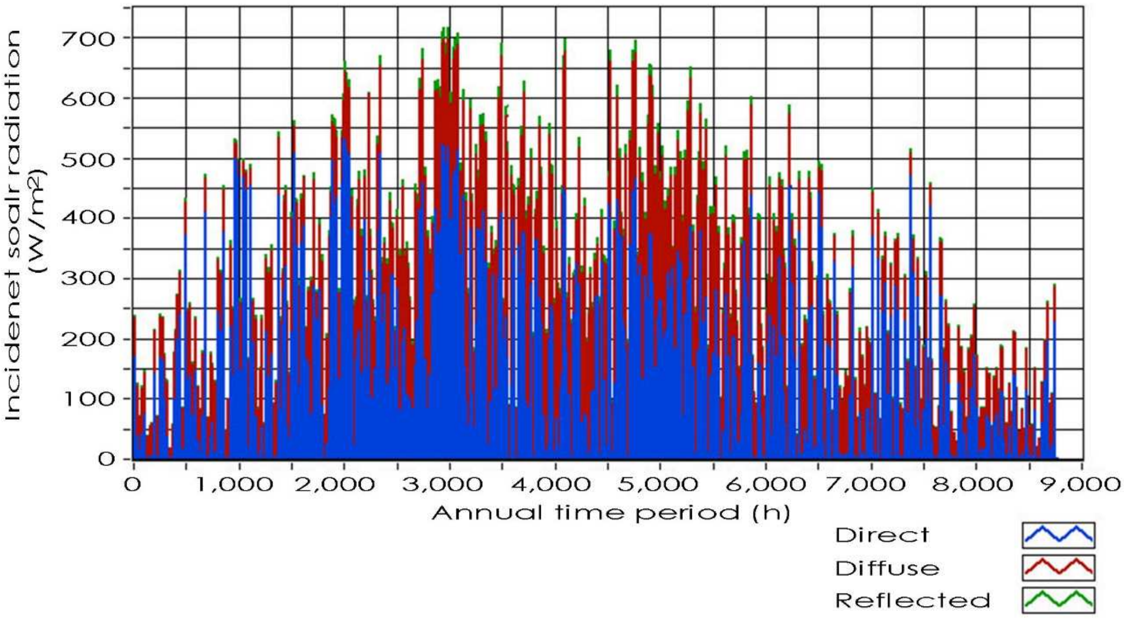


***Figure 18c**: Annual fluctuation and analysis of the incident solar radiation on an inclined surface with 40° installation angle with regard to the horizontal plane.*

From the above analysis it is revealed that the optimum installation angle of the photovoltaic panels is a function of the objective of the photovoltaic plant. Given the high wind potential available in the Cape Clear Island and the relatively low solar radiation due to the northern location of the Island, a sensible approach could be that a potential photovoltaic plant should be installed as a supplement to the wind park, which will undertake the main role towards the energy transition in the island, or even particularly, the energy transition for the transportation sector. The photovoltaic station should mainly focus on the support of the wind power production during summer, when the available wind potential drops (see section 2) and the incident solar radiation is maximised. This means that, following this observation, the sensible approach would be the installation of the photovoltaic plant aiming at the maximization of the captured solar radiation during summer, namely with the angle of 20°.

Power production from the photovoltaic panels

The power production calculation of a photovoltaic station follows the fundamental mathematical background presented in the literature. It is summarized in a comprehensive way in [6]. For the needs of the current study, this procedure will be applied for the installation angle of 20° and for 1 MW_p of installed photovoltaic power. The annual fluctuation of the power production from the photovoltaic station is presented in Figure 19. By integrating the photovoltaic power production time series, the annual electricity production is calculated at 677.1 MWh, giving an annual capacity factor of 7.7%. The electricity production during the summer period (16/3 – 15/10) is calculated at 567.1 MWh, corresponding to a capacity factor of 11.0%.

The low available solar radiation in the Cape Clear Island certainly affects the performance of a photovoltaic station on the island, as clearly depicted in the calculated annual and seasonal electricity production and capacity factors, which are calculated considerably low. The electricity production particularly during the summer months (June to August) is calculated at 267.9 MWh, corresponding to 39.6% of the total annual electricity production and leading to a capacity factor of 11.1%, which can be acceptable. This conclusion strengthens the initial approach that the photovoltaic station, once decided to be installed, should focus on the supplement production especially during summer, when the available wind potential is relatively low.

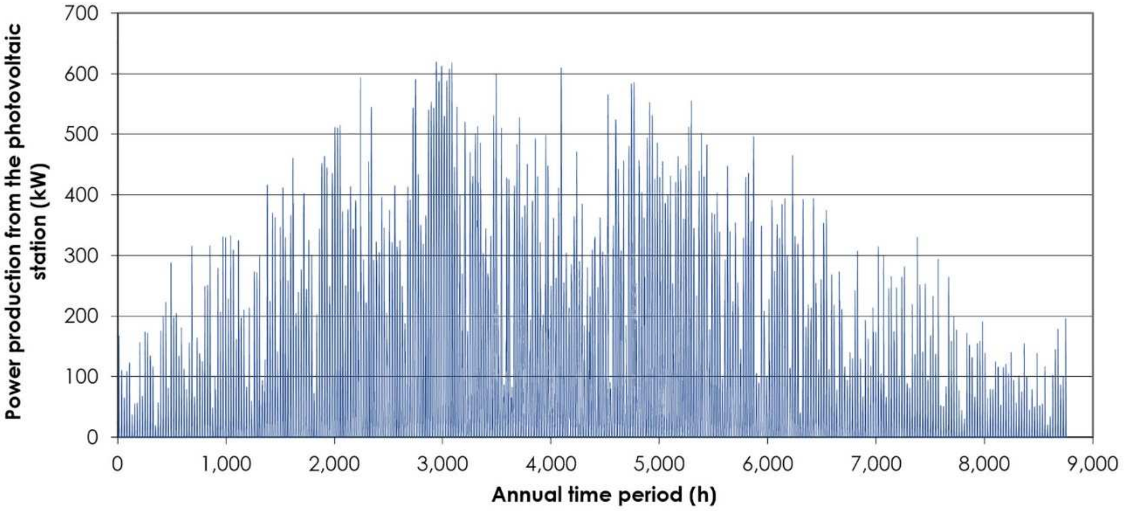


***Figure 19**: Annual fluctuation of the electrical power production from a 1 MW_p photovoltaic station, with 20° installation angle with regard to the horizontal plane at the Cape Clear Island.*

4. Dynamic simulation of the power production system

Objective

Having gathered all the required information regarding both the existing or the anticipating electricity consumptions in Cape Clear Island and the available wind potential and solar radiation, this final section will investigate the appropriate synthesis of power production systems based on the exploitation of the available Renewable Energy Sources (R.E.S.) for the coverage of the electricity demand in the island. The overall approach will be based on the computational simulation of the power demand and production in the island, with annual time series of average hourly values.

Alternative power demand annual profiles

The introduced power production systems will be dimensioned for four alternative annual power demand scenarios:

- firstly, the currently existing annual electricity demand in the island will be considered
- secondly, a micro power system will be studied for the coverage of the electricity demand for the introduction of two electrical vehicles in the island
- thirdly, in a more integrative approach, the anticipating annual power demand specifically for the full energy transition in the transportation sector from fossil fuels to electrical vehicles will be examined
- finally, the expecting total power demand will be introduced for the coverage of both the existing electricity needs and the forthcoming demand from the total substitution of fossil fuels and biomass currently consumed for heating, transportation and cooking in Cape Clear Island.

For the above four alternative power demand scenarios, corresponding to annual power demand time series were developed, based on arithmetic methods and statistical power demand data available for insular systems at the same geographical location (eastern Atlantic Ocean) and under similar climatic conditions.

Specifically, regarding the existing electrical power demand and the expecting electrical power demand for the coverage of the heating needs from heat pumps, two relevant time series were constructed based on the corresponding annual fluctuations in the Faroe Islands, which were available [7]. The time series were adapted linearly for the demand size of the Cape Clear Island, given the calculated annual electricity consumptions for the existing electrical needs and the expecting electrical power demand for the coverage of the heating needs from electrical driven heat pumps.

Regarding the electrical power demand for the transportation needs coverage, a typical charge daily profile for all the cars in the Island was developed. The main charging process will be certainly executed at nights, during which the daily peak for this particular power demand will appear. A second, minor peak is also introduced in the early afternoon hours. The final developed daily charge profile is presented in Figure 20. By integrating this daily profile, the total daily electricity demand for the full coverage of the transportation needs in the Island is calculated on annual average basis at 536.36 kWh.

The annual time series of the electrical power consumption for the electrical vehicles charging is developed by simply replicating the adopted daily charging power profile for all the days of the year, multiplied with a monthly weighting factor, based on the estimated population on the island according to the provided arrivals and departures on monthly basis. In Table 5, the annual departures and arrivals from and to the Cape Clear Island and the corresponding monthly weighting factors are presented.

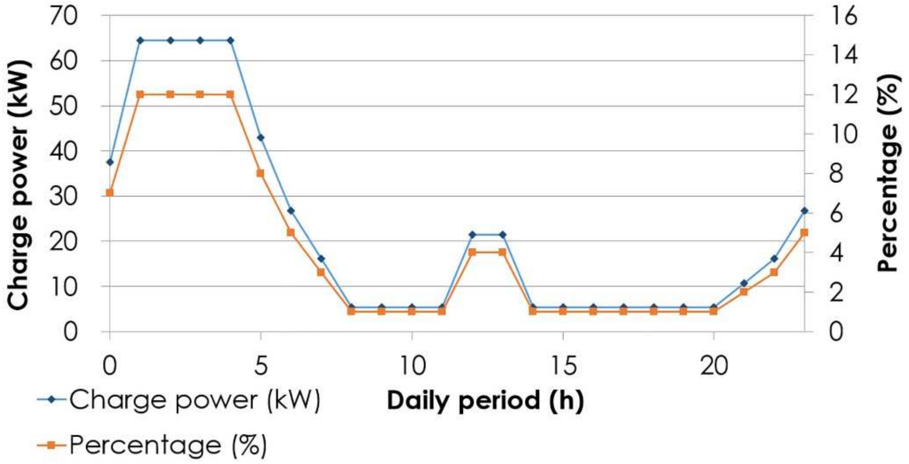


Figure 20: *Introduced electrical vehicles charge daily profile for the full energy transition on the transportation sector in Cape Clear Island.*

Table 5: *Monthly arrivals and departures to and from the Cape Clear Island and monthly weighting factors for the arithmetic development of the transportation and cooking annual power demand time series [8].*

Month	To Baltimore	To Cape Clear	Monthly weighting factors
January	651	415	0.96
February	337	326	0.93
March	1,111	1,264	2.15
April	1,033	870	0.93
May	1,223	1,317	1.68
June	2,374	2,472	2.46
July	4,034	4,048	2.90
August	4,585	4,623	3.21
September	1,974	1,730	1.37
October	931	892	1.08
November	537	489	1.02
December	652	640	1.00

Specifically for the introduction of only two mini-buses of 7 seats capacity for the support of the public transport system in the island, as requested by the applicants, the following assumptions were made, based on the technical specifications of specific commercial models:

- specific electricity consumption 20 kWh/km
- total covered distance per vehicle on annual basis: 10,000 km.

Given the above assumptions, the daily charge profile was adapted to match the power consumption particularly for these two mini-buses. It is presented in Figure 21. By integrating this daily profile, the daily electricity demand for the coverage of the electricity demand for the two mini-buses is calculated at 10.96 kWh. The monthly weighting factors introduced in Table

5 are also applied for the configuration of the electricity demand annual time series for the charging of these two mini-buses.

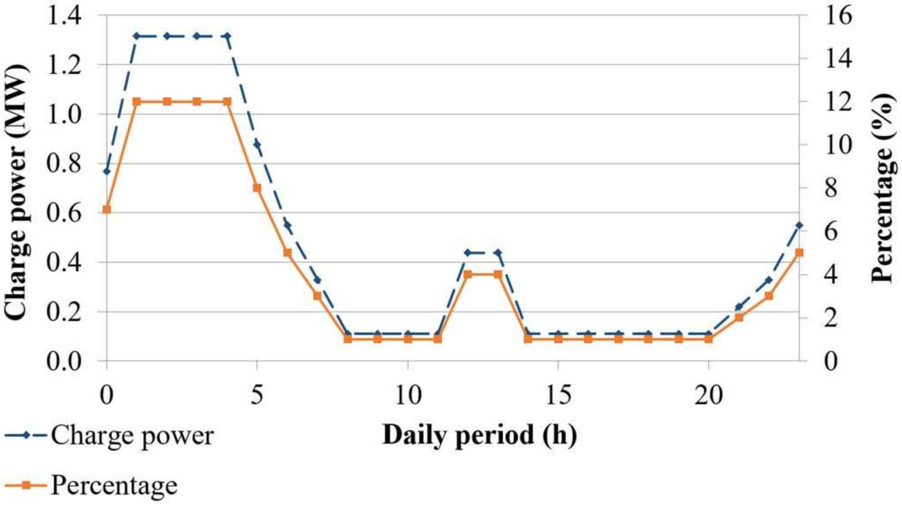


***Figure 21**: Introduced electrical vehicles charge daily profile for the electricity demand coverage for the charging of two mini-buses for the public transport system support.*

Similarly, regarding the electrical power demand expected from the transfer of the cooking needs currently covered with LPG to the electrical grid, a corresponding daily power demand profile was constructed, presented in Figure 22. As seen in this figure, a first minor power demand for cooking is assumed in the morning, for breakfast, while the main power demand is concentrated from 10:00 to 14:00. A second minor demand is placed in the early evening. This daily demand profile was replicated for the whole annual period, using the same weighting factors presented in Table 5.

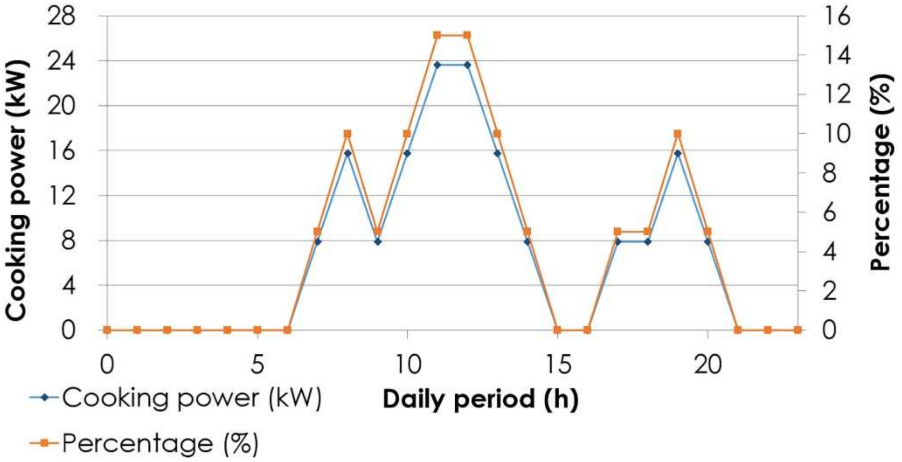


***Figure 22**: Introduced daily demand profile for the coverage of the cooking needs in Cape Clear Island, currently covered with LPG.*

Eventually, with the processes and approaches described previously, all the discrete annual power demand profiles have been created, namely for the current electrical power consumption, for the coverage of the heating and cooking needs from the electrical grid, currently covered with fossil fuels and biomass, for the total transfer of the transportation needs in the electrical grid and particularly, as a first stage, for the coverage of the charging needs of the two mini-buses. We can now proceed to the plotting of the particular annual power demand time series for which the dimensioning and the study of the proposed RES systems will be implemented.

Specifically, in Figure 23, the annual time series for the existing electrical power demand is plotted.

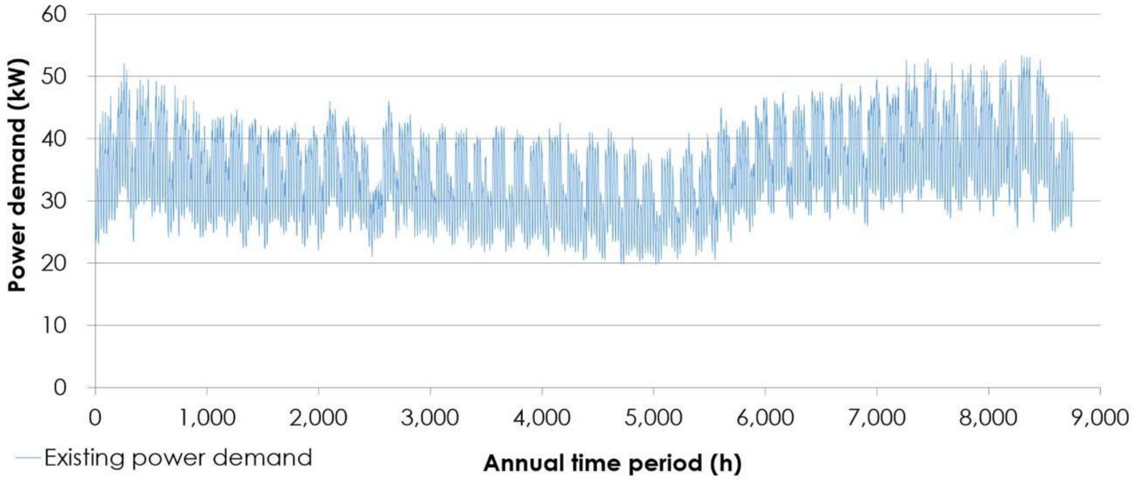


Figure 23: *Annual fluctuation of the existing electrical power demand in Cape Clear Island.*

In Figure 24, the annual time series of the electrical power required for the coverage of the electricity consumption required for the charge of the two mini-buses is plotted.

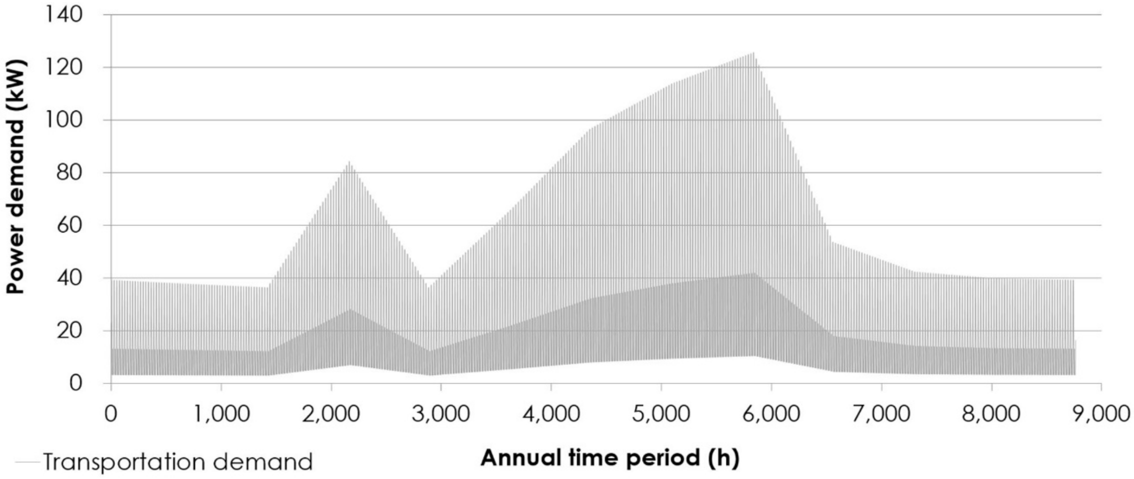


Figure 24: *Annual fluctuation of the electrical power demand for the coverage of the electricity consumption required for the charge of the two mini-buses.*

In Figure 25, the annual time series of the electrical power required for the full energy transition in the transportation sector from fossil fuels to the electrical grid is plotted.

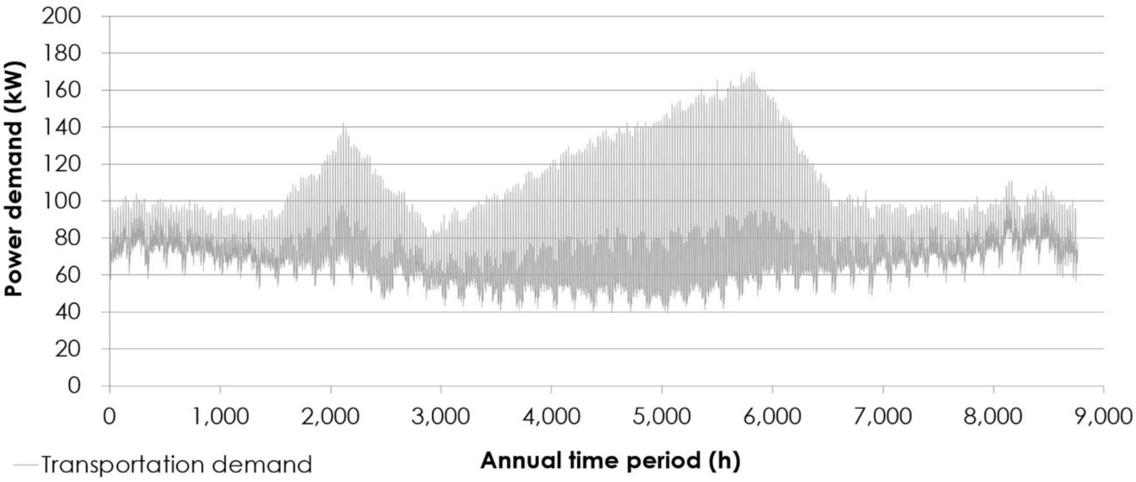


Figure 25: *Annual fluctuation of the electrical power demand for the coverage of the transportation energy consumption in Cape Clear Island.*

Finally, in Figure 26, the annual time series is presented for the electrical power required for the full energy transition in the island, regarding all the aforementioned onshore energy use (existing consumption, heating, transportation and cooking).

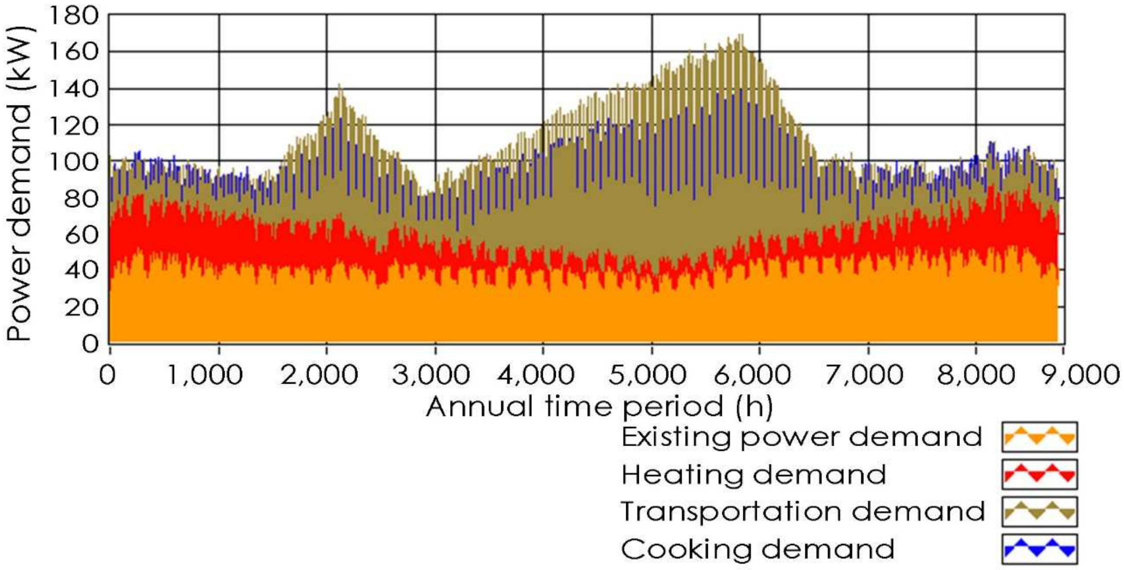


***Figure 26**: Annual fluctuation of the total electrical power demand for the coverage of the all the energy needs on the island.*

A closer insight at the fluctuation of the total power demand is given in Figure 27. Specifically, in Figure 27a the power demand fluctuation is presented for the period from the 19th to the 28th of February (last ten days of February), which corresponds to the low power demand season. In Figure 27b the power demand fluctuation is presented for the first ten days of August, which falls into the high power demand period. The higher contribution of the heating demand is clearly depicted in Figure 27a, while in Figure 27b the demand share of the transportation sector is remarkably increased.

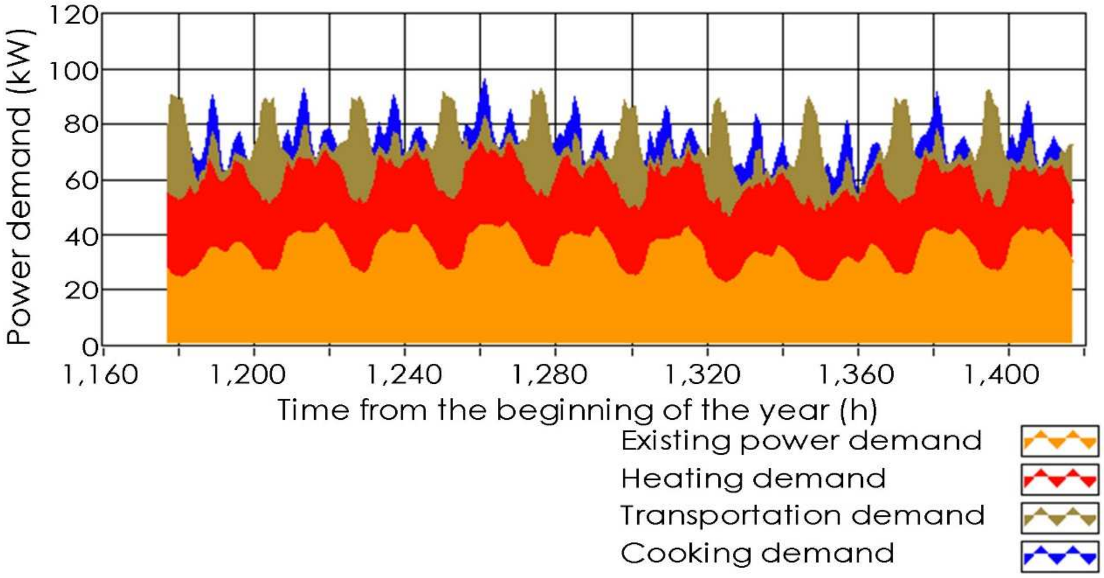


***Figure 27a**: Fluctuation of the total electrical power demand for the coverage of the all the energy needs on the island from the 19th to the 28th of February.*

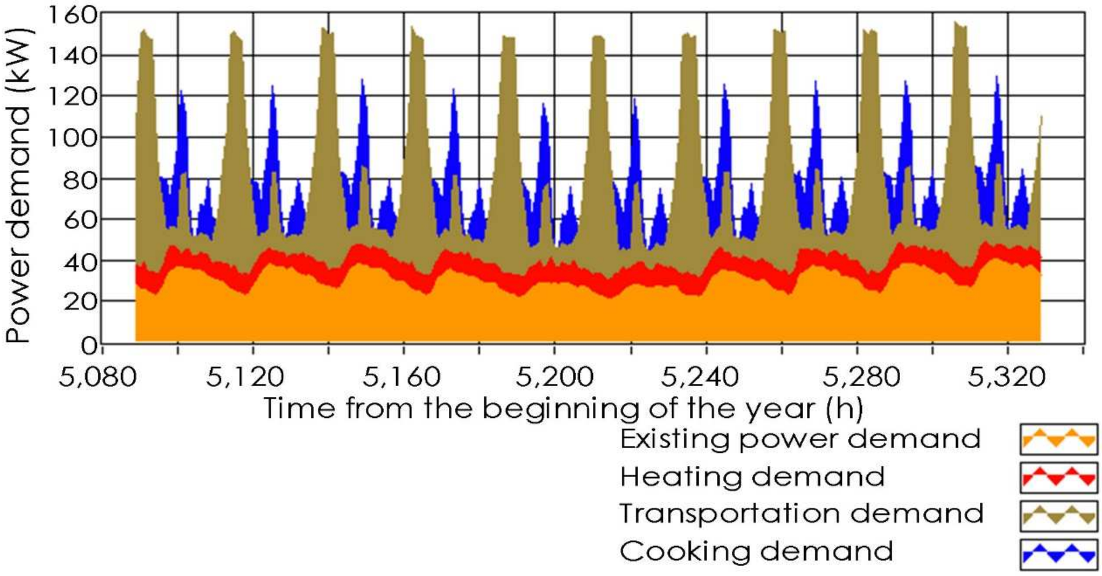


Figure 27b: *Fluctuation of the total electrical power demand for the coverage of the all the energy needs on the island from the 1st to the 10th of August.*

The characteristic power demand features of the above time series are summarized in Table 6. It is underlined that the heating demand features presented in Table 6 refer only to the additional heating demand from the transition of coal, peat, kerosene and timber to electrical heating. Any heating demand already currently with electricity is not included in these figures.

Table 6: *Characteristic power demand features for the alternatively examined demand scenarios.*

Power demand scenario	Existing demand	Heating	2 mini-buses charging demand	Full transportation demand coverage	Full onshore energy transition
Annual electricity consumption (kWh)	304,700	162,583	4,000	195,846	720,608
Daily average consumption (kWh)	834.8	445.4	11.0	536.6	1,974.3
Annual peak power demand (kW)	53.36	38.37	2.56	125.59	169.56
Annual minimum power demand (kW)	19.76	5.25	0.06	3.02	42.33
Annual average power demand (kW)	34.78	18.56	0.46	22.33	82.26

Given that the Cape Clear Island is interconnected, the coverage of the aforementioned power demand profiles will be investigated with wind turbines and photovoltaic panels, under a net-metering mode, aiming at the annual compensation of the annual electricity consumption with the total production from these units.

Dimensioning of the required R.E.S. technologies

As clarified previously, the alternatively examined power demand profiles will be covered with wind turbines and photovoltaic panels. The goal of this approach is the annual compensation of the consumed electricity with the production of the introduced R.E.S. technologies. This approach can be applied given the interconnection of the island with the mainland Irish grid, which enables the constant power supply to the Cape Clear Island, regardless the available power production from the R.E.S. technologies.

The dimensioning of each different system will be executed one by one for each examined demand profile.

Existing power demand:

As seen in Table 6, in this case the annual electricity consumption is calculated at 304,700 kWh. Regarding the potential electricity production from R.E.S. technologies:

- in Table 3, it is shown that the annual electricity production from 1 wind turbine of 50 kW nominal power is 243,267 kWh, with an annual capacity factor of 55.6%
- in section 3, it is calculated that the annual power production from a photovoltaic station of 1 MW_p nominal power equals to 677,052 kWh, with an annual capacity factor of 7.73%.

The installation of a second 50 kW wind turbine will double the aforementioned annual production, exceeding roughly 40% the annual electricity consumption. Hence, it seems more sensible to install only one wind turbine of 50 kW nominal power and cover the remaining power consumption of: 304,700 – 243,267 = 61,433 kWh

with production from photovoltaic panels. With a recalculation of the power production from the photovoltaic station, it is found that the installation of 95 kW_p of photovoltaic panels will give 61,612 kWh on annual basis.

The annual fluctuation of the power demand and the power production from the involved wind turbine and photovoltaics in this scenario is presented In Figure 28.

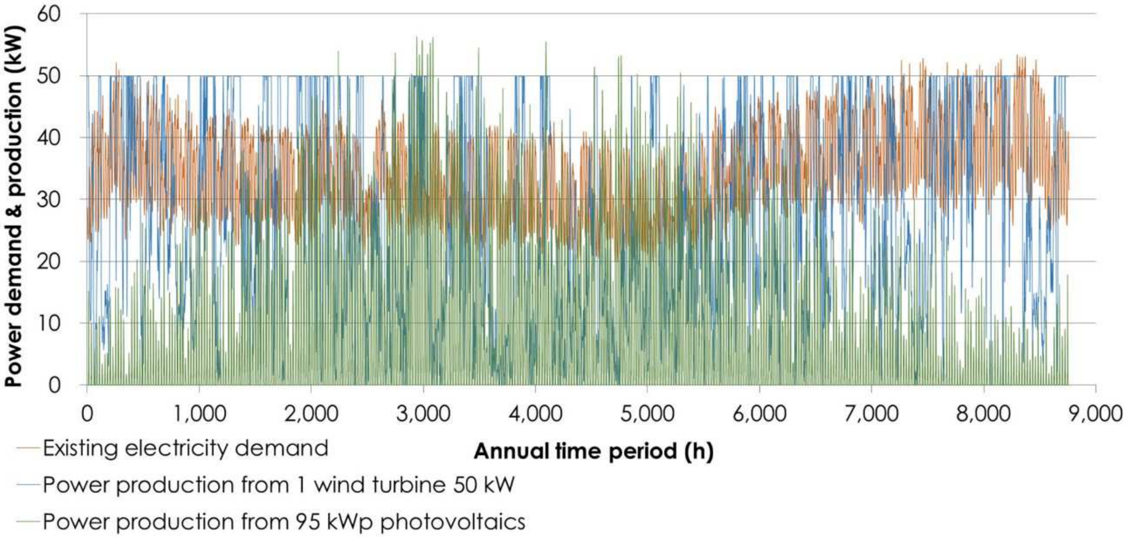


***Figure 28**: Annual fluctuation of the current electrical power demand and the power production from a 50 kW wind turbine and 95 kW_p photovoltaics.*

In Table 7, the monthly variation of the energy production and consumption and the peak power production and demand is analysed.

***Table 7**: Monthly analysis of the energy production and consumption and the corresponding peak power demand and production for the first investigated scenario in Cape Clear Island.*

Month	Demand (kWh)	Production (kWh)			Demand coverage percentage (%)	Peak demand (kW)	Peak production (kW)		
	Consumption	Wind turbine production	Photovoltaics production	RES total production			Wind turbine peak production	Photovoltaics peak production	RES peak production
January	27,237	24,398	1,416	25,814	-5.22	52.10	49.90	28.37	75.12
February	23,164	20,091	2,465	22,556	-2.62	46.84	49.90	37.86	78.97
March	25,323	25,270	5,618	30,887	21.97	45.97	49.90	46.79	96.69
April	24,112	16,349	7,201	23,550	-2.33	46.09	49.90	53.76	90.40
May	23,969	20,157	10,578	30,735	28.23	42.36	49.90	56.28	106.18
June	22,581	13,097	7,787	20,884	-7.52	42.50	49.90	55.49	105.38
July	21,909	13,840	9,017	22,857	4.32	41.61	49.90	53.26	101.30
August	23,646	16,525	7,574	24,099	1.92	44.93	49.90	50.45	87.94
September	26,786	19,478	4,973	24,450	-8.72	47.64	49.90	45.05	94.95
October	28,672	23,783	2,474	26,257	-8.42	52.50	49.90	28.49	74.41
November	28,689	24,352	1,567	25,919	-9.66	52.78	49.90	29.69	71.07
December	28,612	26,286	943	27,229	-4.83	53.36	49.90	17.44	67.34
Annual	**304,700**	**243,627**	**61,612**	**305,239**	**0.18**	**53.36**	**49.90**	**15.12**	**60.33**

The data presented in tabular format in Table 7 are also graphically depicted in Figures 29a and 29b.

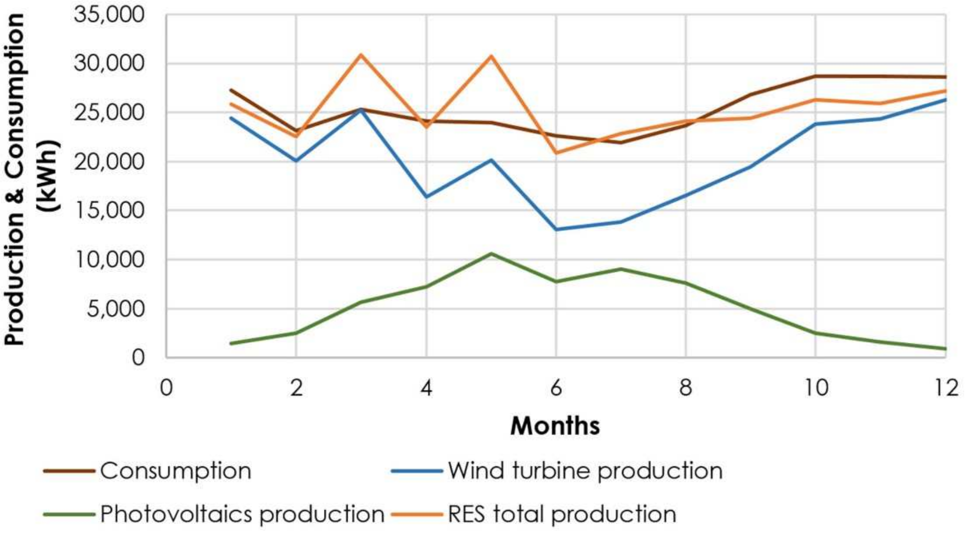


***Figure 29a**: Monthly fluctuation of energy production and consumption for the first investigated scenario.*

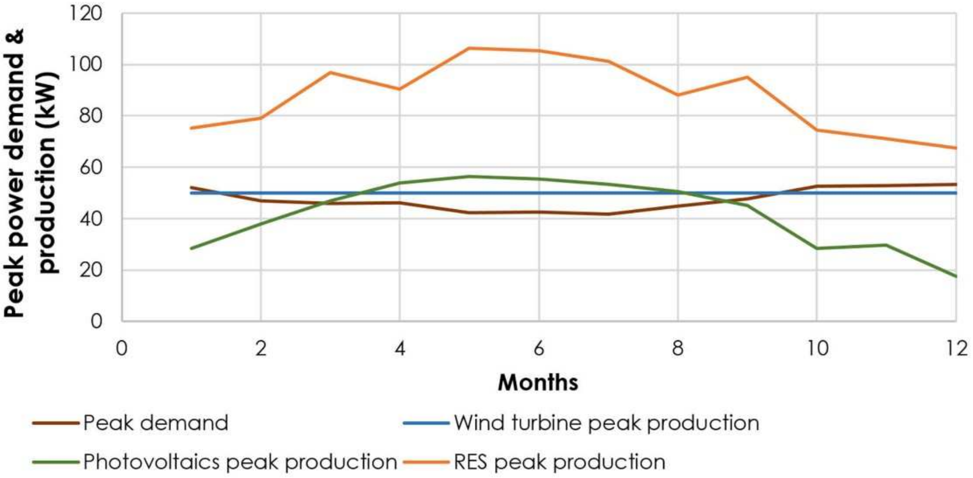


***Figure 29b**: Monthly fluctuation of the peak power demand and production for the first investigated scenario.*

From the above figures and from Table 7 it is seen that the monthly coincidence of the electricity consumption and the production from the proposed R.E.S. technologies is quite satisfying. The photovoltaics' production increases during the summer months, compensating the wind power production drop. Yet, it should be underlined that this is achieved with significantly higher installed R.E.S. power (particularly due to the installation of 95 kW_p of photovoltaics), with regard to the peak power demand.

Introduction of 2 electrical vehicles:

As seen in Table 6, in this case the annual electricity consumption is calculated at 4,000 kWh. Regarding the potential electricity production from R.E.S. technologies:

- in section 2, the annual electricity production from a small wind turbine of 1 kW nominal power installed in Cape Clear Island at a location with annual average wind velocity 6.17 m/s at 5 m height above ground, has been calculated equal at 3,086 kWh
- according to section 3, the annual power production from a photovoltaic station of 1 kW_p nominal power equals to 677 kWh.

Given the annual electricity production from the small wind turbine, the remaining electricity to meet the annual electricity demand for the charge of the two electrical vehicles is:

4,000 – 3,086 = 914 kWh.

With a recalculation of the power production from the photovoltaic station, it is found that the installation of 1.4 kW_p of photovoltaic panels will give 948 kWh on annual basis. Hence, the required annual electricity consumption can be covered by the installation of one 1 kW wind turbine and 1.4 kW_p of photovoltaic panels.

The annual fluctuation of the power demand and the power production from the involved wind turbine and photovoltaics in this scenario is presented In Figure 30.

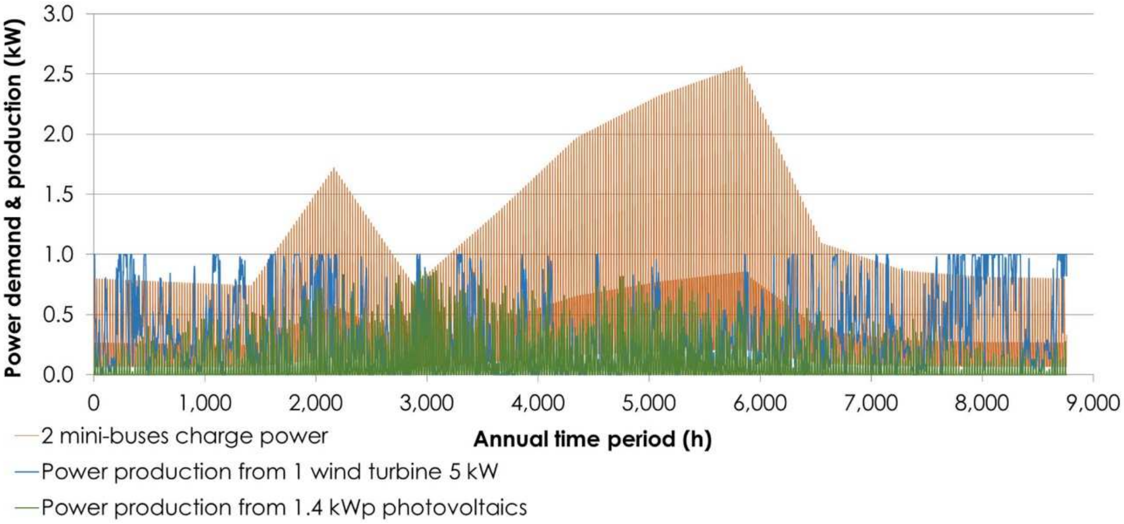


Figure 30*: Annual fluctuation of the electrical power demand for the charge of 2 electrical mini-buses and the power production from a 1 kW wind turbine and 1.4* kW_p *photovoltaics.*

In Table 8, the monthly variation of the energy production and consumption and the peak power production and demand is analysed.

***Table 8**: Monthly analysis of the energy production and consumption and the corresponding peak power demand and production for the second investigated scenario in Cape Clear Island.*

Month	Demand (kWh)	Production (kWh)			Demand coverage percentage (%)	Peak demand (kW)	Peak power production (kW)		
	Consumption	Wind turbine production	Photovoltaics production	RES total production			Wind turbine peak production	Photovoltaics peak production	RES peak production
January	202	313	22	335	65.52	0.80	1.00	0.44	1.24
February	176	249	38	287	62.79	0.77	1.00	0.58	1.45
March	314	360	86	447	42.33	1.69	1.00	0.72	1.68
April	312	179	111	289	-7.17	1.72	1.00	0.83	1.48
May	267	250	163	413	54.70	1.32	1.00	0.87	1.76
June	411	143	120	263	-36.02	1.95	1.00	0.85	1.82
July	553	143	139	281	-49.08	2.31	1.00	0.82	1.73
August	630	157	117	273	-56.66	2.56	0.72	0.78	1.19
September	463	226	77	302	-34.74	2.56	1.00	0.69	1.63
October	254	291	38	329	29.79	1.09	1.00	0.44	1.37
November	210	338	24	362	72.86	0.86	1.00	0.46	1.23
December	208	437	15	451	116.76	0.81	1.00	0.27	1.27
Annual	**4,000**	**3,086**	**948**	**4,034**	**0.84**	**2.56**	**1.00**	**0.87**	**1.82**

The data presented in tabular format in Table 8 are also graphically depicted in Figures 31a and 31b.

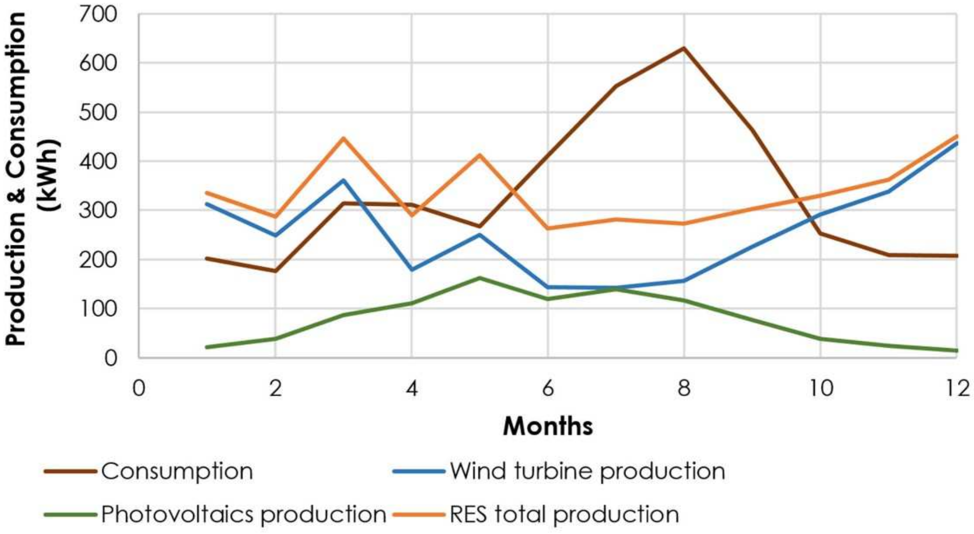


Figure 31a: *Monthly fluctuation of energy production and consumption for the second investigated scenario.*

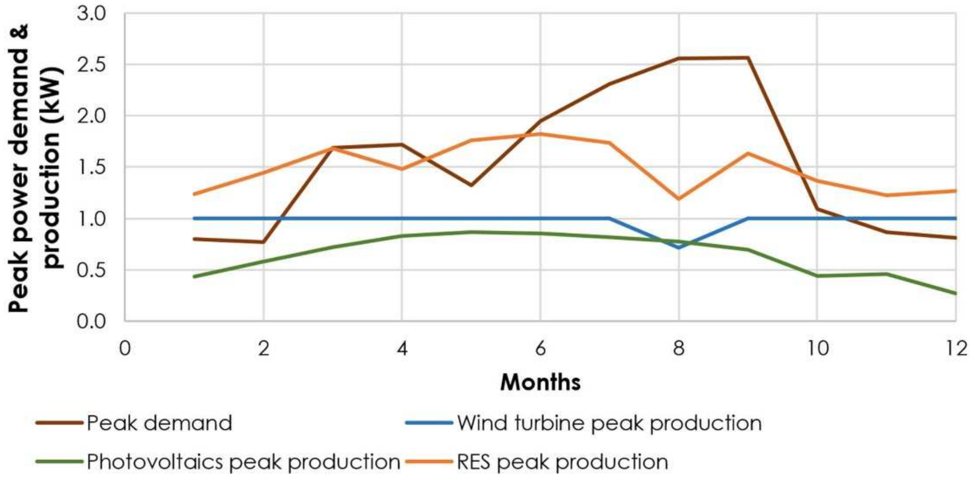


Figure 31b: *Monthly fluctuation of the peak power demand and production for the second investigated scenario.*

From the above figures and from Table 8 it is seen that the power demand for the charge of the two electrical mini-buses is mainly concentrated during summer. The wind turbine production is maximized during winter and the photovoltaics production is maximized, sensibly, during summer. There is considerable divergence between the available production and the power demand in summer. The total power production from the R.E.S. technologies remains almost constantly higher than the power demand during the year, apart from the summer period (July to September) when the power demand exceeds the current production.

Full energy transition in the transportation sector:

As seen in Table 6, in this case the annual electricity consumption particularly for the coverage of the electricity needs for the full energy transition in the transportation sector is calculated at 195,846 kWh. Regarding the potential electricity production from R.E.S. technologies:

- in section 2, the annual electricity production from a 50 kW wind turbine has been calculated at 243,267 kWh
- also, the installation of 290 kW_p of photovoltaic panels will produce on annual basis 196,345 kWh.

Obviously, the installation of one 50 kW wind turbine will be less expensive than the installation of 290 kW_p photovoltaic panels. Hence, even if the final electricity production is roughly 25% higher than the annual consumption, this choice seems to be the obvious one.

The annual fluctuation of the power demand and the power production from the involved wind turbine in this scenario is presented In Figure 32.

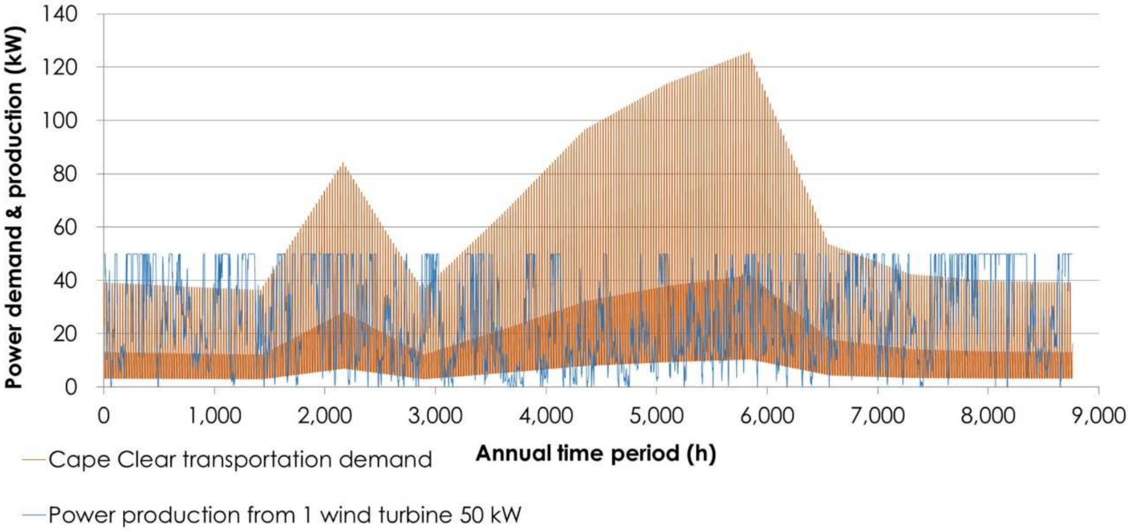


***Figure 32**: Annual fluctuation of the electrical power demand for the full energy transition in the transportation sector and the power production from a 50 kW wind turbine.*

In Table 9, the monthly variation of the energy production and consumption and the peak power production and demand is analysed.

The data presented in tabular format in Table 9 are also graphically depicted in Figure 33.

The conclusions from this third scenario are similar with the previous one. By observing Figures 32 and 33 and Table 8 it is seen that the power demand for the full energy transition in transportation sector in Cape Clear Island is mainly concentrated during summer. The wind turbine production is maximized during winter. There is considerable divergence between the available production and the power demand in summer. The total power production from the R.E.S. technologies remains almost constantly higher than the power demand during the year, apart from the summer period (July to September) when the power demand exceeds the current production.

Table 9: *Monthly analysis of the energy production and consumption and the corresponding peak power demand and production for the third investigated scenario in Cape Clear Island.*

Month	Consumption (kWh)	Wind turbine production (kWh)	Demand coverage percentage (%)	Peak demand (kW)	Wind turbine peak production (kW)
January	9,914	24,398	146.10	39.15	49.90
February	8,625	20,091	132.94	37.58	49.90
March	15,369	25,270	64.42	82.70	49.90
April	15,266	16,349	7.10	84.25	49.90
May	13,060	20,157	54.34	64.82	49.90
June	20,143	13,097	-34.98	95.44	49.90
July	27,062	13,840	-48.86	113.13	49.90
August	30,845	16,525	-46.42	125.21	49.90
September	22,684	19,478	-14.14	125.59	49.90
October	12,421	23,783	91.48	53.56	49.90
November	10,263	24,352	137.27	42.28	49.90
December	10,193	26,286	157.89	39.78	49.90
Annual	**195,846**	**243,627**	**24.40**	**125.59**	**49.90**

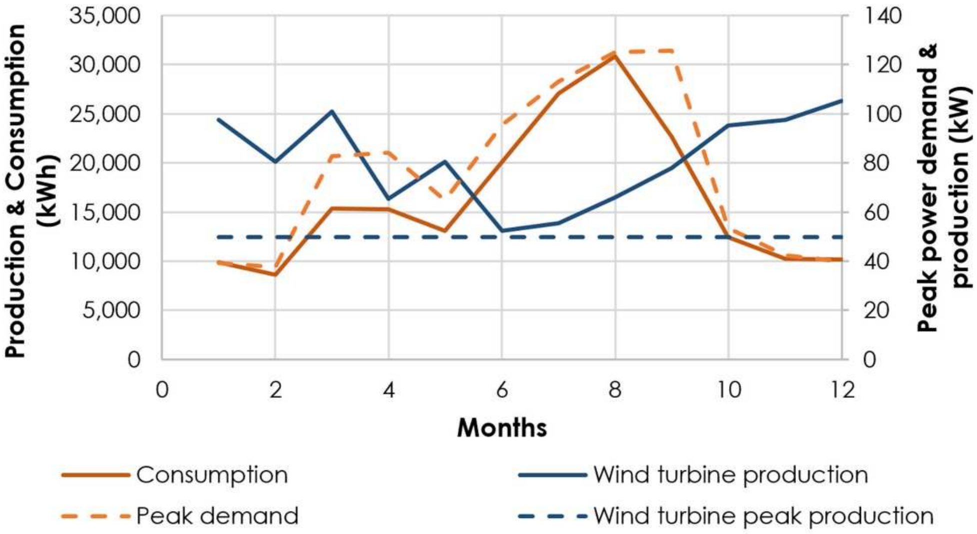


Figure 33: *Monthly fluctuation of energy production and consumption for the third investigated scenario.*

Full energy transition in Cape Clear Island:

In this last investigated scenario, all the onshore energy consumption in the island are transferred to the electrical grid. As seen in Table 6, in this case the annual electricity consumption is calculated at 720,608 kWh. Regarding the potential electricity production from R.E.S. technologies:

- in Table 3, it is shown that the annual electricity production from the first 3 wind turbines of 50 kW nominal power each equals at 714,562 kWh, with an annual capacity factor of 54.4%
- the remaining 720,608 – 714,562 = 6,046 kWh can be calculated with a photovoltaic station with nominal power of 10 kW_p, which will actually give on annual basis 6,770 kWh.

The annual fluctuation of the power demand and the power production from the involved wind turbine and photovoltaics in this scenario is presented In Figure 34.

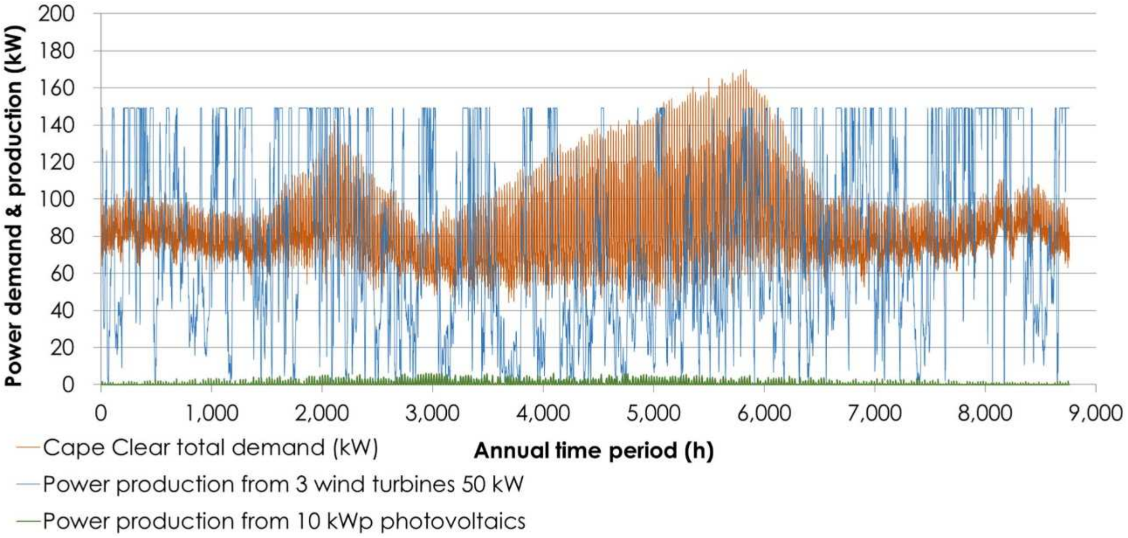


***Figure 34**: Annual fluctuation of the current electrical power demand and the power production from three 50 kW wind turbines and 10 kW_p photovoltaics.*

In Table 10, the monthly variation of the energy production and consumption and the peak power production and demand is analysed.

Table 10*: Monthly analysis of the energy production and consumption and the corresponding peak power demand and production for the fourth investigated scenario in Cape Clear Island.*

Month	Demand (kWh)	Production (kWh)			Demand coverage percentage (%)	Peak demand (kW)	Peak production (kW)		
	Consumption	Wind turbine production	Photovoltaics production	RES total production			Wind turbine peak production	Photovoltaics peak production	RES peak production
January	61,889	71,581	156	71,737	15.91	105.70	149.14	3.12	151.15
February	52,535	58,859	271	59,130	12.55	98.38	149.14	4.16	152.33
March	62,689	74,540	617	75,157	19.89	142.26	149.14	5.14	154.28
April	57,382	47,701	791	48,493	-15.49	135.39	149.14	5.91	153.04
May	51,559	59,034	1,162	60,197	16.75	106.43	149.14	6.18	155.32
June	56,390	38,327	856	39,183	-30.51	130.52	149.14	6.10	155.23
July	63,420	40,295	991	41,286	-34.90	147.37	149.14	5.85	154.78
August	70,745	47,851	832	48,683	-31.18	169.54	149.14	5.54	152.77
September	65,234	56,879	546	57,425	-11.97	169.56	149.14	4.95	154.09
October	57,492	69,601	272	69,873	21.53	104.73	149.14	3.13	151.83
November	57,620	71,670	172	71,842	24.68	103.09	149.14	3.26	151.46
December	63,653	78,224	104	78,327	23.05	110.90	149.14	1.92	151.05
Annual	**720,608**	**714,562**	**6,771**	**721,333**	**0.10**	**169.56**	**149.14**	**1.66**	**149.37**

The data presented in tabular format in Table 10 are also graphically depicted in Figures 35a and 35b.

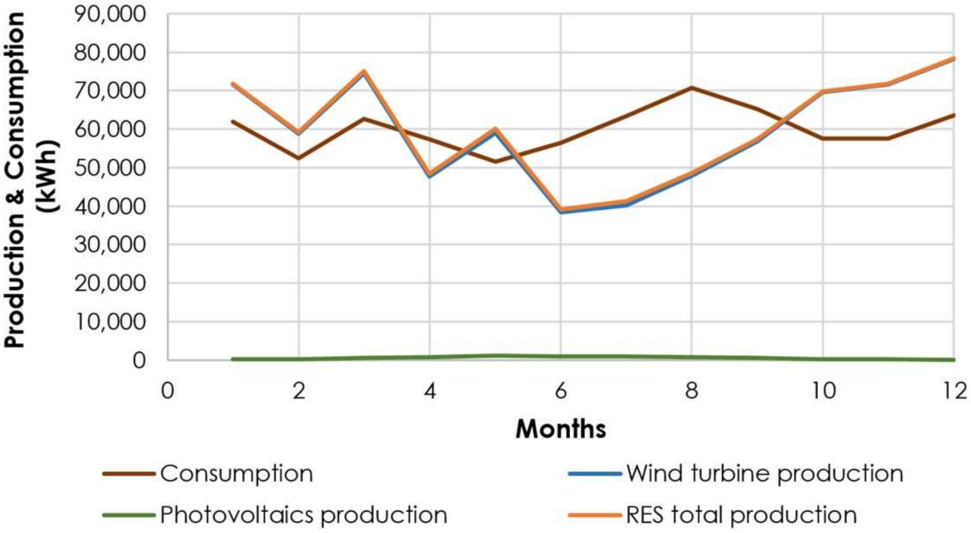


Figure 35a: *Monthly fluctuation of energy production and consumption for the fourth investigated scenario.*

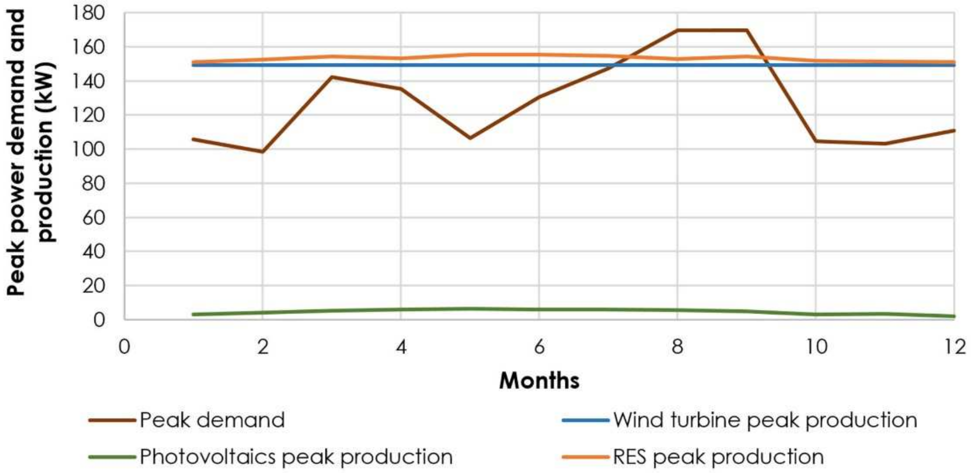


Figure 35b: *Monthly fluctuation of the peak power demand and production for the fourth investigated scenario.*

From the above figures and from Table 10 it is seen that the monthly coincidence of the electricity consumption and the production from the proposed R.E.S. technologies is quite satisfying. The photovoltaics' production is almost negligible. They are introduced to cover the small electricity production shortage of the wind turbines. They could be also avoided with the introduction of proper energy saving measures. The power production is mainly based on wind turbines. The high wind park's capacity factor enables the installation of relatively low R.E.S. power with regard to the peak power demand. The peak power demand and production are also quite balanced. This is favoured by the variety of the covered loads too. For example, the heating and the existing electricity demand increase during winter and drop during summer, unlike the demand for the transportation sector and the cooking loads, which are maximized during summer due to the increased number of residents in the island. The seasonal reverse fluctuation of these loads leads to a more smooth annual power demand profile, with regard to the previously investigated scenarios, enabling the approach of a better balance between the monthly average electricity consumption and production (Figure 35a).

Conclusions

Following the results of the above presented analysis, we could come to the following conclusions:

- The examined area is characterized with rich wind potential. The solar radiation is concentrated during the summer period.
- The interconnection of the island with the mainland Irish grid enables the coverage of the investigated energy loads only with R.E.S. technologies, namely without necessarily the support of storage devices. This leads to the achievement of the final goal, which is nothing else but the energy transition in Cape Clear Island, with the minimum possible set-up and operation cost of the required technologies. Power can be absorbed by the grid whenever the produced power on the island from the R.E.S. plants is lower than the current power demand. On the opposite case, the excess R.E.S. power production can be injected in the mainland Irish grid. The final goal is the annual production – consumption compensation.
- On the other hand, the introduction of storage devices will certainly equip the island with a back-up energy source, increasing the energy supply security and the reaction capacity on the island in case of supply interruptions from the mainland Irish grid. This option can be examined in a follow-up sequel of this report.
- Obviously the coverage of the full energy transition in the island will exhibit the optimum technical and economic indices, because of the more balanced power demand and production profiles. This is the case with the minimum energy transfers between the insular grid in Cape Clear Island and the mainland Irish grid, minimising also the involved energy transportation losses through the undersea interconnection cable. On the other side, the worst case scenario regarding the time coincidence of power production and demand is the sole coverage of the transportation sector demand.

To conclude with, the achievement of high Renewable Energy Sources (RES) penetration in Cape Clear Island seems to be an achievable target, mainly due to the high available wind potential. Photovoltaic panels can be introduced supportively, aiming to supplement any wind power production shortages regarding the power demand. The interconnection of the Cape Clear Island with the mainland Irish grid enables the avoidance of the installation of storage devices, which would increase the total set-up cost of the whole system significantly.

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