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Final Programme Report: CEDR Call 2019 Renewable Energy in Road Infrastructure

ENROAD

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CEDR Call 2019 Renewable Energy in Road Infrastructure Final Programme Report

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by

Pablo Pascual-Muñoz (University of Cantabria), Francisco Somohano-Rodríguez (University of Cantabria), Irune Indacoechea-Vega (University of Cantabria), René Barrera-Cárdenas (SINTEF Energi), Javier Antón (ARUP), Hrefna Run Vignisdottir (SINTEF AS)

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1. Executive Summary

The ENROAD project "Supporting the implementation by NRAs of renewable energy technologies in road infrastructure" is a pioneering initiative funded through the Transnational Road Research Programme, Call 2019 “Renewable Energy in Road Infrastructure”, of the Conference of European Directors of Roads (CEDR). This collaborative effort has been carried out by a consortium formed by ARUP, SINTEF Energi, SINTEF AS, and the University of Cantabria, the latter being the Project Coordinator.

At its core, the ENROAD project is driven to furnish National Road Authorities (NRAs) with technical and regulatory knowledge as a basis to build a user-friendly tool carefully designed to facilitate the long-term seamless integration of renewable energy (RE) technologies into the road infrastructure. This material is intended to optimize both economic and environmental benefits, thereby providing the NRAs with the means to chart cost-effective pathways towards their decarbonization aspirations.

The rationale for this initiative stems from a deep recognition of the challenges of conventional methods of electricity generation, in particular the twin predicament of resource depletion and environmental degradation engendered by the extraction, refining and combustion of the necessary fossil fuels. In response, the European Union has consistently undertaken initiatives to promote the adoption and use of clean and renewable energy sources. Meanwhile, NRAs have a large area of land presumably available for energy generation, which represents a tangible opportunity to improve the environmental impact of the road construction, maintenance and operation.

To catalyse the implementations of RE projects, the ENROAD project adopts a multi-faceted approach, which includes the identification of typical NRA asset topologies and a comprehensive survey of existing renewable technologies suitable for energy generation, and a review of the energy storage systems that are potentially applicable by NRAs. Notably, wind energy (small and large scale) and solar PV energy generation emerge as frontrunners in this project. Furthermore, an exhaustive analysis of prevailing and prospective regulations across targeted nations, alongside stakeholder consultations, was undertaken to obtain information on existing opportunities, challenges, and regulatory frameworks.

Another important aspect of the ENROAD project is the development of an innovative software solution —an advanced GIS-based decision-making tool— meticulously engineered to facilitate a first approach to NRAs in the selection of RE technologies and locations. This decision-making framework, supported by a detailed Excel template, integrates a diverse array of technical, economic and environmental criteria. In particular, this tool allows NRAs to navigate through various stages of project conception, enabling a comprehensive analysis that includes four key aspects: the identification of optimal locations, estimation of potential energy generation, selection of RE technologies, and assessment of their cost-efficiency and financial viability. Within this framework, two generic business models emerge: one is based on energy demand response (the identification of NRAs energy needs), involving self-consumption and surplus storage, while the other revolves around energy supply response, involving the sale of generated energy to the grid.

Once locations have been determined, the characterization of parameters is performed on the basis of public databases detailing solar and wind resources of each location. Subsequent calculations, executed through the Excel template, yield technical outcomes such as peak power and annual energy production

under specific conditions. Furthermore, advanced users can proceed through a sequence of actions that includes collecting energy market data, estimating capital and operational costs, projecting revenues and savings, and finally assessing economic performance and financial viability.

Moreover, the project endeavoured to develop implementation guidelines, organise workshops and develop e-learning modules to speed up the uptake and adoption of ENROAD results by the NRAs. Also, it is important to emphasise that the GIS-based ENROAD tool, while an invaluable asset, represents a preliminary exploration into the realm of potential analysis. As such, end-users are duly cautioned that the data and calculations resulting from it are illustrative and are intended to inform future planning and resource allocation by NRAs.

In short, the ENROAD project is a coordinated effort to promote sustainability through the integration of renewable energies, progressively improving the environmental impact of the road infrastructures and fostering the electrification of the transport sector. The GIS-based user-friendly approach considered for the ENROAD tool represents one step forward in the planning and execution of RE initiatives within road infrastructure. Thus, this systematic approach not only optimizes resource efficiency but also allows informed decision-making by NRAs, thereby contributing to a more sustainable integration of renewable energy technologies into the fabric of modern transportation networks.

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LIST OF ACRONYMS

AEP	Annual Energy Production
AARR	Average Annual Rate of Return
CAPEX	Capital Expenditure
CSS	Cascading Style Sheets
DEGS	Distributed Energy Generation System
DHI	Diffuse Horizontal Irradiance
DNI	Direct Beam/Normal Irradiation
ESS	Energy Storage System
GHI	Global Horizontal Irradiation
GIS	Geographical Information System
GLP	General Public License
GNU	GNU's Not Unix
HAWT	Horizontal Axis Wind Turbine
HTML	Hypertext Markup Language
IRR	Internal Rate of Return
JS	JavaScript
LCA	Life Cycle Analysis
LCOE	Levelized Cost of Energy
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MRL	Market Readiness Level
NMOT	Nominal Module Operating Temperature
NPV	Net Present Value
NRA	National Road Administration
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
O&M	Operation & Maintenance
OPEX	Operational Expenditure
PDF	Probability Distribution Function
PV	Photovoltaic
RE	Renewable Energy
RET	Renewable Energy Technology
REGS	Renewable Energy Generation System
STC	Standard Test Conditions
TMY	Typical Meteorological Year
TRL	Technical Readiness Level
TCC	Total Capital Cost
UTC	Universal Time Coordinated
UX	User Experience
VAWT	Vertical Axis Wind Turbine
WMS	Web Mapping Service
WT	Wind Turbine

INTRODUCTION

This document contains a detailed summary of the work carried out by ARUP, SINTEF Energi, SINTEF AS and the UNIVERSITY of CANTABRIA (Project Coordinator) for the development of the project "Supporting the implementation by NRAs of renewable energy technologies in the road infrastructure (ENROAD)", funded under the Transnational Road Research Programme, Call 2019 Renewable Energy in Road Infrastructure, of the Conference of European Directors of Roads (CEDR).

The contents here referred are based on the successful development and continuous assessment by the Programme Executive Board (PEB) of the technical deliverables and milestones reported throughout the development of the Project. Also, a chapter has been dedicated to the compilation of the questions and answers derived from the discussion that took place after the presentation of the project results at the Final Conference, which was held on October 24, 2023 at Arup's HQ in Madrid, Spain.

1. SELECTION OF RE TECHNOLOGIES FOR NRAs

1.1. INTRODUCTION TO CONVENTIONAL AND BUILT-IN RETs SUITABLE FOR NRAs

The most suitable renewable energy technologies for implementation by NRA along the road asset were introduced in *Deliverable 2.1 "Report of main renewable energy technologies for the road infrastructure"* and the main outcomes of that document summarized in *Deliverable 6.2 "Implementation Guide"*. More specifically, the conventional RETs (Figures 1 and 2) covered in those deliverables were:

- Wind Energy (VAWT & HAWT)
  - Small scale (microturbines)
  - Large scale (0.8 – 15 MW)
- Solar PV Energy
- Mini Hydro Energy
- Micro-scale Biomass Power Plants

Figure 1.- Wild Horse wind farm, Washington (Goebel, 2014)

Figure 2.- Solar highway installation in Augusta, Maine, built by Maine DOT. Source: Maine DOT (2023)

Along with their fundamentals, most important parameters involved were highlighted specially for wind and solar PV systems, for further selection of the RETs to be included in the ENROAD GIS-based tool: main functionalities, components and typologies, performance, location and distances to be considered (when required) or cleaning and maintenance considerations.

In addition to the conventional energy sources and technologies that can be used for the generation of renewable clean energy, in the last few years a good number of institutions have been doing research on less conventional forms of harvesting energy -electricity- in roads. The fact that roads are continuously subjected to solar radiation and vehicle loads makes it possible the energy harvesting phenomenon: the generation of small amounts of power from unused and/or wasted energy. If properly implemented, the harvesting of this energy, which would otherwise be dissipated in roads in the form of heat, vibration or deformation, can supply electricity to streetlights, traffic lights or sensors to monitor the condition of structures.

Based on the framework of this project, the following road energy harvesting systems were discussed in *Deliverable 2.1* and summarized in *Deliverable 6.2* according to the most recent technical literature:

- Solar energy harvesting:
  - Solar PV in roads
  - Thermoelectricity generation (mostly thermoelectric generators, TEGs)
- Kinetic energy harvesting:
  - Piezoelectric energy harvesting (mostly piezoelectric energy harvesters, PEHs)
  - Electromechanical or EM generation

These technologies have been proved to perform when installed within the road asset, which means that renewable energy is actually generated by using these devices. As for the solar energy harvesting, not only will these systems provide some energy but will also help to mitigate the harmful effects of the heat on the pavement by removing it. Thus, important problems such as plastic deformation of roads (rutting), bitumen aging and hence, roads durability, or even the well-known urban heat island (UHI) effect might be alleviated by removing part of the heat accumulated in the upper layers of the road pavement. So, even if the low performance and low energy generation capacity of the road-related energy harvesting technologies turn them into technologies difficult to apply at a commercial large scale, their use in a near future is plausible.

1.2. SURVEY FOR NRAs ON IMPLEMENTATION OF RETs

Design and Participants

The survey was designed and sent to several different NRAs stakeholders in the EU in order to: 1) test their interest on the topic; 2) Collect information about their environmental targets, if any; 3) collect their opinion on the criteria used for the selection of RETs, topology and locations; 4) collect information about previous experiences on the topic.

For the design of the survey, the simplest and minimum possible number of questions were generated in order to maximize the number of participants and collect as much information as possible. Likewise, the professional free software *Limesurvey* was used so that the survey could be filled out and the answers sent from a computer or even the mobile phone. The 12 questions proposed are listed below:

Q1. Does your organization have internal targets to reduce energy use and/or GHG emissions?

Q2. Does your organization currently generate Renewable Energy along the road asset?

Q3. Which were the main reasons for the investment in RETs? Check all that apply?

Q4. Is your organization considering the generation of RE along the road asset?

Q5. **In your opinion, what is the main barrier stopping the NRAs from investing on RE technologies?**

Q6. **Do you think that a decision support tool would be of help for NRAs to move forward?**

Q7. **How is, in your opinion, the social acceptance in your country of RETs within the road assets?**

Q8. **Which of the following RETs would you consider for implementation? Check all that apply.**

Q9. **For which of the following energy consumers would be the RE used? Check all that apply.**

Q10. **Which of the following road topologies would you consider for the RETs? Check all that apply.**

Q11. **Which of the following criteria would you use for the selection of RETs? Check all that apply.**

Q12. **Which of the following criteria would you use for the location of RETs? Check all that apply.**

** Q3 & Q4 Only if the answer to Q2 was "Yes"*

The link to the survey, along with a short introduction to ENROAD project, was sent to representatives of NRAs of the following 28 European countries: Spain, France, Italy, Belgium, Ireland, Sweden, Denmark, The Netherlands, Norway, Germany, Austria, Portugal, Hungary, Rumania, Poland, Luxembourg, Latvia, UK, Switzerland, Finland, Czech Republic, Liechtenstein, Estonia, Bulgaria, Slovenia, Iceland, Lithuania and Malta. More than 100 emails were sent to the different representatives.

Main results from the survey

Out of the 28 European NRAs surveyed, at least one representative of 16 countries sent a full answer to the survey: Spain, Italy, Belgium, Ireland, Sweden, The Netherlands, Norway, Germany, Austria, Latvia, UK, Portugal, Hungary, Denmark, Switzerland and Luxembourg. This means that 60% of the organizations surveyed sent a full answer to the questionnaire. It should be highlighted that these are not necessarily official responses from the NRAs but mere contributions to this project by people involved to a certain extent in the management of the road infrastructure (i.e., road managers, heads of technology, strategic advisors, etc.).

The answers revealed very different and interesting results, some of which are summarized here:

- While 75% of the European countries surveyed have internal targets to reduce the energy use or GHG emissions, only half of them currently generate electricity from renewable sources within the NRAs lands/assets.
- Savings in electricity cost and social demand were the most preferred reasons for the investment in RETs by all the countries that answered Yes to Q2, but followed very closely by the reduction of GHG emissions and fossil fuels. To power active devices on the road network in a sustainable way, or the lack of power supply in remote locations were other reasons given.
- With respect to main barriers preventing the NRAs from investing on RE technologies, results are very clear, with economic and regulatory barriers taking the top two positions (Figure 3). Cost of investment, long authorization or administrative procedures, no feed-in tariffs for public bodies or not being primary purpose for NRAs are some of the specific answers obtained.
- More than half of the countries that are not currently generating RE along the road asset do not plan to do so in the near future.

- More than 85% of the respondents estimate that the social acceptance of using RETs within the road assets in their country is high (43%) or medium (43%).

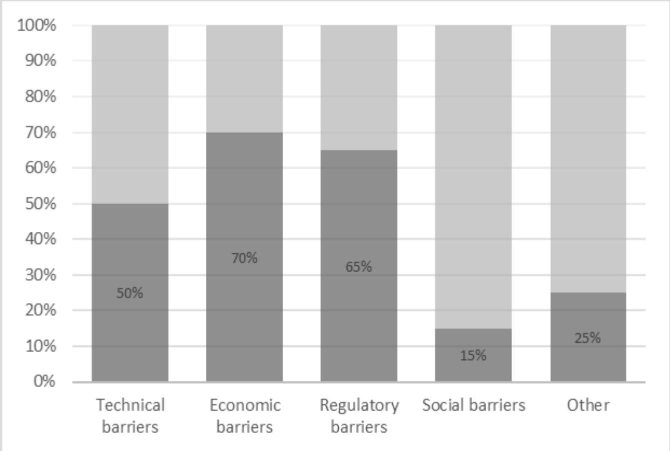

Figure 3.- Results to question Q5 of the survey

- To the question regarding the RETs that NRAs would consider for their implementation, answers are clearly in line with the implementation of small scale RETs, more specifically small PV systems, with more than 90% of the countries voting for it. Small wind turbines (55%) and large PV systems (45%) also seem to be within the preferences of the NRAs representatives. On the other hand, small hydro or micro biomass are far from being an option (Figure 4).
- Road lighting (75%) and tunnel lighting (70%) are the most preferred energy consumers (Q9) for using the RE generated along the road network, closely followed by others like EV charging (69%) or information panels (63%).
- Rest areas (80%), canopies (75%), signals and panels (65%) and roofs (60%) were defined by the respondents as the most convenient topologies for the installation of the RETs. On the other hand, lakes, rivers and channels were the less voted option. This is somehow consistent with the RETs mostly considered by the NRAs for their implementation along the road asset.

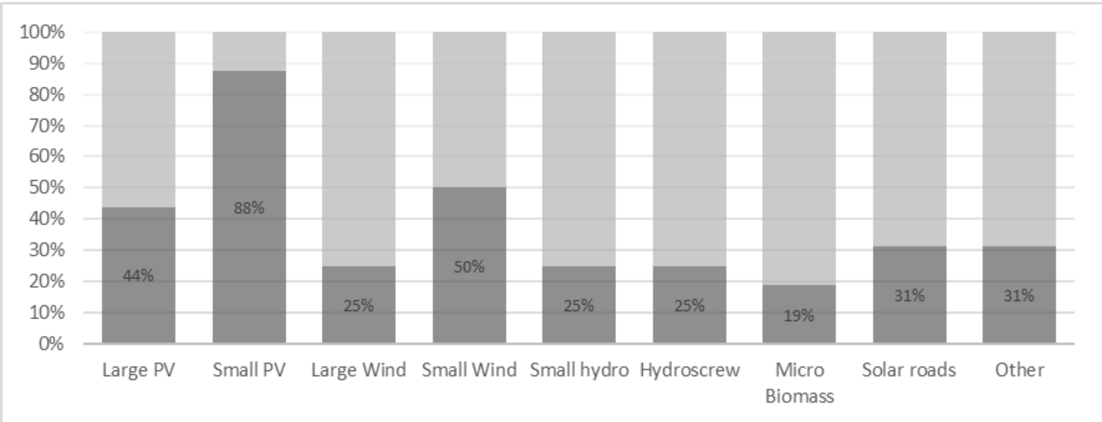

Figure 4.- Results to question Q8 of the survey

- Cost of installation, cost of maintenance, environmental impact and Life Cycle Cost are the criteria that most of NRAs would use for the selection of RETs, with over 70% of representatives voting for them (Figure 5).

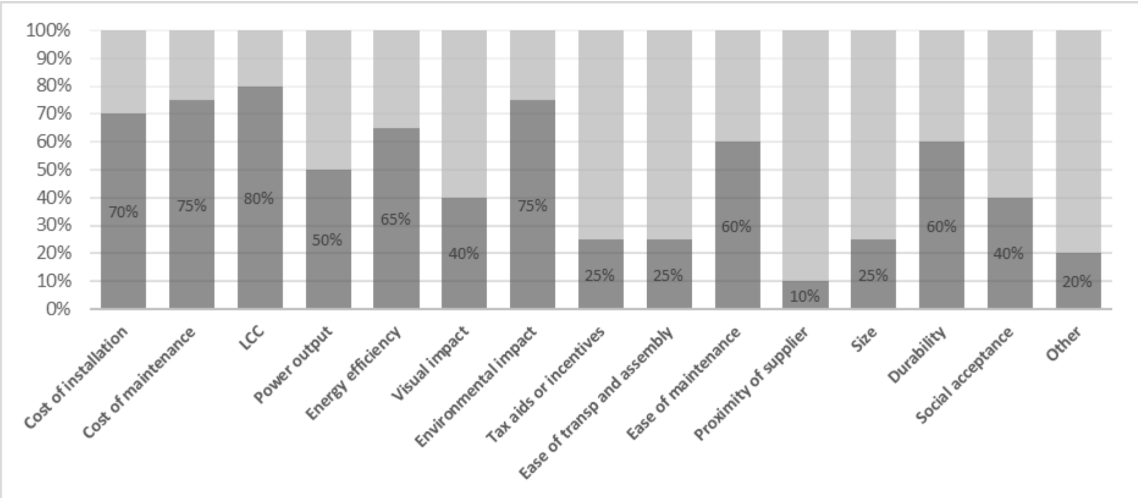

Figure 5.- Results to question Q11 of the survey

- Avoiding traffic disruption, impact on road safety and distance to the road would be the criteria used for the location of the RE technologies, which is definitely in line with the nature of the NRAs and the fact that lowering the impact to the road and traffic is a major concern for them.

1.3. EXISTING EXPERIENCES WORLWIDE

In order to determine potential topologies and locations for the implementation of RETs by the NRAs, a detailed search of previous experiences was carried out including scientific papers, technical papers and brochures, websites, repositories, etc. A list with the most significant experiences worldwide found so far was presented in *Deliverable 2.1.* Size, power output or energy supplied were considered, but also parameters such as maintenance events, social importance, amount of information found, topology and location. Very small installations and old unattended installations have been omitted.

According to the inventory of current experiences found, the following 4 main groups were made based on the technology and topology involved:

- Solar PV panels integrated into the road pavement (a.k.a. solar roads).
- Solar PV panels integrated into the noise barriers (a.k.a. PVNB).
- Solar PV panels/wind turbines in big areas aside or out of the road.
- Solar PV panels/microturbines in rooftops of buildings or infrastructures.

Below is a very brief summary of some of the experiences identified to the date of delivery of *Deliverable 2.1*, along with other relevant information.

PV Panels integrated into the road pavement (Solar Roads)

- At the time of the study, only a few countries were identified as hosts of this type of renewable energy technology: France, Germany, The Netherlands, Luxembourg, China and USA.
- The first stretch of the company SolaRoad was built in Krommenie, province of Noord-Holland, in October 2014 (Figure 6). It was 90 m long and was built as a bike path. The partners were: TNO, Ooms Civiel, Imtech Traffic & Infra, and the Province of Noord-Holland. Total cost was €3.5M,

€1.5M of which were provided by the province of Noord-Holland.

- Similar technology and construction process were used for other SolaRoad facilities, of which the most significant were a 50 m long road with heavy traffic in Haarlemmermeer, and a 100 m bus lane in Spijkenisse. The electricity was to be delivered to the grid (TNO, 2019; SolaRoad, 2021).
- A very well-known 1 km road stretch with 2800 m^2 of Wattway PV panels was built in Tourouvre, France, in 2016 (Figure 6). With a maximum power output of 420 kW, this facility was aimed at generating 280 MWh/year (Patel, 2017). Financed by the Ministry of Environment, the project had a cost of €5M. The cost per 1 kW was about 17€, too expensive when compared to the 1.3€ cost of a conventional solar facility at the time (Pultarova, 2017).

Figure 6.- SolaRoad in Krommenie in TN (SolaRoad, 2021) and Solar road in France (The Guardian, 2016)

- In 2018, BAM built two sections in The Netherlands: 50 m2 stretch with Wattway technology on the N401 near Kockengen (Utrecht) that was claimed to generate enough energy to power a household for 1 year (BAM1, 2018); and a 20 m^2 strip of PV panels on an emergency lane of the A2 road (Rijkswaterstaat, 2021). According to Gerben van Bijnen, Hoofduitvoerder at BAM Infra, test goals were achieved the first section and two other sections were built that are still running: a bridge deck (35 m^2) and bike path (30 m^2) in Hengelo and Grave, respectively (Figure 7).

Figure 7.- N401 road, A2 motorway, Hengelo and Grave, NL. Source: BAM

- In recent years, other small Wattway installations have been built in Europe for applications such as EV and bike charging. As for the situation overseas, two small test sections have been built in Georgia (USA) in the last few years and a flagship project was carried out in China in 2018.
- A 50 m^2 stretch was built in Georgia (USA) in December 2016 by The Ray in partnership with GDOT and Hannah Solar. This section was located next to the Visitor Information Center in West Point, part of which is powered by the solar road (Ray, 2016). According to The Ray, ≈ 8400 kWh were

generated in 1 year, enough to drive a single EV more than 50000 km (Ray, 2019-1).

- A solar road stretch was installed in 2020 in the city of Peachtree Corners (Georgia), on a section of an autonomous vehicle test lane in the city's Curiosity Lab. The energy generated, about 1300 kWh of electricity per year according to the company, is used to supply an EV charging station at the City Hall that is available to EV motorists at no cost.

PV Panels integrated into the noise barriers (PVNB)

- The world's first PVNB came into use in 1989 in the municipality of Domat/Ems, Switzerland, along the A13 road. This 103 kWp installation was supported by the Swiss Federal Roads Office (FEDRO) and built by the TNC AG (Switzerland). The solar panels are fixed to a 2 m tall structure mounted at the top part of the 800 m long barrier (Poe et al., 2017).
- Another relevant PVNB was built in Aubrugg, near Zürich, in 1997. This 8 kWp installation was the world's first bifacial PVNB and consisted of sound-reflecting PV modules designed by ASE GmbH (Figure 10). Initially 100 m long and 1.5 m high, in 2005 the barrier was expanded and update with more efficient bifacial cells (Nordmann and Clavadetscher, 2004; SEAC, 2015).
- A 1650 m long grid connected PVNB, with PV area of ≈2200 m^2, was built along the A9 highway, near Ouderkerk aan de Amstel, in The Netherlands. It was a ≈220 kWp system comprised of 2160 c-Si modules on top of a barrier with tilt angle of 50°. The PVNB was financially supported by the EC and the Netherlands Agency for Energy and Environment (Jochems, 2013; Nordmann and Clavadetscher, 2004; Van der Borg and Jansen, 2001).
- In 2003 the world largest PVNB was installed in Freising (Germany), along the A92 highway. This 6000 m^2 and 1200 m long barrier (Figure 8) was the first in which ceramic-based PV modules with noise reduction properties were used and no conventional barrier was needed (Jochems, 2013; Grottke et al., 2003). The barrier is able to produce ca. 620 kW of electricity, which is sold back to the grid (Kotzen and English, 2009).
- The PVNB in Marano d'Isera (Italy), commissioned and exploited by Autostrada del Brennero SpA, is 1067 m long and 5.6 m high, and consists of 5000 m^2 of standard c-Si modules (Figure 8). With 730 kWp power capacity and energy generation of 690 MWh/year, this is one of the largest in the world. Electricity is fed into a medium-voltage 20 kV grid (SEAC, 2015; Jochems, 2013).


Figure 8.- PVNBs in Fresing, Germany (Wikimedia, 2011) and Marano d'Isera, Italy (Autobrennero, 2009)

- A new bifacial PVNB was installed along the A50 road near Uden (TN) in 2020 in the context of the Solar Highways Life+ project (Solar Highways, 2021). With a total budget of ≈5M€ and carried out by Rijkswaterstaat and TNO, it was built by Heijmans (Figure 9). The 400 m long PV noise barrier consists of 4 m high PV panels and the energy generated is fed into the grid. To date, this barrier remains largest bifacial solar noise barrier in the world (SH Final, 2020). During the 18-month monitoring, 325 MWh were generated, with an overall performance ratio of ≈74%.
- Two experimental PVNBs have been installed in Genk (Belgium) and Rosmalen (The Netherlands) in the context of the Rolling Solar project (Figure 9). The PVNB in Rosmalen is 12 meters wide and is formed by 5 cassettes, 1 meter high each, on top of a 1-meter plinth. Two of the cassettes contain bifacial crystalline modules, one thin film CdTe modules and the remaining two contain double-sided thin film CIGS modules. The tests started in 2021 (Rolling Solar 2, 2021).

Figure 9.- PVNB in Uden (Solar Highways, 2020) and Rosmalen (Rolling Solar, 2021).

- A 500 m long PVNB was built in Australia powered by the Roads Corporation of Victoria (VicRoads) and located at a highway near Melbourne Airport. The PV systems consists of 210 a-Si modules vertically integrated on top of a 4 meters high noise barrier, all of them amounting a total power output of 24 kWp. The electricity generated is fed into the grid (Poe et al., 2017).

PV Panels and/or wind turbines in big areas aside our out of the road and/or buildings

- Several projects have been developed in the last few years for the installation of mostly large PV panels but also wind turbines. Most of them were implemented in the lands of the US DOTs that are close to electrical loads. In terms of road topology, panels or turbines have been installed: aside the road, in rest areas, service areas, aside buildings, depots or even former gravel sites.
- In 2008, the Oregon Solar Highway Program of Oregon Department of Transportation (ODOT) finished the first demonstration project in the US: a PV system with almost 600 panels and a total capacity of 104 kW at the interchange of Interstate 5 and Interstate 205 near Portland. The energy produced was fed into the grid during the day and flew back to illuminate the infrastructure. The project is a PPP between ODOT and Portland General Electric (ODOT, 2016).
- In 2012, the Baldock Solar Station was built at the French Prairie safety rest area, on Interstate 5 in Clackamas County (Oregon). The PV farm consisted of 7000 panels, had a capacity of 1.75 MW and was able to generate 1.97 GWh on an annual basis (Figure 10). The farm was developed in PPP and the electricity is used by PGE to serve its customers, including ODOT. In return for the

land, ODOT receives an annual fee and a percentage of RECs (ODOT, 2016; Innovative, 2021).

- Several actions have been taken by the Massachusetts Department of Transportation (MassDOT) in the last 15 years regarding the use of RETs along the road asset. In 2019, projects at eight sites were completed amounting a total capacity of 4.3 MW. MassDOT expected to save $525,000 a year, in addition to the $75,000 received in annual lease payments, as projects were developed in the framework of a PPP for which MassDOT leased the sites 20 years and agreed to purchase the energy generated through power purchase agreements (Hodges and Plovnick, 2019).
- A solar array was set up in 2019 at the Exit 14 of the Interstate 85, in Georgia (Figure 10). This was the Southeast's first ROW project and was carried out by the Georgia DOT, Georgia Public Service Commission, Georgia Power, Electric Power Research Institute and The Ray. With a 1 MW capacity, the system counted on 2600 panels. Georgia Power signed a 35-year license with Georgia DOT for its exploitation. The total cost was of ≈ $3 million (Ray, 2018; Ray, 2019-2).
- A solar garden was developed by Novel Energy Solutions near the Interstate 94 in Afton (Figure 10), on a land owned by Minnesota DOT. An area of 11 acres of a former gravel pit was used for the location of a PV farm with 3 MW capacity that provides MnDOT with a $500 lease payment per acre and energy savings from the RE produced (MnDOT, 2020; Twin, 2020; Afton, 2020).


Figure 10.- Baldock Station, Georgia (Innovative, 2021) and Solar Garden, Minnesota (MnDOT, 2020)

- In 2015, the "Wind Train" project involved the construction of a wind farm to power a high-speed rail line between Leuven and Liège, in Belgium. The Greensky park is located along the rail line and the E40 highway and nowadays consists of 16 turbines, 2 MW each. The Park was built in partnership between Electrabel, Société Intercommunale Bruxelloise pour l'Électricité, city of Saint-Trond and Infrabel. Part of this energy goes to power the rail network, whereas the rest is fed into the grid. (Infrabel, 2015; Power Links, 2015; Renewables Now, 2017).

Solar PV panels/microturbines in rooftops of buildings or infrastructures

- Many small size PV panels have been installed in building rooftops, parking canopies or lands next to buildings facilities. Some examples are: the rooftop of the Utah DOT Calvin Rampton Complex, among many others (Blue Sky, 2021; UDOT, 2018); Ohio DOT's maintenance facility in Northwood, adjacent to the highway ROW, along the I-68 (Alternative ROW, 2012); or the solar canopy at the MassDOT Research and Material Lab in Hopkinton off of the I-90 (ROW, 2017).

- Turbines with 1.8, 1.2 x 2 and 32 kW power capacities were installed at Missouri, Utah and Ohio DOT's facilities, respectively. A tower-mounted 32 kW horizontal-axis turbine was placed at the maintenance facility of the Ohio DOT in Northwood, which was sized to meet 65% of the annual electric load of the 5400 m^2 building. With a cost of $200,000 and payback of 12 to 16 years, main concern was about timely maintenance and parts availability (NCHRP, 2013).
- A 2.7 km tunnel along the A3 highway near Aschaffenburg (Germany) was completely covered by PV panels in 2009. It was the largest PV system implemented in the road infrastructure, with a capacity of ≈2.7 MWp (Jochems, 2013; Volpe, 2012).
- A PV system consisting of 16000 monocrystalline PV panels was installed on the roof of a 3.4 km long railway tunnel between Antwerp and the Dutch border along the E19 highway (Figure 16). With 245 Wp per panel, the system was completed in 2011, amounted a total capacity of 4 MWp, had a cost of about 15M€, and a production of 3.3 GWh per year was expected. This energy was planned to be used directly by the trains (Reuters, 2011; Renewables Now, 2010).

No serious maintenance problems (to the knowledge of the authors of this document) have been reported in the more recent experiences here referred. Further information about the monitoring of some of these experiences can be found in *Deliverable 2.1*.

1.4. CONCLUSIONS AND RECOMMENDATIONS

Roadside renewable energy technologies have been here referred as conventional technologies that could be installed by NRAs along the road asset: solar PV, wind turbines, small hydro and micro-scale biomass power plants. In Table 1, TRL and MRL levels for the existing technologies are presented. The estimation of the TRL levels has been based on the actual definition of the methodology (level of development and maturity of the technology) and it has been made in consonance with the expertise level of the members of the University of Cantabria as well as with the information reported by the study *"Guidance on TRL for renewable energy technologies"*, issued by the European Commission. An accurate estimation for the MRL is not as straightforward as very specific information of the technologies has to be known. For this reason, a simpler indirect criterion has been used: number of manufacturers found.

Table 1.- Technology and Market Readiness Levels for the conventional RETs

Technologies		TRL	MRL
Wind Turbines (Large and small generation)	Three-bladed	9	9
	Savonius	8	7
	Darrieus	8	7
	Venturi	7	2
	Small three-bladed	9	9
	Vortex	5	1
Photovoltaic (PV)	Silicon Monocrystalline	9	9
	Silicon Polycrystalline	9	9
	Silicon Amorphous	9	9
	Thin film technologies	8	6
	Multi-junction	5	2
	Organic	5	2
Mini Hydro	Pelton	9	9
	Francis	9	9
	Kaplan	9	9
	Ossberger	9	8
	Turgo	9	8
Micro-Scale Biomass	Micro-Scale CHP plants	8-9	5-6

Based on the fact that the ENROAD project is focused on high TRL technologies and medium to high MRL market status, the following conclusions could be drawn:

- Even if large wind energy generation along the road asset is possible, planning, construction, maintenance and end-of-life of these devices are of course to be highly considered. As for the small-scale generation, any of the technologies considered can be used except for Vortex, which is still under development. Savonius turbines are actually an in-use technology, but their energy performance is much lower than the others' performance.

- All the solar PV technologies considered could be used except for the Multi-junction and Organic technologies, both of which are still under development. The multi-junction technology has a very high cost and very high cost/efficiency ratio, reason for which devices with this technology have been used only in very specific situations so far.
- Large-scale hydro is obviously discarded for the purpose of the ENROAD, while all the mini hydro technologies are suitable for their use in small-scale hydro power plants, including the Ossberger and Turgo turbines, which are actually variations of the most very well-known ones.
- In the last few years there seems to be a growing interest on the development of the Micro-Scale biomass CHP plants, and even if this is a promising technology for its installation in large buildings, there is still work to do both in terms of technology and commercialization.

TRL levels for built-in or non-conventional RETs have been gathered from the technical literature, while MRL levels can never be higher than 2-3 for all the technologies when used in roads. In Table 2, values of TRL and MRL for the energy harvesting technologies and the solar roads (built-in PV panels) are shown.

Table 2.- Technology and Market Readiness Levels for the non-conventional RETs

Technology	TRL	MRL	References
Solar PV roads	8-9	2-3	Jiang et al. (2017); Wang et al. (2019); Zabihi and Saafi (2020)
Thermoelectric	3	1-2	Jiang et al. (2017); Wang et al. (2019); Zabihi and Saafi (2020)
Piezoelectric	4	1-2	Jiang et al. (2017); Wang et al. (2019); Zabihi and Saafi (2020)
Electromagnetic	3-4	1-2	Wang et al. (2019); Zabihi and Saafi (2020)

Based on the low TRL and MRL levels of the energy harvesting technologies, the following considerations could be made in the context of the ENROAD project:

- The development of solar PV roads clearly stands out from the other renewable energy harvesting technologies. However, while they are based on a very advanced technology like the PV and make use of the incident solar radiation, the other technologies harvest the energy wasted by vehicles. Therefore, the four technologies are not fully comparable.
- According to the technical literature consulted, the low TRL values of the technologies (except for the solar PV roads) are due to the very low conversion efficiencies as well as the fact the no proper large-scale experimental tests have been done.

Apart from those coming from TRL and MRL levels, other conclusions can be drawn regarding the use of conventional and non-conventional RETs and the road topologies where they must be implemented:

- The proximity to the road of large-scale wind turbines is something to be taken into account due to potential safety issues, particularly those coming from the fall of ice from the blades and the fall of the blades themselves, but also the noise generated. For this, a certain distance to the road should be kept that mitigates that risk. A minimum 100 m distance has been reported as resulted from a very interesting study carried out in Denmark in 2012, but further research should be done in case of installations along and close to the road.
- Photovoltaics (PV) is no doubt the most versatile technology for application along the road asset:

it can be implemented in the form of PV systems (solar farms) in service areas, rest areas or in the roadside; solar canopies of parking lots; solar panels in cut slopes or noise barriers; small modules on traffic signals, etc. Cleaning and maintenance operations are of paramount importance due to the potential decrease in the energy efficiency of the installations caused by dust, bird droppings, exhaust emissions or tree leaves, among others.

- Accessibility to the energy installation is key to a correct monitoring and maintenance but on the other hand, the higher the accessibility, the higher the likelihood of vandalism and therefore, the higher maintenance costs. Thus, when the installation is accessible to the people, special care has to be taken of certain details during the design and construction phases: proper protection of electronic devices and wires, proper fastening and/or locking of the key elements, etc.
- The technical suitability of the solar roads has been proven, however, their low performance and the important maintenance issues (cell breakages and surface degradation) occurred in the scarce experiences so far makes it necessary the test of new large-scale prototypes for properly assessing those durability problems. In the last few years, a couple of experimental solar roads, much shorter than the previous ones, have been built aimed at improving the energy yield of this technology.
- Photovoltaic Noise Barriers have been proved to be a suitable technology for NRAs in terms of energy efficiency, maintenance and durability. However, newest PVNBs are only 1-2 years old so monitoring is required to accurately assess their global performance. Cleaning of the PV systems in the barriers can be of great importance for ensuring an optimum energy efficiency. The most urgent challenge for the development of the PVNBs is their financial viability.
- Low efficiencies of non-conventional RETs rule them out for their application by NRAs, at least in what large-scale projects is concerned. The green energy harvested by these technologies can on the other hand have multiple potential small-scale applications such as powering of pavement health monitoring devices, traffic lights, information panels, infrastructure, sensors, etc.
- The suitability of the energy harvesting technologies is hindered not only by their low efficiencies but also by their very high cost as compared to the traditional power generation.

2. ENERGY STORAGE SYSTEMS (ESS)

The report delivered as an Annex of *Deliverable 2.2* aimed to identify the Battery Energy Storage Systems (BESS) that are potentially applicable to NRAs in the area of renewable energy production. The study focused on the market and technologies available for renewables integration in the grid.

The methodology adopted was to carry out research and analysis at a global level and then to do the same exercise at European level of existing and foreseen BESS technologies and applications for renewables on the road infrastructure. Arup based the report on public data and its own benchmarks, when available.

There is a wide range of battery and cell technologies available on the market for energy storage purposes. As such, depending on the application, the most appropriate technology will vary. Each type of battery technology has its own advantages and disadvantages. For example, energy density, response time and shelf life are some of the key characteristics which are used in the selection of a battery technology in a particular application. Figure 11 details the suitability of battery technologies across applications in fast response systems, distribution scale systems and large capacity grid scale systems.

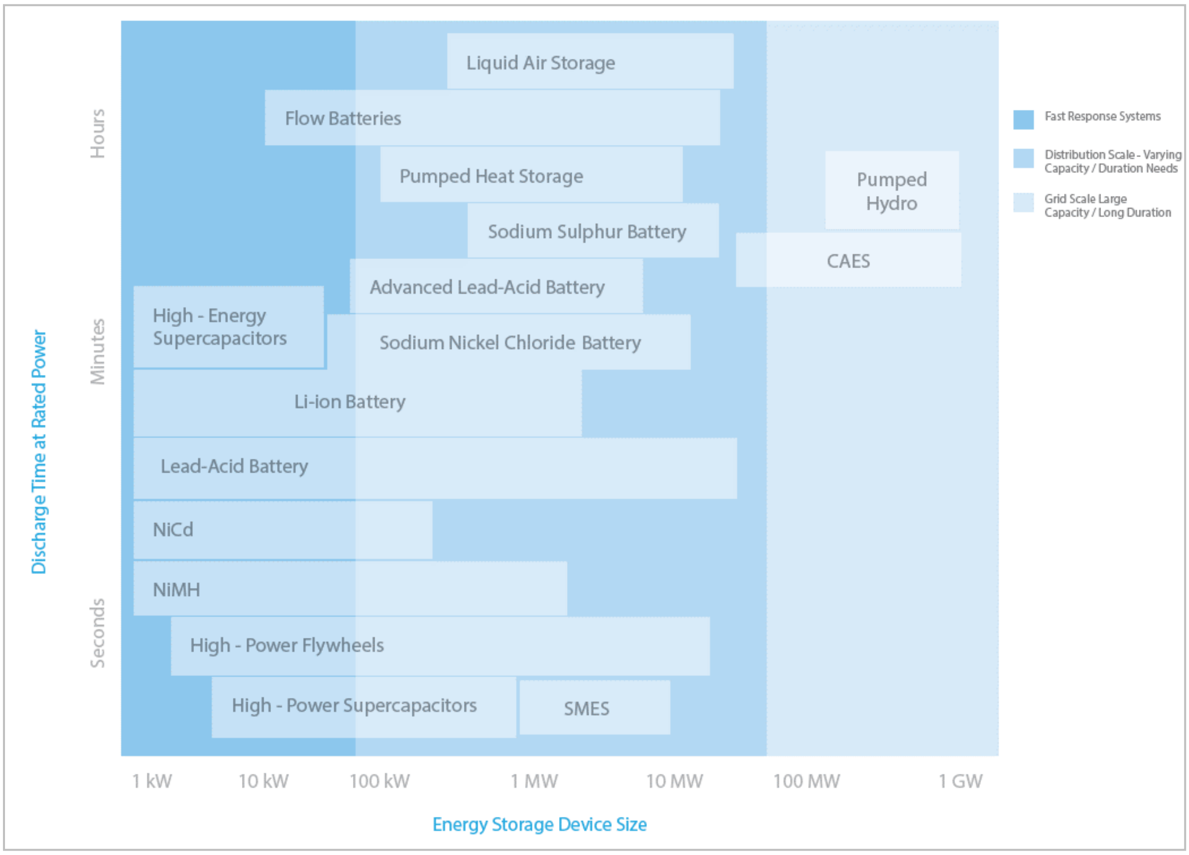

Figure 11.- Application and technology overview. (Arup, 2019)

Technologies appropriate for grid scale applications are those which have been considered as part of this study due to the requirement of integration of renewables technologies on the road infrastructure. Other applications for stationary batteries include, for example, distributed batteries. These are batteries situated close to the end user of electricity, e.g., in a house or office building.

2.1. KEY APPLICATIONS FOR BATTERY STORAGE IN GRID

Grid scale batteries may be implemented into the energy system to serve a range of functions.

- Grid services to provide system stability e.g., frequency response and reserves, voltage control and reactive power, constraint management and inertia.
- Capacity markets e.g., the integration of batteries with renewable technologies to provide long term security in supply of renewables.
- Wholesale energy arbitrage e.g., storing or purchasing electricity from grid when prices are low and reselling back to grid when prices are higher.

Key findings

Table 3 details different storage needs within the sector of stationary battery applications.

Table 3.- The need for storage (Arup, 2019)

Storage need	Revenue stream	Revenue stream	Revenue stream
The ability to match generation and demand. Shift generated energy from off peak times to when it is needed. Grid level and small-scale domestic applications.	Price arbitrage, reduction in demand charges	Minutes - Hours	kW - MW
Peaking plants are needed in order to meet changes in supply and demand conditions. Storage could provide this capacity in certain circumstances and reduce the need for fossil fuel peaking.	Electric supply capacity – power capacity contract and price arbitrage	Hours	MW
Increase the efficiency of thermal generation by ensuring a constant output. Storage can provide these load following services.	Load following – power capacity contract	Minutes - Hours	MW
Storage can be used to reconcile momentary differences between supply and demand. Storage can both adsorb and provide energy providing a twofold service.	Balancing services – power capacity contract	Seconds - Minutes	MW
Storage can provide reserve capacity that can be called upon in the event of the usual electricity supply resources becoming unexpectedly unavailable.	Electric supply reserve	Hours	MW
To maintain voltage and frequency at the required levels following a large disturbance requires a fast response. Storage can provide this service.	Regulation response and voltage support – Avoided penalties from system operator	Milliseconds - Seconds	kW - MW
Energy storage used for transmission support improves T&D system performance by compensating for electrical anomalies almost instantly.	Transmission network support – Avoided penalties from system operator	Milliseconds - Seconds	kW - MW
Transmission systems are becoming congested during periods of peak and off-peak demand. Storage can be used to mitigate this issue instead of investment in new transmission assets.	Asset upgrade deferral – Avoided cost of infrastructure investments	Hours	kW - MW

Storage to provide energy in the event of a system failure until the system is restored, or alternative energy sources are available.	Electric service reliability – Reducing production / operating losses	Hours	kW - MW

2.2. TECHNOLOGIES FOR RENEWABLES INTEGRATION

Figure 12 shows the percentage share for different ESS in applications for renewable energy integration projects globally for the previous 10 year (since 2013). Based on this figure and the previous table, the following technologies were selected for review: lithium-ion, flow batteries, lead-acid, sodium sulphur, flywheels and nickel-based batteries.

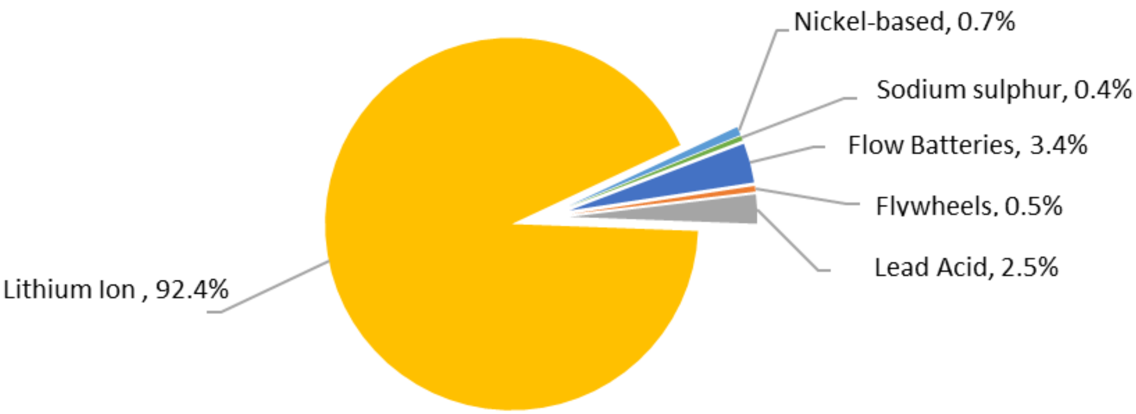

Figure 12.- Global share of commissioned and planned renewables integration energy storage projects by energy storage technology since 2013 (BloombergNEF, 2023)

2.2.1. LITHIUM-ION

Lithium-ion batteries are a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. Due to their high energy density, they are commonly used in consumer electronic products such as smart phones. They are also commonly used in electric vehicles, a deployment which is expected to drive down cost and improve performance. The technology can be scaled up to utility scale size and used in grid applications such as frequency response. Research and development is on-going in various other chemistries of the battery type with a view to improving performance and reducing the cost. Lithium-ion battery technologies comprise a range of chemical make-ups, for example, lithium iron phosphate (LFP), lithium manganese oxide (LMO), lithium nickel cobalt manganese oxide (NCM) and lithium titanate (LTO). **The main two lithium-ion sub-chemistries used within the stationary storage market and LFP and NMC** (Table 4).

Lithium-ion batteries are the most widely used technology for grid energy storage purposes in the European and global market, having the ability to supply megawatts of power for hours at a time. At the time of writing, 610 out of 723 battery storage projects listed in Europe on BloombergNEF databases use lithium-ion technologies as the primary energy storage technology in their systems (BloombergNEF, 2023).

Markets for integration in the grid include frequency regulation, price arbitrage and renewables integration.

Table 4.- Summary of Li-ion technologies (Cubes, 2022)

Chemistry	Abbreviation	Typical Use
Lithium Cobalt Oxide	LCO	Mobile consumer devices, laptops, smartphones
Lithium Iron Phosphate	**LFP**	**Stored energy for mission critical environments, EVs**
Lithium Nickle Cobalt Aluminium Oxide	NCA	EVs
Lithium Manganese Oxide	LMO	Medical devices, power tools, consumer devices
Lithium Nickel Manganese Cobalt Oxide	**NMC**	**EV powertrains, power tools, electrical grid storage**

Renewables integration projects

At the time of writing, Arup identified 80 commissioned energy storage projects in Europe serving the purpose of renewable systems integration. Additionally, 65 projects were identified for battery storage in the pipeline, either recently announced or with financing secured. Upon review of these projects, trends in upscaling of capacity can be seen within the market (BloombergNEF, 2023). Some examples:

- GIGA Buffalo Solar Wind Energy Storage Project. A 24MW/48MWh storage project located in the Netherlands, developed by GIGA Storage BV. This project was commissioned in 2022 and is co-located with both wind and solar assets.
- Enerparc Buettel Energy Storage Project. A 12MW/8MWh energy storage system located in Germany, commissioned in April 2023. This project supports a 35MW distributed generation solar PV installation.
- GRIDSERVE Clayhill Farm Energy Storage Project. This project is a 6MW/6MWh energy storage installation in Bedfordshire, UK, commissioned in 2016. The energy storage facilitates a 10MW PV plant.
- Quinbrook Fortress Energy Storage Project. Announced in 2020, this battery storage project will provide 150MW/300MWh of storage to a 350MW PV plant in Kent, England.
- Hive Energy Bluesky300 Hybrid Solar Energy Storage Project. A 100MW energy storage project will be connected to a 100MW PV plant located in Greece. This projected was announced in September 2022.

Key findings

Some decision-making findings are summarized in Table 5.

Table 5.- Decision-making findings. Lithium-ion. (Arup, 2019 and BloombergNEF, 2023)

Lithium ion	
Round-trip Efficiency	88-90%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	512 MW / 742 MWh
Advantages	• Very high energy density • Ability to tolerate large number of discharges cycles • High efficiency • Most mature energy storage technology for renewable energy integration purposes
Disadvantages	• High costs • Negative effects of overcharging and over discharging

2.2.2. FLOW BATTERY

Flow batteries are a rechargeable battery using two liquid electrolytes, one positively charged and one negative, as the energy carriers. The electrolytes are separated using an ion-selective membrane, which under charging and discharging conditions allows selected ions to pass and complete chemical reactions. The electrolyte is stored in separate tanks and is pumped into the battery when required. The storage capacity of flow batteries can be increased by simply utilising larger storage tanks for the electrolyte. Several chemistries are possible for the battery.

Like Li-ion batteries, flow batteries can comprise of a range of chemistries, the most common ones being vanadium redox and zinc bromine. Vanadium redox is the most commercially mature technology available for flow batteries. The modularity and scalability of flow batteries mean that they are suitable for many grid applications such as load balancing, standby power and the integration of renewable energy sources.

Renewables integration projects

The number of flow battery installations identified for renewables integration in Europe is limited. A total of 6 projects have been identified in state of commissioned within Europe, with each installation having relatively low capacities when compared to those using lithium-ion technologies (BloombergNEF, 2023). Some examples are:

- **REDT Cornwall Energy Storage project.** A vanadium redox flow battery installation in the UK with a storage capacity of 1.08MWh. The battery was commissioned in 2017 and supports a 350kWp solar PV installation.

- Robert Bosch & BWP Braderup-Tinningstedt Braderup Flow Battery Energy Storage Project. A 0.325MW/1MWh vanadium redox flow battery installed in Germany. This project was commissioned in 2014 and is located alongside a 18MW wind farm.
- EGPE Son Orlandis Solar Energy Storage Project. This project is a 1.1MW/5.5MWh vanadium redox battery installation in the Balearic Islands, Spain. Construction began in December 2021. It will support energy storage needs for a 3.34MW solar farm.

Although the identified market for flow batteries in Europe is limited, there are installations that confirm the technical viability of the technology for renewable integration within the grid (BloombergNEF, 2023):

- Liaoning Datang International Wanfangdian Zhenhai Wind Energy Storage Project. A 10MW /40MWh vanadium redox Energy storage installation, commissioned in 2020 in China. This project serves a 100MW windfarm.
- Hokkaido Electric Minamihayakita Substation Energy Storage Project. A 15MW/60MWh vanadium redox storage system installed in Japan in 2015. This project stores energy and smooths output from a utility scale solar and wind farm.

Key findings

Some decision-making findings are summarized in Table 6.

Table 6.- Decision-making findings. Flow Battery. (Arup, 2019 and BloombergNEF, 2023)

Flow battery	
Round-trip Efficiency	74-77%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	3MW / 12MWh
Advantages	• Less sensitive to high depths of discharge • Ability to tolerate large number of discharge cycles • Virtual unlimited capacity
Disadvantages	• Low energy density • Limited project examples in Europe

2.2.3. LEAD ACID

Lead acid battery technology is the most established battery technology. There are several variants of the technology available. Flooded lead-acid batteries immerse the electrodes in liquid electrolytes and release gases upon charging. An example of this is a standard 12V car battery. Sealed lead acid batteries come in two forms - absorbed glass mat batteries create energy by immobilising electrolytes with a microfiber glass mat, while gel cell batteries have the electrolyte mixed with silica dust to form an immobilised gel. Sealed batteries do not require the regular addition of water to the cells and vent less gas than flooded lead-acid batteries. However, they have a longer re-charge time and shorter useful life. Advanced lead acid batteries have been developed and are particularly suited to storage applications.

Lead acid batteries are predominantly used for starting vehicle engines as well as for backup power supplies and for grid energy storage. This technology is mature for its use as ancillary service such as an Uninterruptible Power Supply (UPS), with demonstrated applications for bulk energy storage. Lead acid has been demonstrated as storing between 0.1 and 10 MW over a period of hours, but there are examples of projects which have capacities up to 50MW. The technology can be used in applications in grid-scale storage and distributed storage.

Renewables integration projects

Arup identified 3 projects in Europe (Germany) using lead-acid technology for renewables integration applications, the most recent being commissioned in 2019. Outside of Europe wider selection of lead-acid installations exists supporting renewables (BloombergNEF, 2023). Some examples are:

- **Belectric Germany Energy Storage Project.** A 1.6MW/2MWh lead acid battery installation set in Germany. This project was commissioned in 2014 and supports a 67.8MW solar PV plant.
- **Kazenomatsubara Shizen Energy Noshiro Energy Storage Project.** A 9.64MW/24.1MWh system in Japan, and commissioned in 2016. This energy storage project supports a 39.1MW wind farm.
- **Three Gorges Group Changdu Basu Yiqing Solar Energy Storage Project Phase I.** A 5/20MWh lead acid battery connected to a 20MW PV plant in Tibet, China. It was commissioned in 2022.

Key findings

Some decision-making findings are summarized in Table 7.

Table 7.- Decision-making findings. Lead Acid. (Arup, 2019 and BloombergNEF, 2023)

Lead acid	
Round-trip Efficiency	82%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	2 MW / 2MWh * Last installation in 2014. * Note: no planned installations in pipeline.
Advantages	• End of life recycling infrastructure in place • Relatively efficient • Low self-discharge
Disadvantage	• Low energy density • Susceptible to high depths of discharge

2.2.4. SODIUM SULPHUR

A sodium sulphur battery is a molten state battery constructed from sodium (Na) and sulphur (S). The battery casing is the positive electrode while the molten core is the negative electrode. The battery operates at high temperatures of between 300-350°C, while lower temperature versions are under development. In charging, the sodium ions are transported through the ion selective conductor to the anode reservoir. Discharge is the reverse of this process. Because sodium ions move easily across the ion selective conductor, but electrons cannot, there is no self-discharge. When not in use the batteries are typically left under charge so that they will remain molten and be ready for use when needed. If shut down and allowed to solidify, a reheating process is initiated before the batteries can be used again. NaS batteries can be used for many grid applications such as: power quality applications, grid stabilisation and the integration of renewable energy sources.

Renewables integration projects

This type of installation is not popular in Europe, with a total of 10 identified project examples in grid applications. With the specific application of renewables integration, there is one only identified project example within Europe. Outside of Europe, additional examples of installations exist but the technology uptake is still low with just 13 identified commissioned installations in renewables integration globally, many of which are located in Japan (BloombergNEF, 2023). Examples include:

- Enercon Emden Energy Storage Project. A 0.8MW/5.8MWh sodium sulphur battery project. It was commissioned in 2009 in Germany to support a wind farm.
- Kyushu Electric Buzen Energy Storage Project. A 50MW/300MWh NaS Energy storage project in Japan, and commissioned in 2016.

Key findings

Some decision-making findings are summarized in Table 8.

Table 8.- Decision-making findings. Sodium Sulphur. (Arup, 2019 and BloombergNEF, 2023)

Sodium Sulphur	
Round-trip Efficiency	80%-82%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	3 MW / 18 MWh * Last installation in 2012. * Note: no planned installations in pipeline.
Advantages	• High energy density • Long life cycle • Quick response
Disadvantages	• Heating required in process • Safety issues with molten sodium

2.2.5. NICKEL BASED

Nickel-based batteries are a type of rechargeable battery technology that use nickel-based compounds as their positive electrode or cathode. There are two main types of nickel-based batteries. There are a variety of different chemistries which make up this technology group, for example, nickel-cadmium (Ni-Cd), nickel-metal hydride (Ni-MH) and nickel-sodium chloride.

Nickel sodium chloride is used within stationary storage applications, its chemistry consisting of a nickel chloride cathode, a beta alumina separator and a liquid sodium anode. The operating temperature of the cell is between 270 C and 350°C. In charging, the sodium ions are transported through the beta alumina to the anode reservoir. Discharge is the reverse of this process. Because sodium ions move easily across the beta alumina but electrons cannot, there are no side reactions, and therefore no self-discharge. When not in use the batteries are typically left under charge so that they will remain molten and be ready for use when needed. If shut down and allowed to solidify, a reheating process is initiated before the batteries can be used again.

Renewables integration projects

Uptake of nickel-based battery installations has not been popular within Europe – the most recent installation was commissioned in 2015 and supports a 10MW PV plant (BloombergNEF, 2023):

- **Enel Green Power Catania Energy Storage Project**. This 1MW/2MWh sodium nickel chloride system was commissioned in 2015 and supports a 10MW PV plant.

Outside of Europe, major examples of the use of nickel-based technologies for renewables integration is also limited. Existing commissioned installations of energy storage plants which use solely nickel-based technology are of smaller scale, with capacities in the range of 0.1 – 2MW.

Key findings

Some decision-making findings are summarized in Table 9.

Table 9.- Decision-making findings. Nickel Based. (Arup, 2019 and BloombergNEF, 2023)

Nickel based	
Round-trip Efficiency	85%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	3 MW / 1 MWh * Last installation in 2015.
Advantages	• High energy density • Fully recyclable • Long life (20 years)
Disadvantages	• Heat may be required • Unsuitable for short cycling

2.2.6. FLYWHEELS

Flywheel energy storage makes use of the mechanical inertia contained within a rotating flywheel in order to store energy. Flywheels store electrical energy by using the electrical energy to spin a flywheel (usually by means of a reversible motor/generator). In order to retrieve the stored energy, the process is reversed with the motor that accelerated the flywheel acting as a brake extracting energy from the rotating flywheel. In order to reduce friction losses, it is common to place the flywheels inside a vacuum with the actual flywheel magnetically levitated instead of using conventional bearings.

Flywheels as storage devices are more suited to improving power quality by smoothing fluctuations in generation, as opposed to having long output durations. This is because of the ability of flywheels to rapidly charge and discharge. Controlling grid frequency is an important feature and the need for this service will increase as the penetration of intermittent generating units increase.

Renewables integration projects

Examples of flywheel installations within Europe for renewables integration is limited. This is partly due to the technology being more suited to improving grid stability and smoothing instead of power storage. An example project includes (BloombergNEF, 2023):

- **S4 Energy and ABB Heerhugowaard Wind Energy Storage Project**. Commissioned in 2022, this project combines lithium ion and flywheel technologies to support a wind farm. This project features a 10MWh battery systems with a 3MW flywheel.

Key findings

Some decision-making findings are summarized in Table 10.

Table 10.- Decision-making findings. Flywheels. (Arup, 2019 and BloombergNEF, 2023)

Nickle based	
Round-trip Efficiency	82% - 85%
Total identified capacity and output in Europe in renewable energy integration (includes announced, under development and commissioned projects)	4 MW / 3 MWh
Advantages	• Rapid response time • Low maintenance • Effectively maintains power quality
Disadvantages	• Requirement for precision engineered components. • Must be housed in robust containers

2.3. BATTERY LIFETIME & DEGRADATION

Battery lifetime refers to the length of time a battery can be used before it no longer provides adequate performance. This is often measured in terms of cycles, or the number of times a battery can be charged and discharged before its performance degrades significantly. Battery degradation is the gradual loss of battery capacity and performance over time due to a number of factors, including the usage patterns, the temperature, and the charging and discharging rates.

For stationary batteries, such as those used in RE storage systems, the financial considerations of battery lifetime and degradation are important. Without application, details on capacity and number of cycles for an installation, it is difficult to accurately determine degradation. Various batteries technologies do differ however in their expected lifespan, as detailed in Table 11.

Table 11.- Expected lifespan of different battery technologies.

Battery Chemistry	Expected lifespan
Lithium Ion	10 – 15 years (Cubes, 2022)
Flow Batteries	30 years (Power, 2020)
Lead Acid	5 – 7 years (Cubes, 2022)
Nickel Based (sodium nickel chloride)	15 years (ScienceDirect, 2021)
Sodium Sulphur	15 years (Insulators, 2023)

2.4. EUROPEAN MARKET

Market Overview

Although China is the global leader in the BESS sector, investments in Europe are increasing significantly, with lithium-ion battery production within the continent anticipated to increase rapidly. Utility-scale installations in Europe are expected to scale 11-fold in the coming years, increasing from 3GW/4GWh in 2021 to 33GW/95GWh by 2030 (Nsitem, 2023).

In terms of existing installed capacity in Europe, the market is still very focused on grid services and price arbitage applications more so than renewables integration application, as highlighted by the graph of installed/planned powers and capacities in Europe for varying energy storage applications in Figure 13.

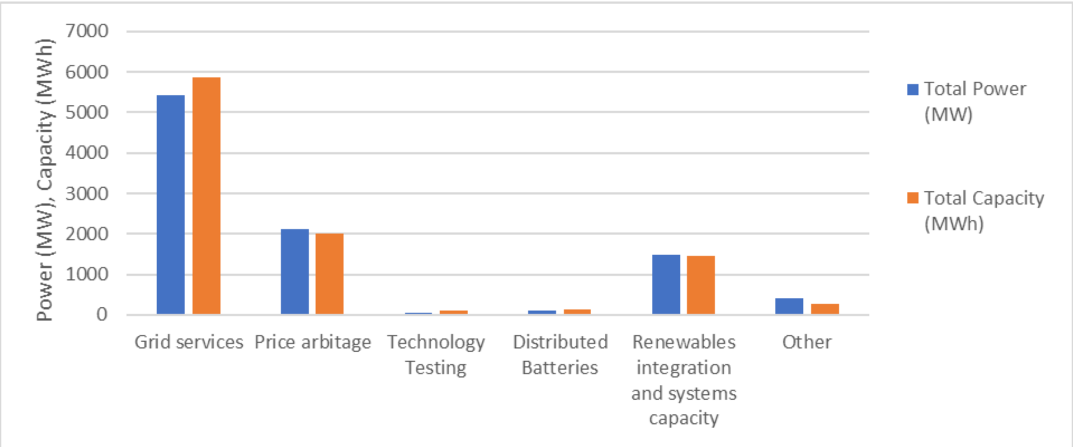

Figure 13.- Overview of battery storage capacities for varying applications in Europe

Regulations and incentives

Europe has set out some of the world's most ambitious decarbonisation targets. It is true, however, that whilst having ambitous climate actions plans to combat reductions in emissions, many european countries lack energy storage specific targets in their policies. Italy and Spain are the only europeans countries which have specific energy storage targets in their NECPs, while the UK, Greece and France have independently set energy storage targets.

Grid scale batteries will play a vital role in balancing and integrating renewable energy generation into the European grid. They will also aid in the distribution of electricity during peak times (to prevent network reinforcements). Batteries are also essential to meet the growing EV demand and reduce transportation related emissions to meet set emission targets. A number of EU countries including Belgium, Finland, France, Germany, Italy, Poland and Sweden announced funding of up to €3.2 billion for battery projects until 2031. However, this focus is mostly on EV batteries rather than battery cells.

Manufacturers

China is the frontrunner in battery manufacturing with 82% of the world's cell manufacturing. As of the end of 2022, 84% of the 132GWh battery manufacturing capacity within Europe was owned by companies headquartered in Asia. Batteries produced in Europe are more expensive than those produced in China – the cost of battery production in China in 2022 was $127/kWh compared to $169/kWh in Europe.

Key battery manufacturers globally include CATL (China), LG (South Korea), BYD (China) and Tesla (USA). Many of these companies have factories situated within Europe, such as the Tesla Gigafactory in Berlin and an LG factory situated within Poland. Key european manufacturers include Nothvolt (Sweden), Italvot (Italy), Morrow (Norway), PowerCo (Germany/Spain) and ElevenEs (Serbia) (Leach, 2023).

2.5. TYPICAL BATTERY COSTS

Arup has conducted this section of the report based on available public data and Arup's most recent benchmarks. The reported market benchmarks are limited and may not be representative of current market figures. Real installations are dependent on the technology and commercial operation date, among other factors.

The graph in Figure 14 shows costs ranges for battery packs for varying battery technologies. Note that costs to create benchmarks for batteries other than lithium ion is limited, mainly due to the lack of installations for comparison. Historical data has been used in these cases. Finance assessors such as Bloomberg focus their costing analysis on lithium ion due to the dominance of this technology within the market. With market maturity the cost of lithium-ion batteries has decreased significantly, particularly in China. The same cannot be said for other battery technologies as their lack of commercialisation means that costs are not expected to decrease to the same levels to that of lithium ion.

The cost of lithium-ion batteries has decreased steadily and significantly since 2010, with an average global cost of €1188/kWh in 2010 to €129/kWh in 2021, as detailed in Figure 15. An increase was seen however in 2022, where the price increased to €137/kWh. This was mainly due to supply chain impacts after the pandemic, as well as the existence of an undersupplied market with high demand.

The cost for lithium-ion batteries can be further split into their sub-chemistries, as detailed in Figure 16. As previously mentioned, NMC and LFP are the sub-chemistries most commonly used in stationary energy storage applications. In 2023, capital costs associated with NMC has an approximate cost of €140/kWh, while that for LFP is €100/kWh. **It is important to note that the prices of batteries fluctuate and is extremely sensitive to the price of raw materials such as lithium and cobalt.**

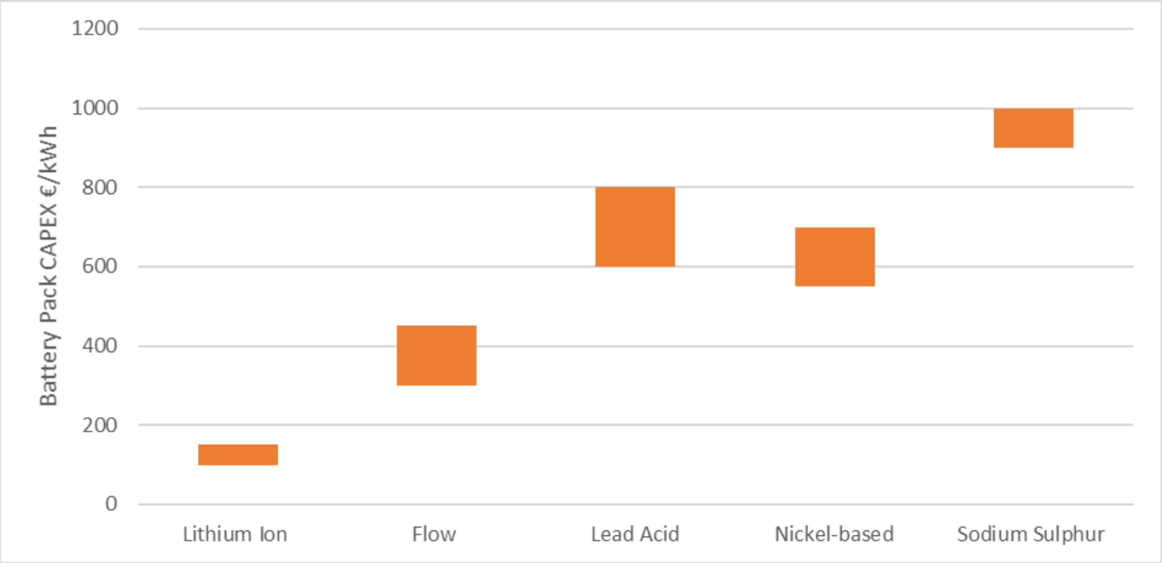

Figure 14.- Capital costs for battery packs for different battery technologies (Arup, 2019) (Lazard, 2018).

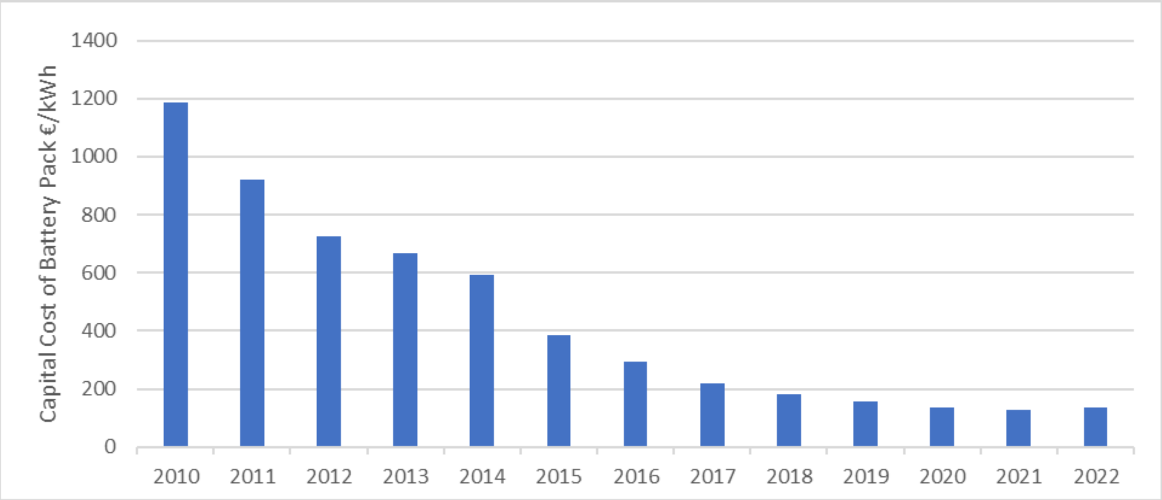

Figure 15.- Average global cost of battery pack since 2010

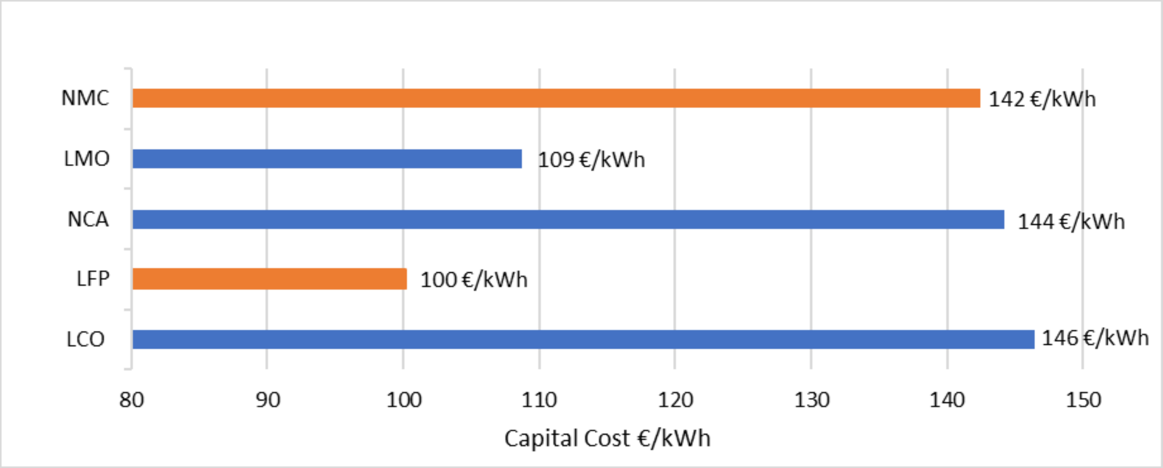

Figure 16.- Global average capital costs for varying lithium-ion chemistries battery packs (BloombergNEF)

Other costs than the battery should be considered that would account for the total cost of a storage installation. Thus, the costs of the battery accounts for a significant proportion of the ESS installation cost, but other aspects in energy storage projects have to be considered such as but not limited to the balance of plant costs or the construction costs. Therefore, the overall cost of the installation per unit installed capacity increases. A range of total estimated costs (CAPEX) based on data from 4 previous Arup confidential projects for lithium-ion installations within Europe (grid connection and transformer cost excluded) might be: 200-450 €/kWh.

Operational and maintenance is a key cost which should also be considered. Benchmark data for battery installations other than lithium-ion is limited due to a limited number of commercial projects globally. The operations and maintenance of storage installation includes monitoring and control, maintenance, safety and environmental considerations. Using information from a number of previous lithium-ion battery projects in the UK, OPEX costs have been reviewed to allow the calculation of a benchmark. The figures may vary depending on economies of scale. The estimated annual operation and maintenance cost for a battery installation is expected to be within the range 14.5 – 18.5 €/kWh.

3. MODELLING OF THE SELECTED RE TECHNOLOGIES

Figure 17 introduces the correlation between the different elements involved in the feasibility analysis of potential **Distributed Energy Generation System** projects for the integration in the road infrastructure and/or NRA land/assets based on different RE generation technologies, which depends on:

- Definition of road infrastructure and/or NRA land/assets, which consist in the characterization of focus application cases: definition of input data and relevant parameters for DEGS evaluation.
- Characterization of the Renewable Energy Source in the specific location.
- Modelling and parametrization of the Renewable Energy Technology (RET).

In *Deliverable 2.2* a full description of models and methods within the evaluation of DEGS were reported. This section briefly summarizes that document focusing on the description of the considered models and parameters for RETs as well as the characterization of the wind and solar energy source.

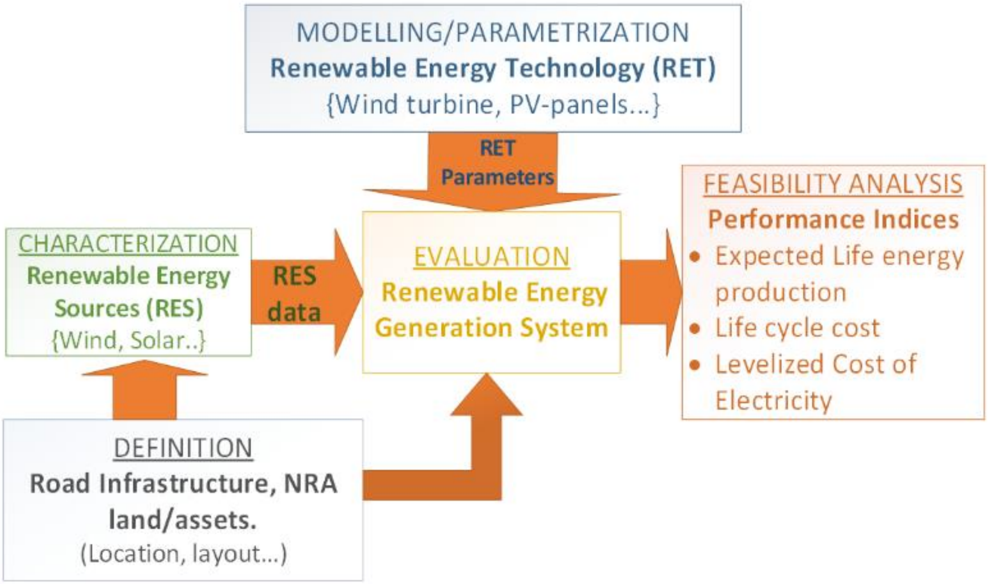

Figure 17.- Evaluation of Renewable Energy Generation system projects in road administration land/assets.

3.1. WIND ENERGY PROJECTS

3.1.1. WIND SOURCE CHARACTERIZATION

A widely used approach to characterize the wind resource is by its wind speed probability distribution function (PDF). There are many PDFs that can be used to characterize the wind resource of a region, but the most used is the Weibull PDF, as it provides a good fit to the annual frequency wind speeds of many sites (Borunda, 2020). In this study, the two-parameter family of Weibull PDFs is used Manwell (2009), which depends on the shape and scale factors of the distribution (k_w and λ_w, respectively) and the wind speed (v_w).

Figure 18 shows an example of the Weibull PDF for different values of shape factor and mean wind speed. The Weibull function factors are normally obtained by fitting the function to the measurements of wind speeds using wind masts for duration of some months to one year through 10 minutes intervals (Sedagha, et al. 2016). Wind profiles are dependent on the height above the ground, ground's surface roughness, the ground's roughness variation, the atmospheric stability, and the geographical elevation (Wass 2018). The wind speed profiles generated from wind speed measurements will be referred to as the mat's height.

There are two common models to estimate/scale wind profile at any given height: the log law and the power law. Here, a simplified log wind profile is considered to scale the wind profile at any given height, the mean wind speed ($\bar{V}_w$) at a height (z) above the ground being estimated as depending on the mean wind speed at the reference height ($\bar{V}_{w.REF}$ and z_{REF}), the zero-plane displacement (z_d) and the roughness length (z_0), which accounts for the effect of the roughness surface. The zero-plane displacement is the height above the ground at which zero wind is achieved as results of flow obstacles such as trees or buildings. It can be approximated as 2/3 to 3/4 of the average height of the obstacles (Holmes 2015). On the other hand, the value of the roughness length depends on the terrain.

In Table 12 the typical values of surface roughness length as reported by Burton (2001) are introduced. The Weibull distribution factors (k_w and λ_w) can be extrapolated at any height of the rotor (z) by using the Justus and Mikhail method (Justus, et al., 1978; Djohra Saheb, 2014).

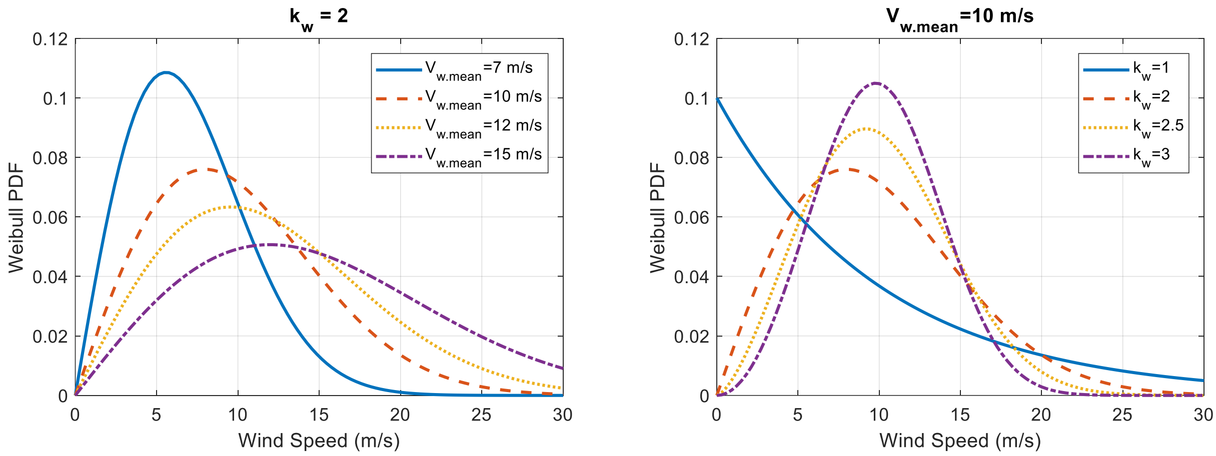

Figure 18.- Weibull PDF for different values of the shape factor and mean wind speed.

Table 12.- Typical values of surface roughness length for various types of terrain.

Type of terrain	Typical surface roughness length z_0	Type of terrain	Typical surface roughness length z_0
Mud flats, Ice	1e-5 to 3e-5	Calm Sea	2e-4 to 3e-4
Sand	2e-4 to 1e-3	Mown grass	0.001 to 0.04
Low grass	0.02 to 0.03	Fallow field	0.02 to 0.03
High grass	0.04 to 0.1	Forest and Woodland	0.1 to 1
Built up area, suburb	1 to 2	City	1 to 4

In principle, the expected energy production of a wind turbine can be estimated based on wind Weibull PDF on the target location and the turbine hub height. However, when many wind turbines are going to be placed near each other, as in a wind farm, the prevalent wind direction in the target location is also needed to determine the allocation/arrangement of the wind turbines affecting the effective available area. For a given area, this information is normally given by a wind rose chart. There are multiple data sources that can be addressed to get the wind characterization of a given area, e.g., a global wind atlas is available at Badger (2021), where different speed statistics has been extrapolated for different areas worldwide with a resolution of $9km^2$. Figure 19 presents a simulated wind speed map for central Europe at 100m height as reported in Badger (2021). Besides, there are also specific wind speed data sources for each country which can also be accessed online, for example wind data source for the Iberian Peninsula can be accessed at CENER (2019). Figure 20 shows an example of wind speed stats as reported in CENER (2019) for a place located at 42.64° latitude, -8.67° longitude, with 50mx50m scale.

Additionally, temporal wind speed profile may be needed when wind turbine is intended to be operated in combination with Energy Storage Systems to provide a given energy/power demand. In that aspect, the seasonal and hourly wind speed profiles of the area of interest can provide additional information needed so the ESS can be sized according to the expected load profile. Figure 21 shows an example of seasonal and hourly wind speed profiles taken from Badger (2021) for an aleatory 9 km^2 area located at southern Denmark (55.22°Lat, 9.05°Long) with mean wind speed of 8.42 m/s. The seasonal and hourly wind speed profiles are plotted as wind speed index, which is the relative variation from mean wind speed (8.42 m/s).

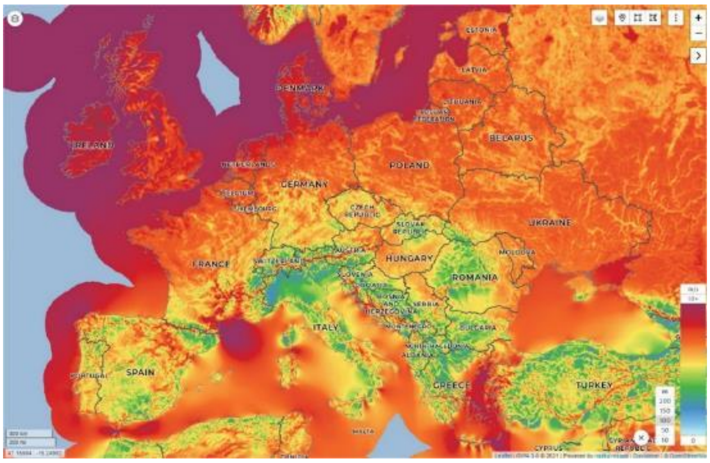

Figure 19.- Simulated Wind speed map for central Europe at 100m height. Source: https://globalwindatlas.info/.

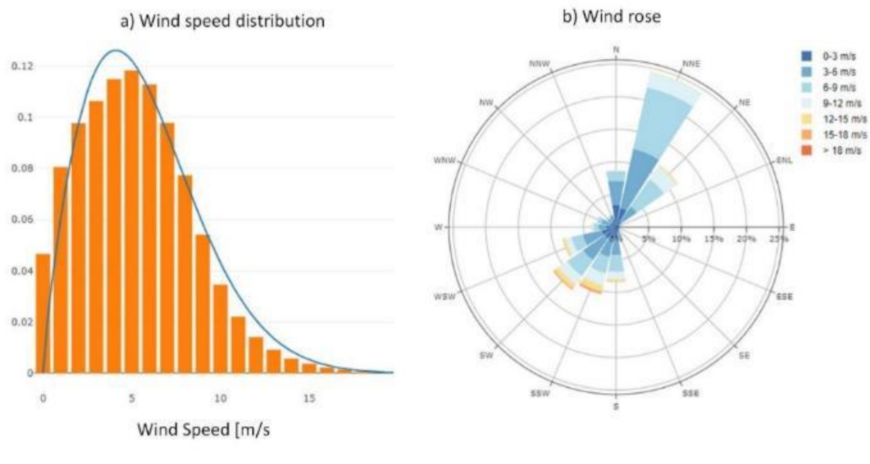

Figure 20.- Wind speed statistics for a place located at 43.342° latitude, -4.145° longitude with 50mx50m scale. a) wind speed distribution at 50m with fitted Weibull PDF ($\bar{V}_w$=6.4m/s, k_w=1.8); b) wind rose at 50m.

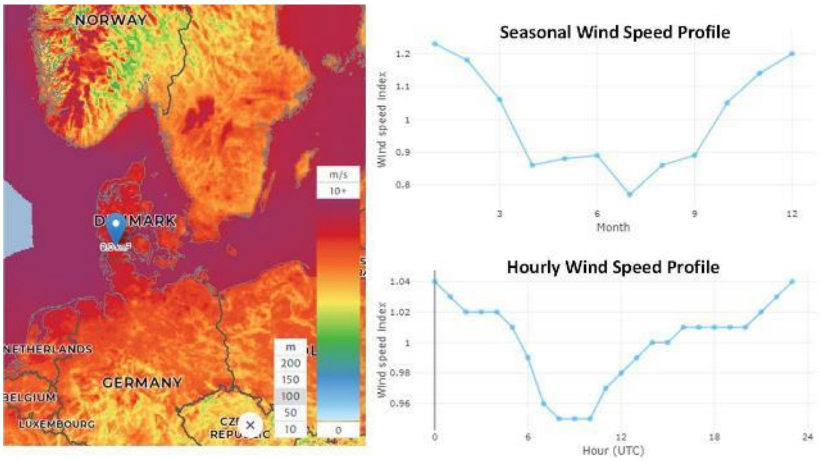

Figure 21.- Seasonal and hourly wind speed profile. Left: location example 9 km2 area at southern Denmark (55.22°Lat, 9.05°Long) with mean wind speed of 8.42 m/s. Right: (top) Seasonal wind speed profile as wind speed index (variation from mean wind speed), (bottom) Hourly wind speed profile. (Source: https://globalwindatlas.info/)

3.1.2. MODELLING AND PARAMETRIZATION OF WIND TURBINES

Power curve model

In general, wind turbines transform the kinetic energy of the wind in rotating mechanical energy through blades/rotor and converts that energy in electric power using an electric generator, which is commonly interfaced by a power electronics converter and power transformer to ensure the right voltage level. For large scale wind turbines, all previous conversion stages can be considered as part of the turbine device as they are normally located inside of the wind turbine nacelle, while for small scale wind turbines, the power converter and transformer are normally considered as additional components of the turbine.

Normally, the generated electrical power versus wind speed curve (also known as power curve) can be found in the wind turbine datasheet, which is provided by the wind turbine manufacturer to quantify the wind turbine performance. For a given wind turbine with provided power curve $P_{WT}(v_w)$, the expected annual energy production *(AEP_{WT})* can be calculated by:

$$AEP_{WT} = 8760 \cdot k_{WTA} \cdot \sum_{i=1}^{N_{vw}} P_{WT}(v_{wi}) \cdot f_W(v_{wi})$$

where the full span of wind speeds from cut-in to cut-out wind speed has been discretized into N_{vw} wind speed bins with equal width, and the total AEP is calculated by summing all contributions of each wind speed bin, v_{wi} is the wind speed of the i-th bin at the wind turbine hub height, and f_w is the wind speed PDF of the area of interest scaled to the wind turbine hub height. The factor k_{WTA} is the wind turbine availability, so the product $8760 \cdot k_{WTA}$ estimates the annual operation hours of the wind turbine.

The wind power curve is a unique characteristic of the turbine that depends on factors like aerodynamic blade performance, electric components (generator type, converter architecture, etc.) or power control strategy, among others. However, there are two well-defined power curve shapes in terms of the control strategy applied for high wind speeds, which can be classified as pitch-regulated and stall-regulated. In Figure 22 a comparative example of pitch-regulated and stall-regulated wind power curves is shown.

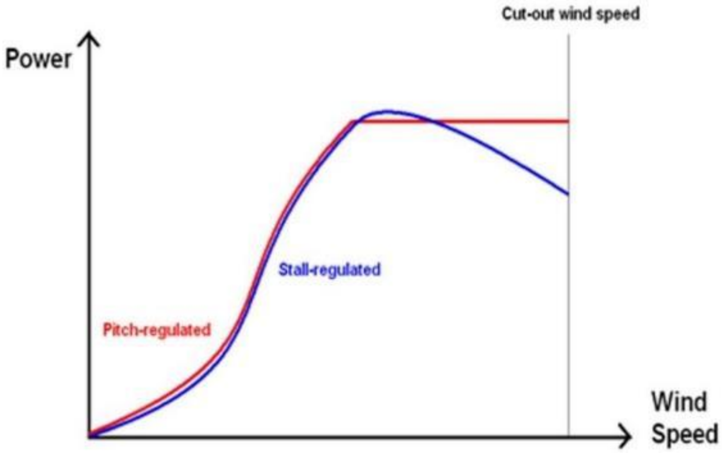

Figure 22.- Comparison of typical wind turbine power curves: Pitch-regulated versus Stall-regulated

Pitch-regulated wind turbines have an active control system that can vary the pitch angle of the turbine blades, which allows to control/limit the turbine rotational speed, or the torque transferred to the shaft at high wind speeds. The pitch-regulated power curve is characterized by increasing power up until the rated wind speed, beyond which it keeps constant rated power up until a cut-out speed.

Stall-regulated wind turbines have their blades designed to perform in a way that at high wind speeds the rotational speed or aerodynamic torque decreases with increasing wind speed above a certain value (usually beyond the rated wind speed) to protect the wind turbine without the need for active controls.

Stall-regulated wind turbines have the advantage of lower turbine capital cost and a lower maintenance associated with more moving parts. However, pitch-regulated systems can deliver constant power output above rated wind speed, while stall-regulated systems are not able to keep a constant power output in high winds. Pitch-regulated control systems are more commonly used for large wind turbines (MW) while stall-regulated control is always used in very small wind turbines.

Expected Lifetime and Warranty period

A warranty is normally designed to protect a product from failure of its component parts over a specific period. A typical warranty period will depend on the type of installed wind turbines and can be anything from 1 to 10 years. On the other hand, the turbine lifetime also depends on the wind turbine technology and specific used components.

For large scale wind turbines, a typical warranty period of 5 years can be considered. As for the lifetime, most of the manufacturers specified a minimum lifetime of 20 years, which can be extended up to at least 25 years depending on environmental factors and the correct maintenance procedures being followed.

Regarding the expected lifetime and warranty period for small wind turbines, based on the collected data for small wind turbines, it is observed that bigger wind turbines have longer warranty period and lifetime. Figure 23 shows the collected data regarding warranty period and lifetime for small scale wind turbines as well as the different trends in warranty period and lifetime for the referred wind turbine technologies.

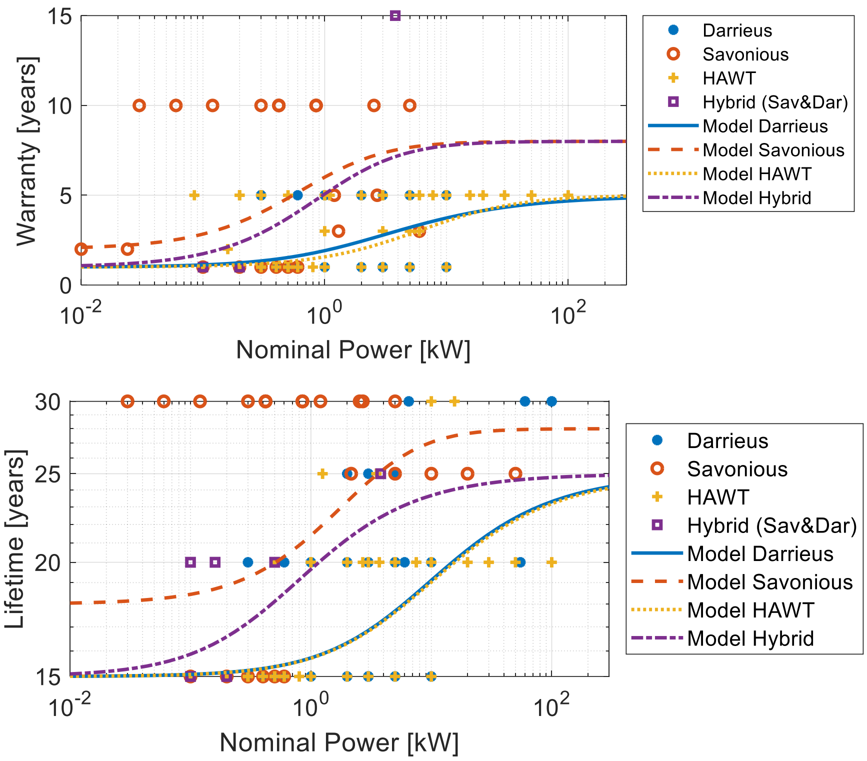

Figure 23.- Warranty period and Lifetime of small-scale wind turbines

3.1.3. WIND FARMS MODELLING AND EVALUATION

The evaluation of the expected annual energy production of a wind farm allocated in each NRA land depends on the wind farm layout. Determining the optimal layout of a wind farm is a complex problem outside of the scope of this study. A simplified wind farm layout problem has been considered in this study. The main parameter definitions for the considered wind farm layout are presented in Figure 24.

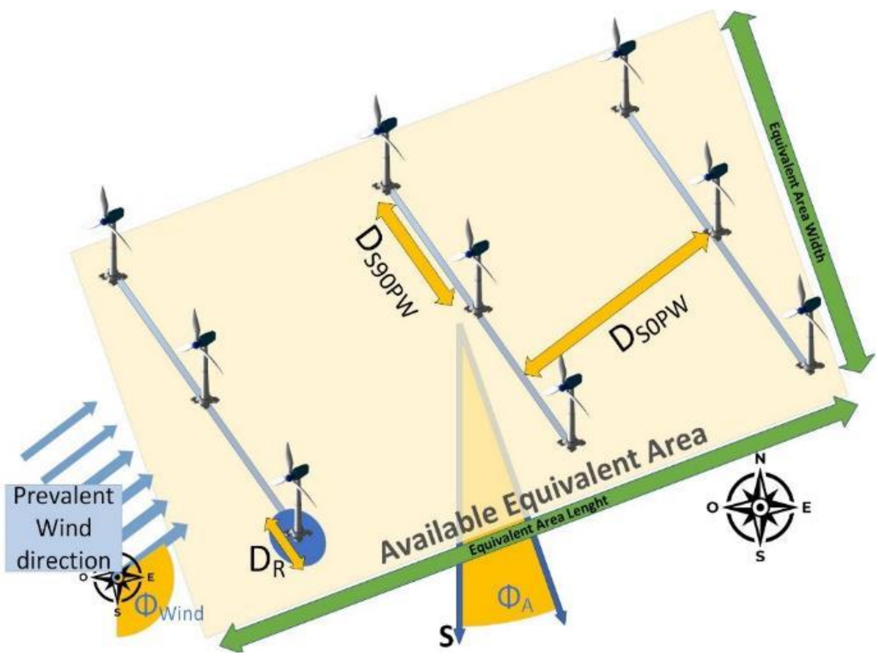

Figure 24.- Main parameter definitions for the considered wind farm layout

Given an available area with equivalent length $\left(L_{eqA}\right)$, equivalent width $\left(W_{eqA}\right)$ and average orientation measured by the equivalent area azimuth angle (ϕ_A) with south reference $(\phi_A = 0°)$ when the equivalent area width in line with East-West direction, the wind farm layout is defined by the number of wind turbines that can be allocated considering an average prevalent wind direction in the site (ϕ_{wind}) measured from the south and assuming a rectangular distribution of the wind turbines with a separation between turbines parallel to the prevalent wind direction *(D_{S0PW})* and a separation between turbines perpendicular to the prevalent wind direction *(D_{S90PW})*.

Figure 25 shows the geometric problem definition for the determination of number of wind turbine rows parallel to prevalent wind direction, where $\Delta\phi_{AW}$ is the delta azimuth angle between the prevalent wind direction and the equivalent area azimuth angle.

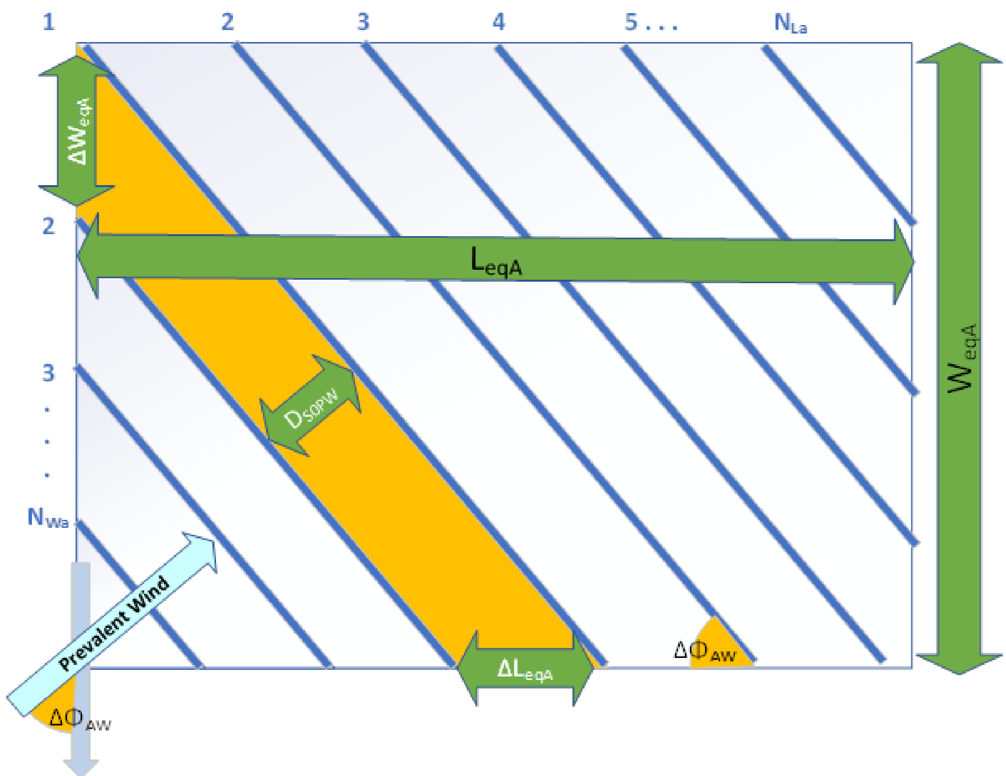

Figure 25.- Geometric problem definition for determination of number of wind turbine rows parallel to prevalent wind direction

The total number of wind turbines allocated in the equivalent area is calculated by:

$$N_{WT} = \sum_{k=1}^{N_{WTRows}} N_{WTperRow\,(k)}$$

Where N_{WTRows} is the number of turbine rows and $N_{WTperRow}$ the number of wind turbines per row.

The expected total wind farm annual energy production ($AEP_{WindFarm}$) can be estimated by:

$$AEP_{WindFarm} = \sum_{k=1}^{N_{WTRows}} AEP_{WTFCT} \cdot N_{WTperRow\ (k)} \cdot k_{WTDerated}\ (k)$$

With the wind turbine derated factor $k_{WTDerated\ (k)}$ accounting for the power ratio of downstream wind turbines respect to upstream wind turbines, and the expected contribution of front wind turbines to the total annual energy production (AEP_{WTFCT}) approximated by:

$$AEP_{WTFCT} = 8760 \cdot k_{WTA} \cdot \sum_{i=1}^{N_{vw}} P_{WT}(v_{wi}) \cdot f_W(v_{wi}) \cdot \eta_{WFCT}(P_{WF.nom}, v_{wi})$$

Where η_{WFCT} is the equivalent efficiency of the wind farm grid connection including power converter and power transformer.

3.1.4. SUMMARY OF WIND TURBINE PARAMETERS

Table 13 shows a summary of wind turbine main parameters needed for wind energy project evaluation. Parameters for two small scale wind turbines and for two large scale wind turbines are reported.

Table 13.- Summary of Wind Turbine main parameters for wind energy project evaluation.

Parameter	Unit	Small Wind		Large Wind	
Wind Turbine Type	--	**HWAT**	**DARRIEUS**	**HWAT**	**HWAT**
Reference	--	**Bornay 6000**	**Aeolos-V 3kW**	**V90-2.0 MW**	**V112-3.3 MW**
Manufacturer	--	BORNAY	Lotus Energy Tech	VESTAS	VESTAS
Nominal Power	kW	6.0	3.0	2000	3300
Peak Power	kW	6.2	3.8	2000	3300
Rotor Diameter	m	4	2.8	90	112
Rotor Height	m	-	3.6	-	-
Nominal Wind Speed	m/s	12	11	11,5	14,0
Cut-in Wind speed	m/s	3.5	2.5	4	2.5
Cut-out Wind speed	m/s	20	20	25	25.0
Survival wind speed	m/s	60	52.5	-	-
Weight (excl. Tower)	kg	107	106	104000	138000
Turbine Cost	EUR	€ 9 068.95	€ 4 594.00	€ 1 550 900.00	€ 2 095 350.00
Parallel spacing btw turbines	Rotor diameter	9	9	9	9
Tangential spacing btw turbines	Rotor diameter	4	4	4	4
Expected lifetime	years	20	20	20	20
Tower Height	m	12	12	80	84
Tower Cost	EUR	€ 2 496.11	€ 2 376.89	€ 199 401.43	€ 269 402.14
Converter Nominal Power	kW	6.8	4.2	2200.0	3630.0
Converter Cost	EUR	€ 1 815.00	€ 1 175.00	€ 265 868.57	€ 373 266.29
Total Cost per turbine	EUR	€ 13 380.06	€ 8 145.89	€ 2 016 170.00	€ 2 738 018.43

3.2. SOLAR ENERGY PROJECTS

3.2.1. SOLAR RADIATION CHARATERIZATION

The amount of sunlight available in each location at a given time is essential information in the design and evaluation of a photovoltaic system. The solar radiation can be characterized by the measured solar irradiance (power per area at a given moment) or radiation and by the solar insolation (total amount of solar energy received at a particular location during a specified period) (Bowden, 2019).

Solar insolation data can be used for rough estimations in simple PV system design while solar irradiance is used in more accurate evaluation of PV system performance which calculates the system performance at each point in the day. The used methods for PV system evaluation in this document are based on solar irradiance data.

The most common format for solar radiation data is Typical Meteorological Year (TMY) (Bowden, 2019). In the process of estimation of the TMY data, meteorological measurements are made at hourly intervals over several years to build up a picture of the local climate. The data set is produced by choosing for each month the most "typical" month out of number of measured years of data. Typically, the variables used to select the typical month are global horizontal irradiance, air temperature, and relative humidity. The TMY data set typically includes the following relevant quantities for PV evaluation:

- **Date and time:** The data is usually an average for the hour and covers half an hour before the sample to half an hour after the sample.
- **Global Horizontal Irradiation (GHI):** Amount of energy striking a horizontal surface during the hour.
- **Direct Beam/Normal Irradiation (DNI):** Irradiation striking a plate perpendicular to the sun's rays but does not include diffuse radiation.
- **Diffuse Horizontal Irradiance (DHI):** Amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun but has been scattered in the atmosphere.
- **Temperature:** Air temperature at 2 meters.
- **Wind Speed:** total wind speed at 10 meters.

TMY data can be obtained from different data sources, depending on the location and availability of data. A global solar atlas (World Bank Group, 2021) has been developed by the World Bank Group, and Figure 26 shows an example of the global map of direct normal irradiation (DNI) and global horizontal irradiation (GHI) provided by the global solar atlas app. Also, the National Renewable Energy Laboratory (NREL) has published a National Solar Radiation Database (NSRDB) with global irradiation datasets, which are available for download (National Renewable Energy Laboratory, 2021). Also, NREL has created EnergyPlus, a free simulation software package, developed under funding from the US Department of Energy, and has publish TMY data covering the period from 2006 and 2021 for about 16000 locations globally, with most of them available at no cost from their website (NREL – EnergyPlus, 2021).

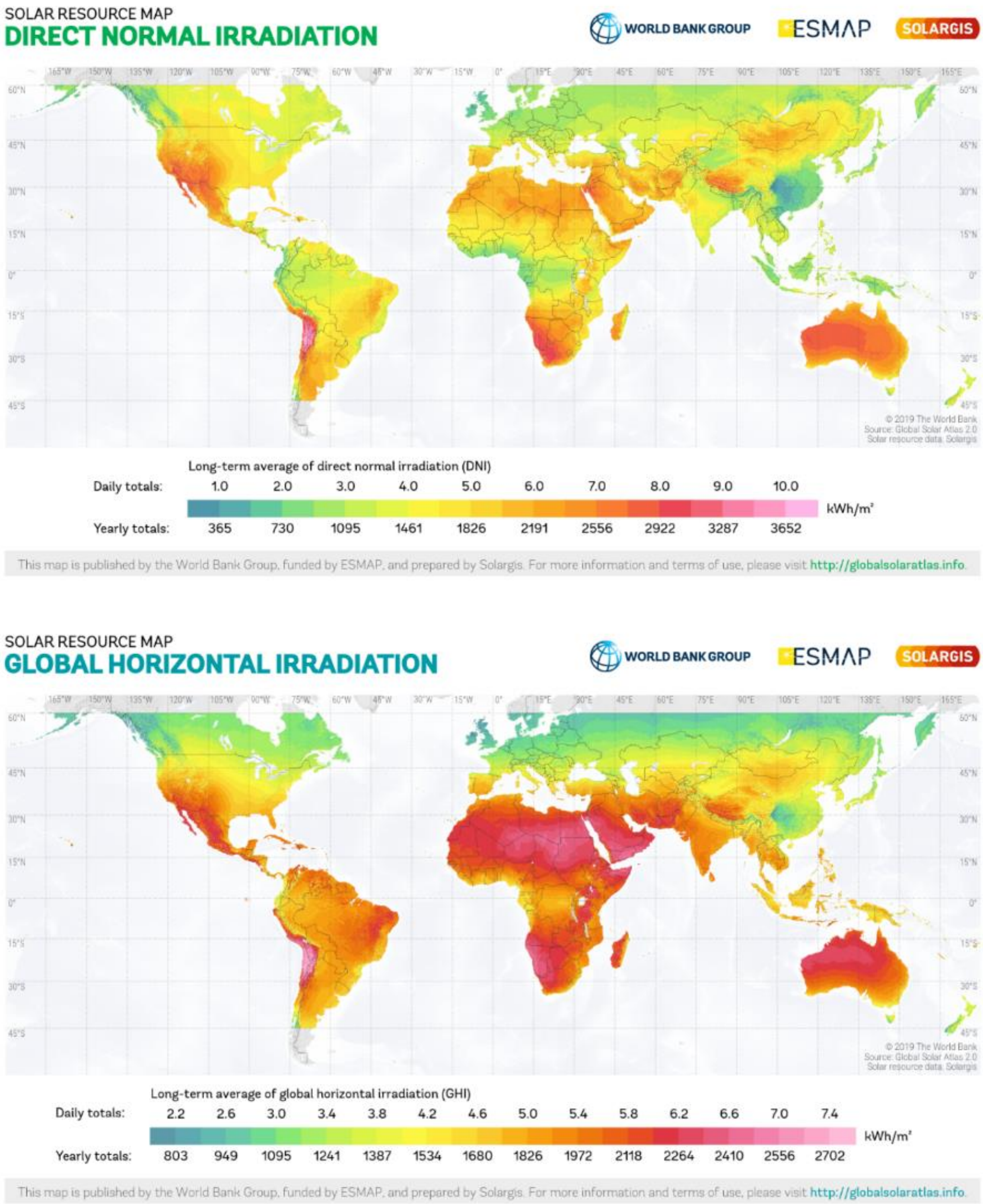

Figure 26.- Global Solar Atlas (World Bank Group 2021), (top) Direct normal irradiation and (bottom) global horizontal irradiation (source: https://globalsolaratlas.info/download)

On the other hand, the Photovoltaic Geographical Information System (PVGIS) (European Commission - EU Science Hub 2020) provides free and open access to information about solar radiation and photovoltaic system performance for any location in Europe and Africa, as well as a large part of Asia and America. Figure 27 shows an example of TMY data obtained from the PVGIS tool for a specific location at 43.342° Latitude and -4.145° Longitude. The calculation of the solar radiation in PVGIS uses information about the local horizon to estimate the effects of shadows from nearby hills or mountains.

The total amount of radiation received by a PV module (G_{PV}) is composed of direct (B_{PV}) and diffuse (D_{PV}) components. The direct component is the irradiance perpendicular to the PV surface. For PV systems with 2-axis trackers, which allow adjusting themselves to face the sun (as sunflowers do), the beam component is the DNI from TMY data.

However, most of the PV systems are fully/partially fixed in place and do not rotate (with few variations in their orientation/tilt angle manually done through the year), so the PV module only gets a portion of the DNI component from TMY data.

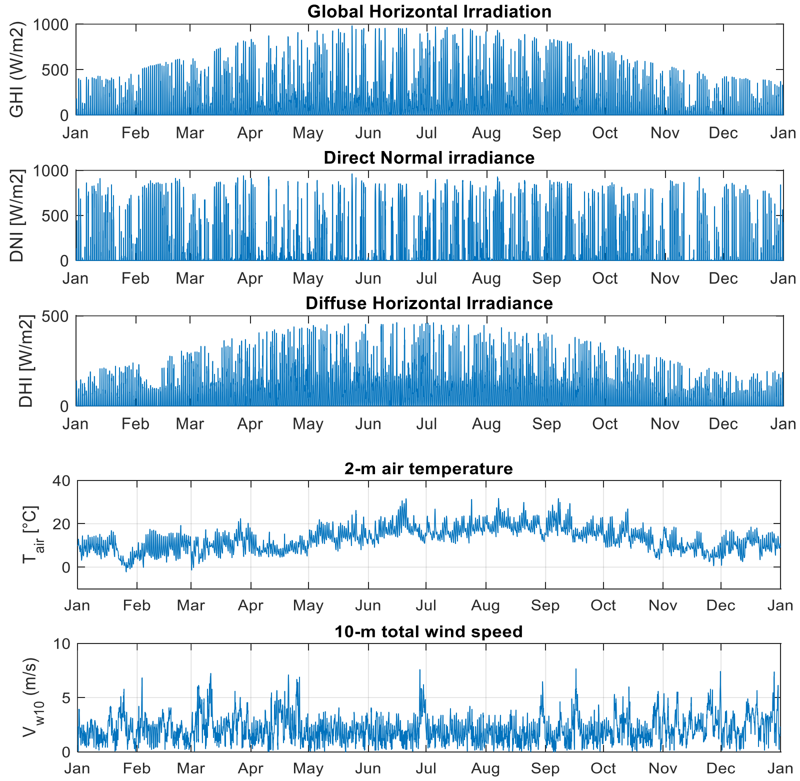

Figure 27.- TMY data obtained from PVGIS tool (European Commission - EU Science Hub, 2020) for a specific location at 43.342° Latitude and -4.145° Longitude

Considering the PV module tilt (β_{Mod}) and azimuth angle (ψ_{Mod}) definitions (Figure 28), it is possible to determine both the PV module beam component and PV module diffuse component (Bowden, 2019). For a more detailed description of these calculations see Deliverable 2.2.

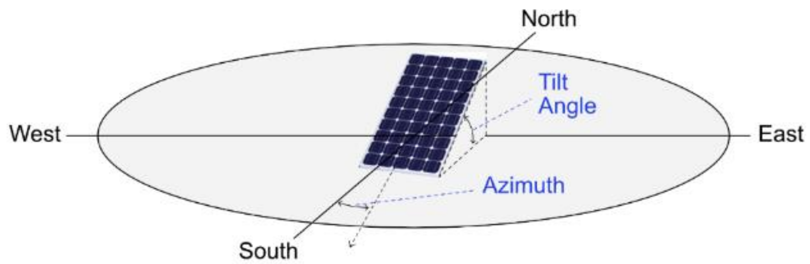

Figure 28.- PV module tilt and azimuth angle definition (source: https://solardesignguide.com/)

Combining the equations for those components with the TMY data, it is possible to calculate the total PV irradiance for an arbitrary oriented and tilted PV module. In Figure 29 the mean annual total PV irradiance as function of module tilt and module azimuth is shown for the TMY data in Figure 27. It should be noted that there is an optimal module orientation and tilt angle that maximize the total annual average PV irradiance (here, the optimal values are $\beta_{Mod.opt} = 36°$ and $\psi_{Mod.opt} = 44°$).

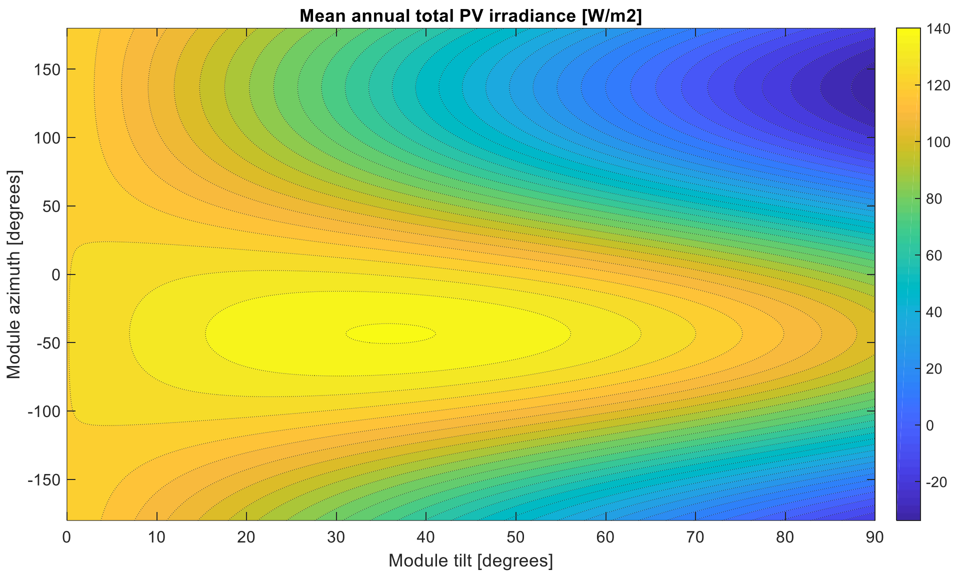

Figure 29.- Mean annual total PV irradiance as function of module tilt and module azimuth for the TMY data plotted in Figure 27. Location: 43.342° Latitude and -4.145° Longitude

3.2.2. MODELLING AND PARAMETRIZATION OF PHOTOVOLTAIC MODULES

PV Model and characteristic curve

The electricity generated by the photovoltaic modules/panels depends mainly on the total amount of radiation received by a solar PV module (G_{PV}), the presence or not of shadows in the installation site, the control method, and the performance of the PV module, which is associated to the module technology.

The electrical performance of the PV module is linked to its voltage-current (V-I) characteristic. Figure 30 illustrates the typical PV cell/module characteristic curve along with the relevant points in the curve: the short-circuit current, the open-circuit voltage and the voltage. Current and power at maximum power point (MPP) operation. Here, it is assumed that the PV control method follows the Maximum Power Point Tracking (MPPT) algorithm (Elbarbary, 2021), so the maximum power output of the solar cell can always be obtained at different conditions.

The V-I characteristic of the PV module at standard test conditions (STC: Irradiance G_{PV} = 1000 W/m2 and module temperature T_{Mod} = 25°C) can be estimated based on the equivalent circuit of a PV cell shown in Figure 31, and using a single exponential model as proposed in Dezso Sera (2007).

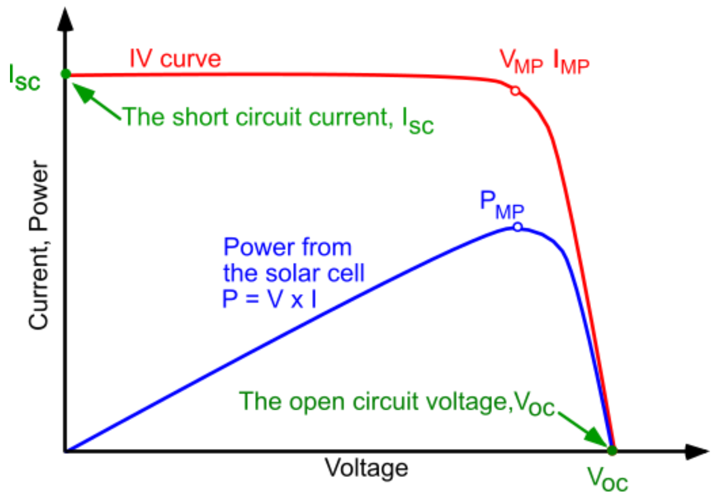

Figure 30.- Illustration of PV cell characteristic curve, Maximum Power Point (MPP), short circuit current and Open circuit voltage. Source: S.G.Bowden (2019)

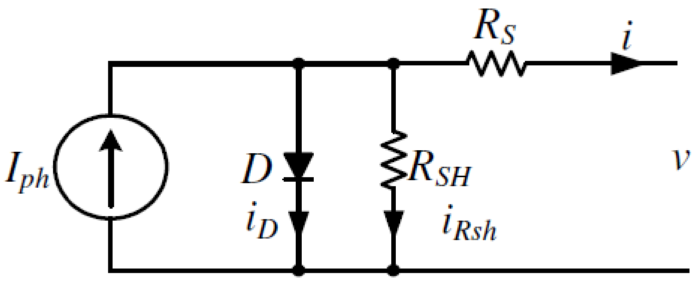

Figure 31.- Equivalent circuit of a photovoltaic cell using the single exponential model (Dezso Sera, 2007).

Therefore, the method proposed by Dezso Sera (2007) has been implemented to estimate the PV model parameters as function of the three key points of the V-I characteristic, normally provided in the datasheet of the PV module, the short-circuit point, the open-circuit point and the maximum power point (MPP), defined by the following values:

- $I_{SC\ STC}$: short-circuit current in STC
- $V_{OC\ STC}$: Open- circuit voltage in STC
- $V_{MPP\ STC}$: Voltage at MPP in STC
- $I_{MPP\ STC}$: Current at MPP in STC
- P_{MPPSTC}: Power at MPP in STC

Table 14 shows an example of typical information provided in the module datasheet, for this example the monocrystalline modules series NeON-R from LG manufacturer have been considered. Once the PV model parameters have been estimated, then the V-I characteristic of the PV module at different conditions (G_{PV} and T_{Mod}) are evaluated. Finally, the MPP operating condition is obtained. Figure 32 shows an example of obtained V-I curves with cell temperature of 25°C and for monocrystalline PV module LG375Q1C-V5 with datasheet parameters as shown in Table 14.

Table 14.- Datasheet info for Monocrystalline modules series NeON R from LG manufacturer.

Mechanical Properties

Cells	6 x 10
Cell Vendor	LG
Cell Type	Monocrystalline / N-type
Cell Dimensions	161.7 x 161.7 mm
# of Busbar	30 (Multi Ribbon Busbar)
Dimensions (L x W x H)	1,700 x 1,016 x 40 mm
Front Load*	6,000Pa
Rear Load*	5,400Pa
Weight	17.5 kg
Connector Type	MC4/MC
Junction Box	IP68 with 3 Bypass Diodes
Cables	1,000 mm x 2 ea
Glass	High Transmission Tempered Glass
Frame	Anodized Aluminium

*Manufacturer Declaration according to IEC 61215 : 2005 (Preliminary)
#Mechanical Test Loads 5400 Pa / 4000 Pa based on IEC61215-2 : 2016
(Test Load = Design Load x Safety Factor (1.5))

Temperature Characteristics

NMOT	[°C]	44 ± 3
Pmax	[%/°C]	-0.30
Voc	[%/°C]	-0.24
Isc	[%/°C]	0.037

Electrical Properties (STC[3])

Model		LG375Q1C-V5	LG370Q1C-V5	LG365Q1C-V5	LG360Q1C-V5
Maximum Power (Pmax)	[W]	375	370	365	360
MPP Voltage (Vmpp)	[V]	37.2	37.0	36.7	36.5
MPP Current (Impp)	[A]	10.09	10.01	9.95	9.87
Open Circuit Voltage (Voc)	[V]	42.8	42.8	42.8	42.7
Short Circuit Current (Isc)	[A]	10.83	10.82	10.8	10.79
Module Efficiency	[%]	21.7	21.4	21.1	20.8
Operating Temperature	[°C]	-40 ~ +90			
Maximum System Voltage	[V]	1,000			
Maximum Series Fuse Rating	[A]	20			
Power Tolerance	[%]	0 ~ +3			

[3] 1) STC (Standard Test Condition): Irradiance 1,000 W/m², module temperature 25 °C, AM 1.5.

Electrical Properties (NMOT[4])

Model		LG375Q1C-V5	LG370Q1C-V5	LG365Q1C-V5	LG360Q1C-V5
Maximum Power (Pmax)	[W]	282	279	275	270
MPP Voltage (Vmpp)	[V]	37.1	36.9	36.6	36.4
MPP Current (Impp)	[A]	7.61	7.55	7.51	7.45
Open Circuit Voltage (Voc)	[V]	40.3	40.3	40.2	40.2
Short Circuit Current (Isc)	[A]	8.72	8.71	8.7	8.69

[4] NMOT (Nominal Module Operating Temperature) : Irradiance 800 W/m2, Ambient temperature 20 °C, Wind speed 1 m/s, Spectrum AM 1.5

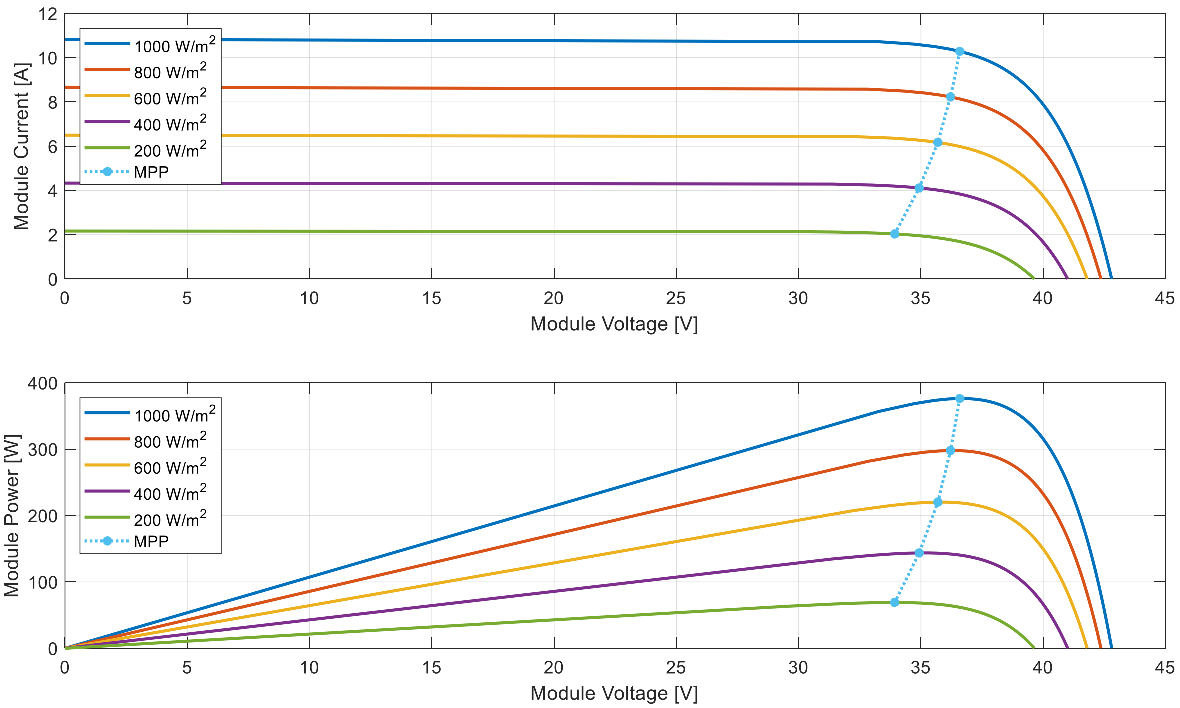

Figure 32.- Example of obtained VI curves with cell temperature of 25°C and for monocrystalline PV module LG375Q1C-V5 with datasheet parameters as shown in Table 18

Normally, the G_{PV} can be obtained from TMY data following the methodology described in section 3.2.1, however, the module temperature will depend on the PV module operating point and on the amount of radiation received. The module temperature can be estimated using the steady-state thermal model for the module presented in Hammami et al. (2017), which has been adapted for the shake of completeness.

The steady-state thermal balance equation for the PV module depends on the area of the PV module (A_{Mod}), the total incident power ($G_{PV} \cdot A_{Mod}$), the total radiative power reflected from the PV module glass surface ($\rho_{RPV} \cdot G_{PV} \cdot A_{Mod}$) with reflection index $\rho_{RPV} = 0.1$, the output power generated by the PV module (P_{MPP}), and the total heat exchange of the PV module ($Q_{Total\,PV}$), which is composed by the convective heat exchange (Q_{ConvPV}) and the radiative heat exchange (Q_{RadPV}) of front and back sides of the PV module.

Figure 33 shows an example of the obtained output power and module temperature as function the of irradiance G_{PV} and the ambient temperature for monocrystalline PV module LG375Q1C-V5 with datasheet parameters as shown in Table 14. The use of the proposed simplified model can speed up the computation of annual energy production by avoiding the solution of nonlinear equations in the V-I curve and thermal model for the different operating conditions throughout the year.

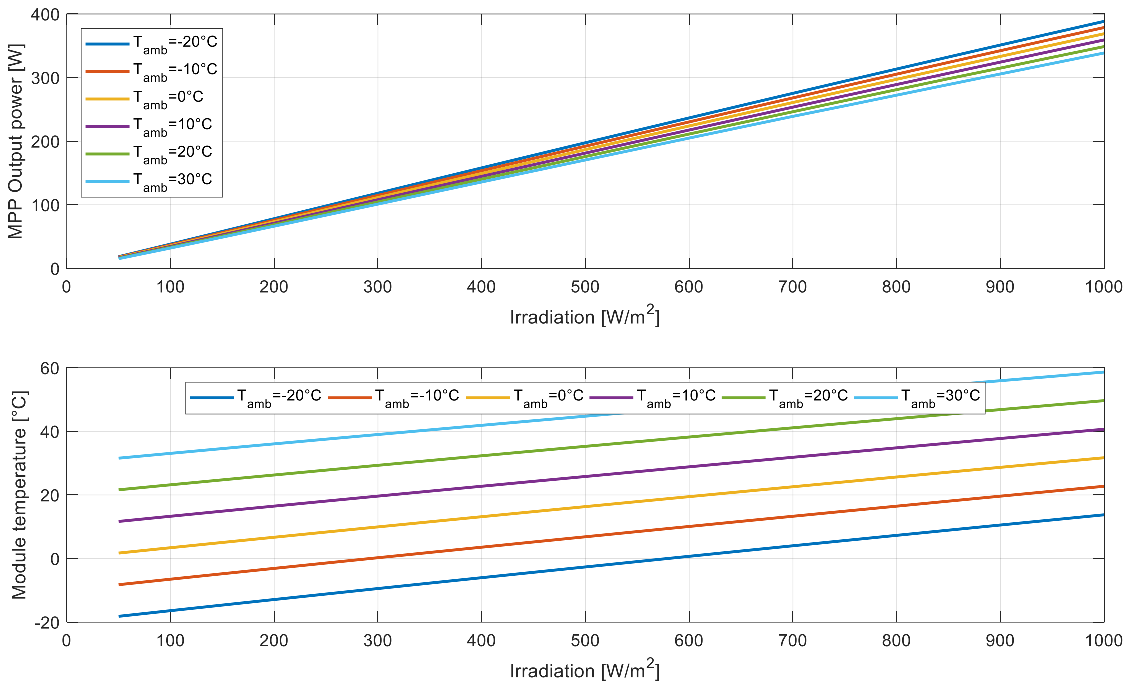

Figure 33.- Example of obtained output power and module temperature as function of irradiance and ambient temperature for monocrystalline PV module LG375Q1C-V5 with datasheet parameters as shown in Table 14

Finally, for a given PV module with defined voltage-current curve, the expected annual energy production (AEP_{PVM}) can be calculated by:

$$AEP_{PVM} = \sum_{t_h=1}^{8760} P_{MPP}\left(G_{PV}(t_h), T_{amb}(t_h)\right)$$

Where $G_{PV}(t_h)$ and $T_{amb}(t_h)$ are the time series for PV irradiance and ambient temperature that can be evaluated from available TYM data for the location of interest.

Expected Lifetime and Warranty period

The product warranty of the checked PV modules is between 5 and 15 years, which varies depending on the manufacturer. On the other hand, a 25 years performance warranty is typically given for crystalline silicon modules, which basically defines the expected lifetime of modules to be 25 years.

The performance warranty is normally associated to a linear degradation provided by the manufacturer, which is the maximum output degradation per year that can be expected after the first year of usage. Figure 34 shows the collected data related to linear output degradation for the analysed PV modules.

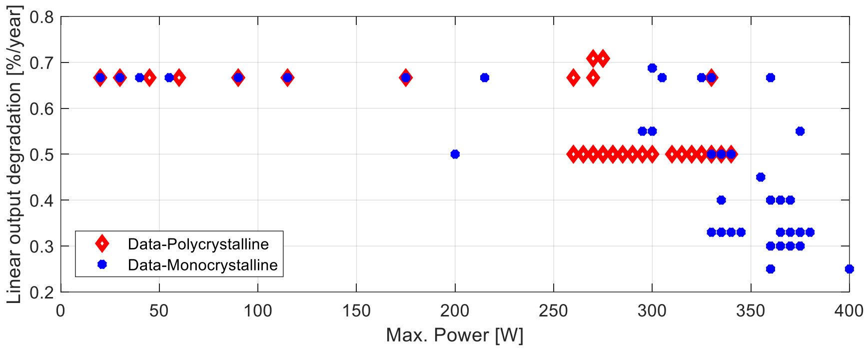

Figure 34.- Warranty - Linear Output Degradation for analysed PV modules

3.2.3. SOLAR PV FARMS MODELLING AND EVALUATION

In a similar fashion as the wind farm case, the evaluation of the expected annual energy production of a solar PV farm allocated in each NRA land depends on the solar farm layout, which basically is defined by the number of PV modules with defined tilt and azimuth orientation that can be placed in the given area. To determine the optimal layout of a solar farm is a complex problem outside of the scope of this study. A simplified solar farm layout problem has been considered in this study. The main parameter definitions for the considered solar PV farm layout is presented in Figure 35.

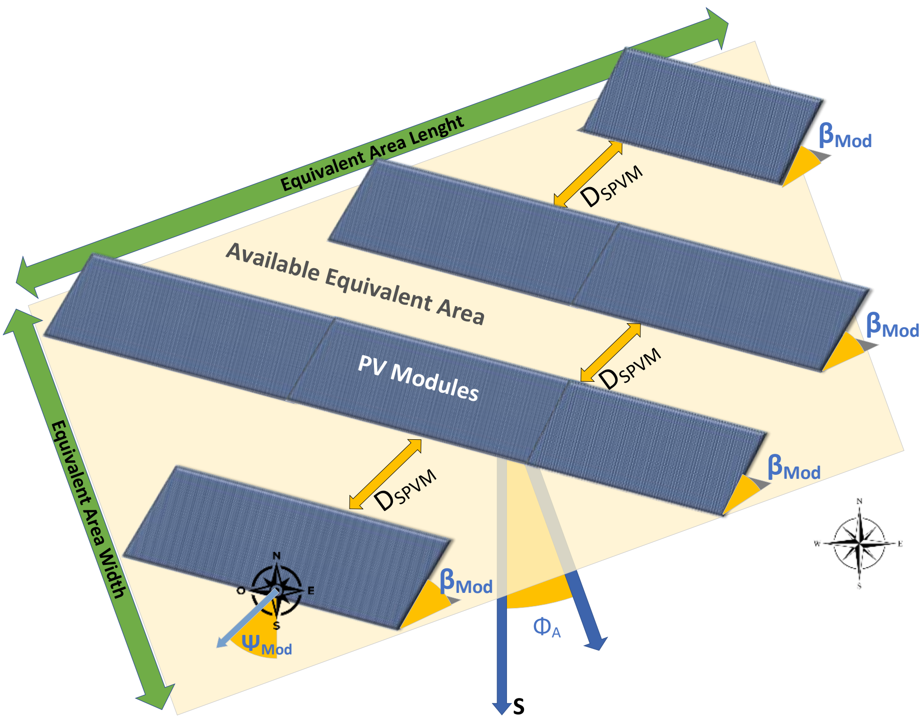

Figure 35.- Main parameter definitions for the considered solar PV farm layout

Given an available area with equivalent length (L_{eqA}), equivalent width (W_{eqA}) and average orientation measured by the equivalent area azimuth angle (ϕ_A) with south reference $(\phi_A = 0°)$ when the equivalent area width in line with East-West direction, the solar farm layout is defined by the number of PV modules that can be allocated considering module tilt (β_{Mod}) and azimuth orientation (ψ_{Mod}) measured from the south and assuming a rectangular distribution of the PV modules with a separation between PV modules parallel to the module azimuth orientation (D_{SPVM}) but not separation between PV modules in the same row perpendicular to the module azimuth orientation.

Figure 36 shows the geometric problem definition for the determination of number of PV module rows perpendicular to the module azimuth orientation, where $\Delta\phi_{AW}$ is the delta azimuth angle between the module azimuth and the equivalent area azimuth angle.

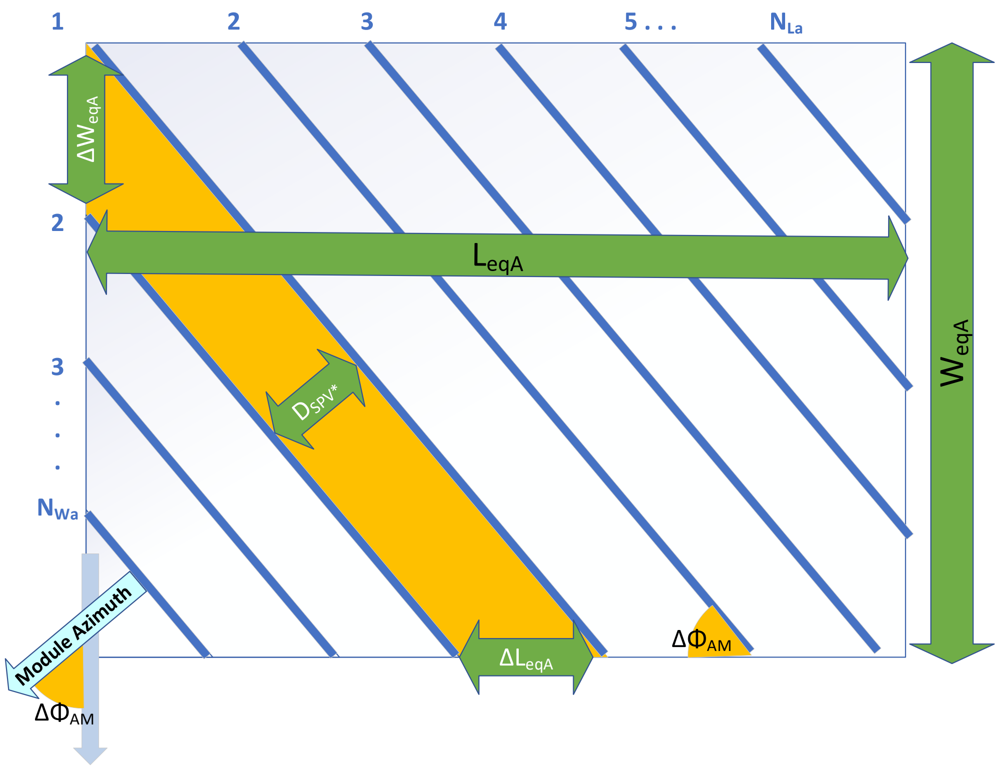

Figure 36.- Geometric problem definition for determination of number of PV Module rows perpendicular to the module azimuth orientation.

The maximum number of PV modules that can be allocated in the equivalent area is calculated by:

$$N_{PVM} = \sum_{k=1}^{N_{PVRows}} N_{ModperRow\,(k)}$$

Where N_{PVRows} is the number of PV rows and $N_{ModperRow}$ the number of PV modules per row.

Once the maximum N_{PVM} for a given area is estimated, the number of strings in the solar farm ($N_{stringPV}$) can be evaluated. The maximum number of strings ($N_{stringPV.MX}$) is constrained by the maximum open circuit voltage of individual PV modules ($V_{OC\,mx}$) and the maximum DC voltage of the PV farm connection ($V_{DC\,mx}$), which is normally limited to 1000V for the silicon PV modules considered here.

Since the PV modules have a negative thermal coefficient for the pen circuit voltage, the V_{OCmx} can be estimated considering the lowest expected ambient temperature in the location of interest. On the other hand, the minimum number of strings ($N_{stringPV.MN}$) is constrained by the minimum operating voltage of the individual PV modules (V_{MPPmn}) and the minimum DC voltage of the PV farm connection (V_{DCmn}), which is normally limited by the PV inverter operation limits.

The number of strings in the solar farm is selected to fulfil:

$$N_{stringPV.MN} \leq N_{stringPV} \leq N_{stringPV.MX}$$

Then, the number of PV modules per string ($N_{ModString}$) and the string voltage limits can be evaluated.

The expected total solar PV farm annual energy production ($AEP_{SolarFarm}$) can be estimated by:

$$AEP_{SolarFarm} = \sum_{k=1}^{N_{PVRows}} N_{ModperRow\ (k)} \cdot k_{PVShadow}(k) \cdot \left(\sum_{t_h=1}^{8760} P_{MPP}\big(G_{PV}(t_h), T_{amb}(t_h)\big) \cdot \eta_{PESF}\big(P_{SF.nom}, N_{PVM} \cdot P_{MPP} \cdot k_{PVShadow}(k)\big) \right)$$

Where P_{MPP} is the output power of a single PV module, which can be evaluated as described in section 3.2.2; η_{PESF} the power electronics converter efficiency of the solar farm interconnection, which depends on the nominal solar farm power and output power; and $k_{PVShadow}$ the PV row self-shading factor, which models the effect by which rows of PV panels cause shading to subsequent rows. The self-shading factor is modelled based on the Self-shading and shadow angle definition show in Figure 37.

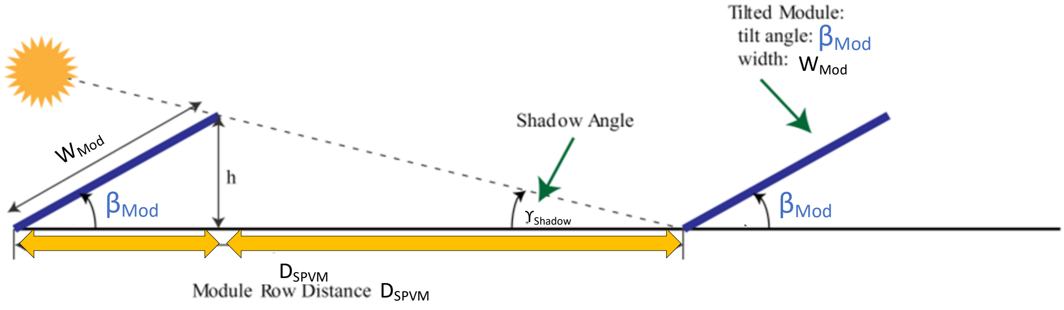

Figure 37.- Self-shading and shadow angle definition. Source: figure adapted from Energy (2016)

3.2.4. SUMMARY OF PV MODULE PARAMETERS

In Table 15 a summary of PV module main parameters needed for the evaluation of solar energy projects is shown. Exemplary data for three PV modules are reported.

Table 15.- Summary of PV module main parameters

Parameter	Unit	Monocrystalline	Monocrystalline	Polycrystalline
Reference	--	**A-330M GS PERC**	**JAM72S30-530**	**CS6U-335P**
Manufacturer	--	ATERSA	JA SOLAR	Canadian Solar
Number of cells	--	60	144	72
Module Length	mm	1640	2278	1960
Module Width	mm	992	1134	992
Module Thickness	mm	35	30	35
Module Weight	kg	17.5	27.8	22.4
Maximum Power (at STC)	W	330	530	335
Module Efficiency	%	19.78	20.50	17.23
Maximum Power (at NMOT)	W	279	401	247
Cost per module	EUR	€ 297.00	€ 220.00	€ 167.00
Output Power Model:				
k_{PG0T0}	--	0.6959	1.0933	0.599962
k_{PG1T1}	--	2.17E-07	4.41E-07	7.33E-07
k_{PG0T1}	--	-0.0012	-0.0020	-0.00097
k_{PG1T0}	--	-5.70E-05	-1.34E-04	-0.0003

4. LEGISLATIVE & REGULATORY FRAMEWORK

4.1. RESEARCH & DUE DILIGENCE REPORT ON NATIONAL AND EU REGULATIONS

This report aims to identify the relevant national and EU regulations applicable to the NRAs in the energy production area. It analyses regulations concerning renewable energy production, energy supply for government entities and the generation and commercialization of electricity by examining various figures and business models such as demand aggregators, renewable energy communities and charging infrastructure among others. Its objective is to provide a baseline for further analysis to identify potential risks, pitfalls and barriers in implementing energy generation business models for NRAs.

4.1.1. EU REGULATIONS

In 2015, the EU committed to limiting global warming to well below 2°C and to pursue efforts to limit to 1.5°C. The Winter Package in 2016 proposed eight measures to transition to a clean energy economy. By 2019, three directives were enacted, including the Renewable Energy Directive and the Regulation on the Governance of the Energy Union and Climate Action. Moreover, the European Green Deal (EGD), presented in 2019, established the goal of net zero greenhouse gas emissions by 2050. To reach the EGD's goals, the commission pledge to improve the existing legislation to fit for 55% emission reduction by 2030. Within the framework of the EGD, and after revising its targets, the current renewable energy target for the EU was set at 42.5% by 2030. Additionally, the GHG intensity was set to reduce by 16% in the transport sector by 2030.

Governance of energy union and climate action objectives

The Regulation on the Governance of the Energy Union and Climate Action establishes a framework for reliable and transparent governance to achieve the European Union and Paris Agreement objectives. As such, member states are required to develop National Energy and Climate Plans (NECPs) every ten years focusing on targets regarding GHGs emissions, renewable energy, energy efficiency and interconnection of electricity. In addition, the EU strategy for Energy System Integration highlights the need for reviewing and refocusing different aspects to meet the 2050 energy and emissions targets. For instance, this includes an expansion of Emissions Trading Systems to include emissions from road transport by revising policies and raising the standard of vehicles by 2030 to achieve climate neutrality. This transition must also be accompanied by the development of the infrastructure to recharge and refuel these vehicles.

The Green deal and the Internal electricity market

The internal market for electricity Directive aims to establish an integrated and competitive electricity market to accelerate the uptake of renewable energy. This regulation sets common rules for generation, transmission, distribution, energy storage and electricity supply. The Clean Energy Package, included in this Directive, enables the integration of large amounts of variable electricity generation and the integration of flexibility from demand response and storage, stimulating investments and empowering electricity customers. The EU Strategy for Energy System Integration aims to facilitate the operation of electricity networks by advocating coordinated planning and operation of the energy system "as a whole" across several infrastructures and sectors.

4.1.2. COMPARISON LEVEL: AMBITIONS, GOALS AND COMMITMENTS

As a general overview, most of the countries under the study show no important barriers concerning their ambitions (see green colours in Figure 38) as they all belong to the European Union (apart from the UK and Norway who have nevertheless aligned or more ambitious commitments).

All the countries under this study have presented long-term strategies to reduce the greenhouse gas emissions; all of them in line with the overall goals set by European Union decarbonization strategy according to the analysed legislation.

Related to the strategies, all the analysed countries have presented National Energy plans (2021 to 2030) in order to get over the major climate challenges. The plans are ambitious and will be a positive driver toward the implementation of renewable energy projects in the road infrastructure.

Regarding Norway and United Kingdom, Norway is not part of the Union and as of 31 January 2020, the UK has left the EU and will therefore not contribute to EU targets or be bound by the Renewable Energy Directive after the Transition Period ends. This fact on its own is not a barrier as the countries have set targets and commitments aligned, or even more ambitious than those of the EU. Nevertheless, they have no pressure from the union to achieve them in order to comply with the overall union target.

	Germany	Austria	Ireland	Netherlands	Belgium	Denmark	Sweden	Norway	U.K.
National Long Term Strategies									
National Energy Climate Plans									
2030 Framework for the Union - Targets									
Binding Overall Union Target 2030									

Figure 38.- Ambitions, Goals and Commitments Matrix

4.1.3 GERMANY

Regulatory Framework

The most relevant laws in German legislation are the Energy Industry Act EnWG and the Renewable Energy Sources Act EEG:

- **Energy Industry Act EnWG** is a policy framework which aims to improve competition, security on energy supply and sustainable energy production. It includes a requirement for electricity labelling based on the energy sources, enabling consumers to make informed choices about their suppliers and the energy sources they use.

- **Renewable Energy Sources Act** The most recent amendment to the EEG, which was published in 2023, states that a minimum of 80% of Germany's total electricity consumption must be derived from renewable energy sources by the year 2030 and net zero by 2045.

Relevant figures and structures to be defined

The relevant legislation for defining figures and structures in various areas is as follows:

- **Demand aggregators**: Demand response management on distribution level financial benefits are organized by EnWG, the operating reserve markets are based on EnWG, the renewable suppliers are based on the EEG and the Electricity Grid Access Ordinance StormNZV.
- **Closed distribution networks and renewable energy communities** lack clear legal definitions, although citizen energy communities are defined in the EEG and offer simplified access for small windfarm auctions.
- **Charging infrastructure** is addressed in the proposed Building E-Mobility Infrastructure Act. Technical standards for charging equipment are regulated in Charging Infrastructure Regulation.
- **PPAs** are primarily governed by EnWG, EEG and Electricity Network Fee Ordinance StormNEV.

4.1.4. AUSTRIA

Regulatory Framework

The most relevant laws in Austrian legislation are the Electricity Act, the Green Electricity Act and the Renewable Expansion Act:

- **Electricity Act EIWOG** covers electricity generation, transmission, distribution, electricity supply, system charges, billing, internal organization, unbundling and transparency of the accounts.
- **Green Electricity Act ÖSG and Renewable Expansion Act EAG** aims to support green electricity generation through subsidized feed-in tariffs and investment grants. It sets a goal of generating 100% renewable electricity supply by 2030.

Relevant figures and structures to be defined

The relevant legislation for defining figures and structures in various areas as follows:

- **Demand Aggregators:** Energy aggregation and access to operating reserve auctions is considered in the latest EAG proposal.
- **Closed Distribution Networks and renewable energy communities** are defined on the latest EAG proposal.
- **Charging infrastructure** is addressed in the Clean Energy in Transport policy framework.
- **PPAs** are a common practice in Austria despite not being mentioned in main legislation, they are driven by renewable energy plants.

4.1.5. THE NETHERLANDS

Regulatory Framework

The most relevant laws in Dutch legislation are the Climate Act, Energy Act and the environmental and spatial planning acts:

- **Climate Act** legislation establishes the CO2 emissions reduction targets aligned with international agreements. This act is updated every 5 years based on the current situation. It aims for a 95% emission reduction compared to 1990, achieving carbon neutrality by 2050. As a medium-term objective, it requires a reduction in emissions by 49% by 2030.
- **Energy Act** regulates the electricity market, protects the customer's position and guarantees the energy availability.
- **Acts on environmental and spatial planning** policies that regulate locations for the renewable development, the implementation of CO2 certificates for transport, set rules for permits and environment and set limitations on nitrogen emissions.

Relevant figures and structures to be defined

The relevant legislation for defining figures and structures in various areas is as follows:

- **Demand Aggregators** are addressed in the new Energy Act.
- **Closed Distribution Networks and renewable energy communities** are defined on the Grid Code, located within the Energy Act which describes the regulations on private and public grids. In addition, the Electricity Act provides further rules on independent network operation.
- **Charging infrastructure** is addressed in the Clean Energy in Transport policy framework.
- **PPAs** legal framework is covered in the Energy Act and certification of green energy is covered by the GoO Act.

4.1.6. BELGIUM - FLANDERS

Regulatory Framework

The most relevant laws in Belgian legislation are the Climate Act, Energy Act and the Environmental and Spatial Planning Acts:

- **Belgian Integrated National Energy and Climate Plan** captures the EU Energy and Climate policy. On this basis, Flanders agreed its **Flemish Climate strategy 2050**.
- **Energy Act** states that both the regional and federal governments share responsibility for electricity and natural gas markets. Federal energy laws include the Electricity Act 1999 and internal electricity market. Moreover, the VREG is the Flemish regulator supervised by the Flemish Parliament, overseeing electricity and gas markets, including green energy regulation. Energy law in Flanders is governed by the Energy Decree, Energy Decision, and technical rules.

- **Acts on environmental and spatial planning** collect different laws covering rules and regulations for spatial planning, environmental impact and permitting for sustainable development including the Flemish Environmental Regulation (VLAREM) and the Spatial Planning Act.

Relevant figures and structures to be defined

The relevant legislation for defining figures and structures in various areas is as follows:

- **Demand Aggregators:** ELIA is national grid operator and is addressed in Federal Grid Code 2019.
- **Closed distribution networks and renewable energy communities** are covered by the VREG and part of the Energy Decree.
- Investments on **charging infrastructure** are being made to develop a network of charging points for electric vehicles. The VREG covers the different distribution operators.
- **PPAs** and green power legal framework is covered in the Energy Decree and Energy Decision of Flanders.
- **Offshore** is regulated by CREG. This organism is responsible for offshore wind concessions, permitting and green power certification.

4.1.7. DENMARK

Regulatory Framework

The most relevant laws in Danish legislation are the Act on promotion of renewable energy, the Act on promotion of savings in energy use and the Electricity supply Act:

- **Act on promotion of renewable energy** to encourage renewable energy production, reduce reliance on fossil fuels, ensure energy security, and lower CO2 emissions in accordance with climate and environmental goals.
- **Act on promotion of savings in energy use** to promote energy savings and efficiency, considering climate, environmental security of supply, and economics. It covers efficiency and energy use reduction in products, plants, processes, buildings, and information to consumers.
- **Electricity supply Act** to ensure secure, affordable, and environmentally sustainable electricity supply, while protecting consumer interests and providing them with influence in the electricity sector's management.

Relevant figures and structures to be defined

The relevant legislation for defining figures and structures in various areas is as follows:

- **Demand Aggregators**: There is no legal framework currently, but it is not disallowed.
- **Closed distribution networks** do not have specific mention in the law, but they are closely related to the executive order on net calculation for their own electricity producers.
- **RE communities** do not currently have a legal framework, but are not disallowed.
- **Charging infrastructure** is governed by the Act on infrastructure for alternative fuels.
- **PPAs** are under discussion among industry. No specific framework has been identified yet.

4.1.8. UNITED KINGDOM

Regulatory Framework

As of 31 January 2020, the UK has left the EU, and therefore will not contribute to EU targets or be bound by the Effort Share Regulation after the Transition Period ends. However, the UK has its own objectives. In the UK's British Energy Security Strategy and the Nationally Determined Contribution it is stated that all regions have high ambitions and work hard to reduce the GHG emissions along every sector with a global target of reducing UK GHG emissions by around 68% by 2030, compared to 1990 and net zero by 2050. The most relevant laws in UK legislation are the Electricity Act 1989 (as amended), the Energy Act 2013, Electricity Market Reform (EMR), Energy White Paper and the Road to Zero:

- **Electricity Act 1989 and Energy Act 2013** provide a complete framework for development of renewable energy technologies in the UK, with a range of measures to support the sector and to incentivize investment.
- **Electricity Market Reform (EMR)** is intended to provide a stable and predictable framework for investment in low-carbon energy sources, while also ensuring that there is sufficient capacity to meet electricity demand
- **Energy White Paper (Dec 2020)** establishes plans for transformation of transport, energy and infrastructure in order to delivery significant decarbonization of power in the 2030s and net-zero by 2050.
- **British Energy Security Strategy (April 2022)**
- **Road to Zero** sets out the UK's strategy for cleaner road transport in order to delivery zero-emission transport by 2030 and the development of the required charging infrastructure and manufacturing capability.

Key Industry players

The key players and roles in the electricity transmission, distribution and supply sectors in the UK are showcased below:

- The transmission owners for the different regions are: National Grid Electricity Transmission (NGET) for England and Wales, Scottish Hydro Electric Transmission Plc for northern Scotland, and SP Transmission Plc. for southern Scotland. The System Operator in England, Wales and Scotland is the National Grid Electricity System Operator (NGESO).
- There are six Distribution Network Operators that own and operate the distribution networks (Electricity North West, Northern Powergrid, Scottish and Southern Energy, SP Energy Networks, UK Power Networks and Western Power Distribution).
- There are companies that generate and supply electricity (Centrica, EDF, E.ON, etc.), companies that only generate (UK Power Reserve, EPH, etc.), and smaller suppliers and energy aggregators.
- The market operator is Elexon, responsible for delivering the Balancing and Settlement Code.

- Ofgem (Office of Gas and Electricity Markets) is the government regulator for the electricity and downstream natural gas markets in Great Britain.

Relevant figures and structures to be defined

Figures and structures in various areas are described below:

- **Self-consumption** has been in place for several years. The self-consumption installation has an electricity supply contract either through a supplier or aggregator. The simple scheme is limited to very low capacities depending on grid connection voltage. Large installations need to go through the normal permitting process.
- **Demand Aggregators** are commonly used by consumers with supply points spread. Demand aggregator can deliver demand response services.
- **Renewable energy communities**, the Smart Export Guarantee, the Renewable Heat Incentive, and the Local Energy Programme are meant to incentivise local generation.
- **Closed distribution networks** allow a distribution exemption holder to apply to Ofgem for classification as a Closed Distribution System (CDS). Ofgem must agree to classify the distribution exemption holder if it meets the criteria laid down in regulations.
- **Charging infrastructure** is supported by the Government with a variety of schemes, including in people's homes and workplaces. The electric vehicle infrastructure strategy was published in March 2022. The provision of charging infrastructure was also included in amendments to the Building Regulations 2010, in June 2022.
- **Power Purchase Agreements (PPAs)** are often used, specifically long-term PPAs. The UK has a relatively healthy short-term PPA market which a number of policies have facilitated. Similarly, the Contracts for Difference scheme, prompts PPAs referenced to the CfD price.

Relevant British supporting plans and strategies are showcased below:

- **Smart Export Guarantee (SEG)** are a financial incentive to support distributed and small-scale renewable generation. The SEG tariff is a guaranteed price for each unit of electricity exported to the grid. It is an obligation for licensed energy suppliers to offer eligible generation projects an SEG tariff rate.
- **Contracts for difference (CFD)** for larger schemes of low carbon generation, with an installed capacity of at least 1MW. The application process for CFD is more complex than for SEG scheme.

4.1.9. IRELAND

Regulatory Framework

The most relevant laws in Irish legislation are The Programme for Government, The National Energy and Climate Plan 2021-2030, Climate Action Plan, and Climate Action and Low Carbon Development Bill:

- **Programme for Government** goes beyond NECP and EU efforts, focusing on higher ambition. It includes expanding microgeneration, focusing on rooftop solar energy, increasing sustainable energy communities and prioritizing microgeneration development with the ability to sell excess power back to the grid.

- **National Energy and Climate Plan 2021-2030** focuses on decarbonization, energy efficiency, security, markets, and innovation. It includes a 7% GHGs yearly reduction, aims for 70% renewable electricity, and promotes 15% of demand through PPAs.
- **Climate Action Plan** includes a road map outlining the climate policy to halve emissions by 2030 and to achieve net zero by 2050. It includes support for microgeneration, allowing individuals to sell excess electricity. The plan also promotes community participation in renewable generation and sets EV targets with charging infrastructure development.
- **Climate Action and Low Carbon Development Bill** includes legislation that commits Ireland to net-zero carbon emissions by 2050, including policies to achieve a 7% GHGs emissions yearly reduction and annual revisions of the Climate Action Plan.

Relevant figures and structures to be defined

Relevant Irish market demand aggregators are:

- **Microgeneration Support Scheme** allows individuals and communities to sell renewable electricity to the national grid.
- **Renewable Electricity Support Scheme** aims to enable community participation in renewable energy projects by providing pathways to support the projects. It includes financial assistance for renewable electricity projects and aims to diversify technology diversity by broadening the renewable electricity technology mix.

Relevant Irish supporting plans and strategies are showcased below:

- **EirGrid "Delivering a secure sustainable electricity system" programme** aims to put in place the correct structure, level, and type of service to ensure the electricity system can operate securely with higher levels of non-synchronous renewable generation. It also promotes the use of Smart Grid technologies allowing greater user participation.
- **National Transport Authority- Statement of strategy 2018-2022** aims to align land use and transport policies to promote sustainable transportation. Proposals will be developed to integrate land use and transport plans at the local level. Guidance will be provided to support statutory bodies in achieving sustainable transport objectives.
- **Corporate PPAs** are a well-established, proven concept in the energy market.

4.2. RED FLAG REPORT

Arup carried out an energy regulation assessment examining general EU legislation and the specific measures adopted by selected countries (Germany, Austria, Netherlands, Belgium-Flanders, Denmark, Sweden, Norway, Ireland, and UK). To perform this analysis, the chosen rules to study were the ones regarding the generation and commercialization of electricity at EU level and in each of the mentioned target countries. By observing Figure 39, users can easily identify which countries may be more suitable for a potential business case in which the implementation of renewable energies is involved.

Low risk has been assigned to regulations that do not present any barriers for their implementation in the country. Medium risk is considered when the possible barrier is considered manageable but may require ongoing monitoring and review. Finally, high risk represents a material and unmanageable barrier to the implementation that would render a certain strategy/business model unfeasible.

In this section, a summary of the potential risks, pitfalls and barriers have been ordered by risk. The countries with no relevant risks detected have not been mentioned, for further information, refer to the red flag report of the project. The analysis has been structured based on the requirements made to the countries by the three main EU legislation on energy and climate.

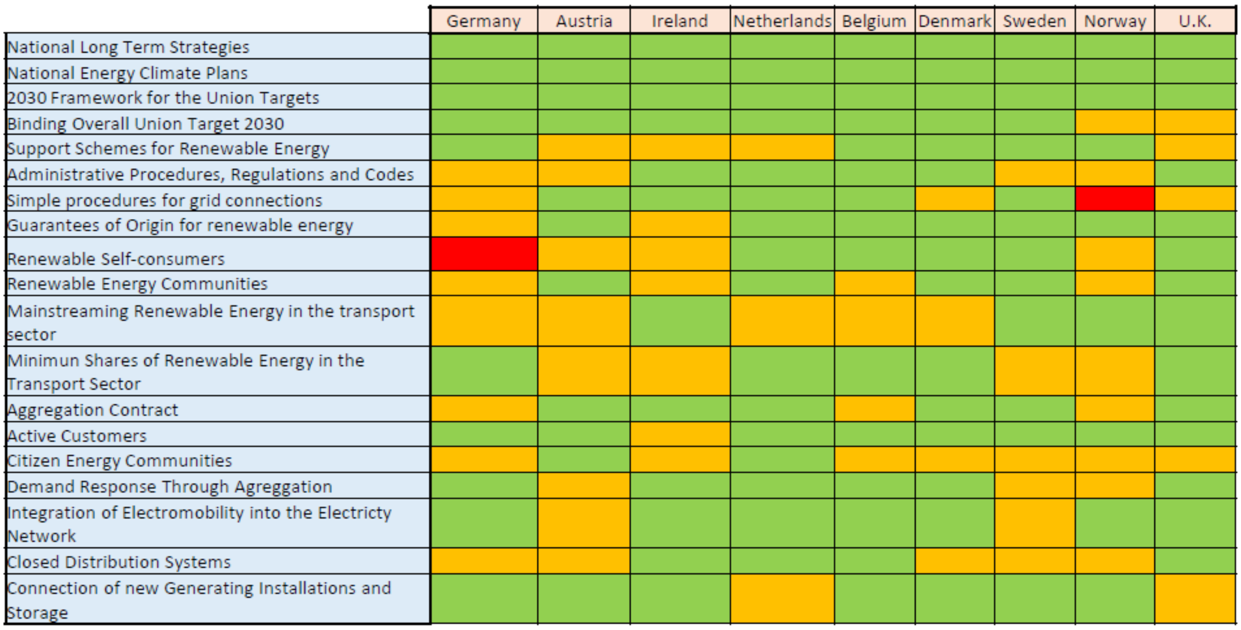

Figure 39.- Overview matrix on potential barriers/challenges for implementation of RES

4.2.1. GOVERNANCE OF THE ENERGY UNION AND CLIMATE ACTION

Low Risk:

- **National long-term strategies** are required to be developed by Member States and must be consistent to their national energy and climate plans. They have been correctly addressed and they will be a positive driver for renewable energy in road infrastructures.
- **National energy and climate plans** must be updated by Member States every ten years. Currently, they must pay special attention to the 2030 targets for GHGs emission reduction, renewable energy, energy efficiency and electricity interconnection. They were analysed and presented in all countries.
- **2030 framework for energy and climate for the Union's objectives** for GHG emission reductions, most of the countries have already developed concrete strategies.

4.2.2. PROMOTION OF THE USE OF ENERGY FROM RENEWABLE SOURCES

Low Risk:

- **Binding overall Union target for 2030** aims to achieve a renewable energy consumption collectively in EU's Member States of at least 42.5%.
    - Barriers regarding this topic are present in **Austria**, as its measures to reduce emissions are implemented by different government levels, as such, the coordination of the different government levels could pose a challenge for the project.
    - In **Ireland**, barriers include an unknown roadmap regarding hydrogen development.
    - By leaving the EU, the UK will no longer contribute to the EU's renewable energy targets. Although the UK has set a new target of 22-29% renewable energy share by 2030, it is a less ambitious target than the EU target.
- **Opening of support schemes for electricity from renewable sources from neighbouring countries**: The Commission introduced an obligation on Member States to partially open their support schemes for cross-border renewable energy producers.
    - Barriers arise in the **Netherlands** as in the new SDE++ (Sustainable energy transition subsidy scheme), electricity production competes with CO2 saving solutions. In addition, this scheme will no longer be available in 2025 which could be a potential risk for the project.
    - There are additional barriers in **Sweden** as, although two joint support schemes exist with Norway and Denmark, the green electricity installations which are able to receive electricity certificates are the ones located in Sweden.
- **Calculation rules with regard to the minimum shares of renewable energy in the transport sector**: To meet the minimum renewable energy requirement for the transport sector (14%*), the share of renewable electricity shall be considered four times its energy content when supplied to road vehicles and 1.5 times when supplied to rail transportation.
    - Barriers in **Austria** include the lack of legislation regarding the minimum share of renewables in the transport sector.
    - Two main barriers have been identified in **Sweden.** Firstly, biofuels from waste and residues are double-counted against the Renewable Energy Directive goal. Also, rail traffic electricity is the only one reported as renewable in Sweden, excluding other modes of transport.
- **Other provisions on renewable energy in the transport sector** may be developed. Member States shall take measures to ensure the availability of fuels from renewable sources for transport, including in relation to publicly accessible high power recharging points.
    - Barriers in **Austria** include the lack of legislation regarding this topic.

Medium Risk:

- **Support schemes for energy from renewable sources** may be applied to achieve renewable energy targets in each State by incentivizing renewable electricity integration and market responsiveness.

  - Barriers exist in **Austria**, as the subsidies for PV plants on agricultural or grassland areas are limited unless these areas are specifically designated for the construction of PV installations.
  - **Germany** faces challenges in securing support due to its complex and competitive processes.

(*) the Renewable Energy Directive has been updated as October 2023, EU2023/2413. The figures in this report might refer to the older version EU2018/2001. Specifically, the minimum renewable energy requirement for the transport sector has been increased to 29%.

  - In addition to that, **Ireland** has no subsidy scheme for hydrogen, which could be a potential barrier for the development of hydrogen-based technologies in the future.

- **Administrative procedures, regulations and codes** must be simplified. Member states shall remove unjustified barriers and facilitate the integration and deployment of PPAs.
  - Barriers exists in **Austria**, where renewable PPAs are not specifically addressed by legislation. Moreover, the existence of PPAs directives in **Sweden** is considered unclear. This lack of rules could jeopardize project implementation and financing conditions.
  - In **Sweden**, the solar electricity market has expressed concerns about regulations favouring residential owners and small systems, limiting solar expansion. To address this, a tax exemption limit has been raised to exempt PV systems up to 500 kW.
  - **Germany** has recently implemented legislation on Renewable Energy communities in the Renewable Energy Expansion Act in 2021 so its implementation is starting to be deployed.
  - **Norway** has extensive requirements for renewable energy developments acting as a barrier.
- **Simple-notification procedures for grid connections** must be established where renewable installations or self-consumers' aggregated production units are connected to the grid by notifying the distribution system operator.
  - Barriers exists in countries such as **Germany**, where projects with a 10.8 kW capacity or higher must go through a standard connection approval process.
  - In **Sweden** electricity utility suppliers have the right to reject grid connection for 11 kW or smaller capacity plants.
  - The country with highest barriers is **Norway**, which is introducing access payments and charges related to the system's costs, a financial burden for the installation's owner.
  - There are additional rules in **Denmark** depending on the size and type of connection that may pose obstacles. As such, grid connection for plants up to 11 kW can be rejected if they are not three-phase. Net-metering for 50 kW and above plants is determined by Energinet.dk. Solar energy installations up to 50 kW require a private supply system, while larger installations can be connected to a private supply system or located at the place of consumption.
  - Higher risks exist in **Norway** and the **UK**, where no simplified procedure for grid connection or renewables is available. The government is going to publish a Connections Action Plan in summer 2023 for simplified grid connections in UK. This has not yet been completed.
- **Guarantees of origin for energy from renewable sources** must be available for request from a renewable energy producer. Its issue will certify the renewable production.

  - Small barriers exist in **Germany**, where electricity from projects subsidized by EEG is not allowed to issue GOs. Therefore, it cannot be commercialized as renewable electricity.

  - In the same way, renewable generators in **Ireland** covered by a government support scheme will not receive GOs, but their attributes will be transferred to the supplier with whom they have a PPA. Suppliers without a PPA can purchase GOs from renewable generators without receiving support.

- **Renewable energy communities** must be available for household customers to participate in them.
  - Barriers regarding this topic include countries like **Belgium-Flanders**, **Norway** or **Ireland** which have not developed specific framework regarding the promotion and development of this communities. As such, some potential business models would not be viable.

- **Mainstreaming renewable energy in the transport sector** must have a share of at least 14%* by 2030. Each member state shall set an obligation to ensure this portion within the final energy consumption.
  - Barriers exists in **Austria** or **Germany**, as no dedicated legislation has been issued yet. On the other hand, in countries where targets are set, such as **Ireland**, there are barriers as electric vehicles are slowly entering the market and charging infrastructures are not sufficient.
  - In addition, countries such as **Belgium-Flanders** include hybrids and biofuels in this scheme even though they are not a clean alternative and no measures for aviation and shipping have been established.

High Risk:

- **Renewables self-consumers** must be taken into account in legislation. They can impose non-discriminatory charges and fees on self-consumers. Member States should create a specific framework to support the development of renewables self-consumption, which can involve third-party ownership or management of the installation.
  - With a slightly lower risk, countries such as **Austria** or **Ireland** lack regulations regarding this topic, which raises some uncertainty for the projects.
  - **Norway** has several economic barriers, such as solar panel costs 70%, which are higher than in neighbouring countries such as Denmark or Sweden. Furthermore, no specific frameworks promoting self-consumption have been identified.

4.2.3. COMMON RULES FOR INTERNAL ELECTRICITY MARKET

Low Risk:

- **Active customers**: Member states shall ensure that all active customers that own an energy storage facility have the right to connect to the grid.
  - Barriers arise in **Ireland** as there is currently no definition of Active Consumers.

- **Integration of electromobility into the electricity network**: Member states shall provide the necessary regulatory framework to facilitate the connection of publicly accessible and private recharging points to the distribution networks.

(*) the Renewable Energy Directive has been updated as October 2023, EU2023/2413. The figures in this report might refer to the older version EU2018/2001. Specifically, the minimum renewable energy requirement for the transport sector has been increased to 29%.

  - Countries such as **Austria** have some barriers regarding the legislation on this topic, as no charging station legislation has been passed, which could have a negative impact on the project if not promoted by the government.

- **Connection of new generating installations and energy storage facilities**: The transmission system operator shall establish and publish transparent and efficient procedures for a non-discriminatory connection of new generating installations and energy storage facilities to the transmission system.

  - Barriers arise in the **Netherlands**, as the transmission or distribution system operators must connect installations and clients upon request, except when transport capacity is insufficient. Alternative options such as cable pooling can be considered.

Medium Risk:

- **Aggregation contract**: Member States must guarantee customers the freedom to buy and sell electricity services independently from their supply contract and chosen electricity provider.

  - Countries such as **Norway** and **Germany** do not have specific regulations on this matter.

- **Citizen energy communities**: Member States must establish supportive regulations for energy communities and have the option to authorize them to manage local distribution networks.

  - There are barriers in most of the study countries including **Germany**, **Belgium-Flanders**, **Denmark**, **Sweden**, **Norway**, **UK** and **Ireland**, as no legislation have been identified.

- **Demand response through aggregation**: States must promote and enable the involvement of demand response through aggregation, allowing the consumers offering demand response to participate in electricity markets on equal terms with producers.

  - Barriers on this topic include lack of legislation in **Sweden**, **Norway** and **Austria**.

- **Closed distribution systems**: Member states have the option to classify a distribution system that serves non-household customers within a specific site, thus allowing for a separate regulatory treatment.

  - Barriers regarding lack of regulation are present in **Germany**, **Austria**, **Belgium- Flanders**, **Denmark**, **Norway**, **UK** and **Ireland.** These distribution systems can potentially provide interesting business cases for NRAs for large scale projects supplying several customers.

  - DSOs are not allowed to own and operate storage devices in **Sweden**. This creates a barrier for traditional charging station owners, as they may face difficulties in obtaining connection approvals compared to storage devices. However, the use of storage devices could help charging station owners reduce costs.

4.3. CONTRACTOR REPORT: IMPLEMENTATION GUIDELINES BASED ON CURRENT REGULATION AND EXPECTED DEVELOPMENTS

This report aims to identify the National and EU regulations, potentially applicable to NRAs in the area of RE production. By setting out and summarising the work done to identify the applicable regulations, the report can act as a reference resource to help the NRA's answer the following two questions:

- Based on the research undertaken within ENROAD, what is the current relevant European and national regulatory framework dictating what can be done in terms of decentralised renewable energies in the target countries?
- What opportunities and challenges arise from the research and the country specific stakeholder integration workshops?

4.3.1. BELGIUM-FLANDERS

As an EU Member State, Belgium has implemented EU energy legislation on electricity and natural gas. Electricity and natural gas markets have been unbundled: a single grid operator is appointed for a designated area. Within this area, the grid operator is responsible for the operation, maintenance and development of the grid. The grid operator has to grant non-discriminatory third-party access to producers, suppliers and off-takers against regulated tariffs. The regulatory authority oversees market functioning and compliance by market actors (Law Reviews, 2022).

Belgium's National Energy and Climate Plan sets a 2030 target to reduce greenhouse gas emissions from the energy sector by 35% from 2005 levels, to reach 17.5% renewable in gross final energy consumption, and significantly reduce energy demand. Belgium has made progress on the goals. Coal-fired generation was phased out in 2016 and Belgium is a global leader in offshore wind, with 2.23 GW in 2020 and plans for 5.7 GW or more by 2030 (IEA, 2022).

Belgium remains reliant on fossil fuels and is facing energy security challenges. Nuclear energy covers over half of the electricity demand, while the federal government plans to phase out most nuclear generation by 2025. Almost half of Belgium's gas imports comes from The Netherlands with most delivered through a dedicated network connected to the Groningen gas field, which was due to cease production in mid-2022. Belgium is working to address energy security issues and has one of the most interconnected electricity grids in Europe (IEA, 2022).

National and Regional Climate and Energy plans

European legislation is integrated in federal (Belgian) legislation and by the Flemish Government in Flemish legislation. The most relevant laws in Flanders legislation are the Climate Act and Energy Act in addition to the Flemish energy and climate plan (Analogue to the NECPs).

Climate Act: The Belgium federal government has together with the districts of Flanders, Walloon and Brussels agreed the **Belgian Integrated National Energy and Climate Plan** ("NEKP"). The Plan captures the Energy and Climate policy of the European Union which includes security of supply, competitiveness and sustainability. On that basis, the Flemish government has on 19 December 2019 agreed its **Flemish Climate**

strategy 2050 ("Vlaamse Klimaatstrategie 2050") which will be integrated and notified to the European Commission as part of the Belgian Climate Strategy 2050. Additional to the Belgian NECP there is a Flemish specific energy and climate plan (Vlaams Energie en Klimaatplan) 2021-2030

Electricity Act: In Flanders, both the region and the federal government are responsible for the electricity and natural gas markets. The federal government sets regulation for transmission, high voltage grid and non-renewable energy production. Federal energy law is captured in the **Electricity Act 1999** ("Wet Elektriciteit") and **Direction common rules internal electricity market** ("Richtlijn 96/92/EG van 19 december 1996 betreffende gemeenschappelijke regels voor de interne markt voor elektriciteit (art. 20)")

Energy decree: Decree of 8 May 2009 ("het Energiedecreet") laying down general provisions on energy policy (Energy Decree), which sets out the basis of the energy policy in Flanders and has been updated several times to include new obligations, e.g., those arising from the Renewable energy directive REDII

Other applicable regulation

The **VREG** (Vlaamse Regulator van de Elektriciteits- en Gasmarkt) is the Flemish regulator supervised by the Flemish Parliament that regulates electricity and gas markets in the Flemish Region and is responsible for the green energy regulation. The energy law and regulations in Flanders are laid down in the **Energy Decree and Energy Decision** ("Energiedecreet" and "Energiebesluit") and the **technical rules** ("Technische Reglementen").

Acts on environment and spatial planning: Different laws cover rules and regulations for spatial planning, environmental impact and permitting for sustainable development: **Flemish Environmental Regulation** (VLAREM) and **Spatial Planning Act** (Decreet tot aanpassing en aanvulling van het ruimtelijke plannings-, vergunningen- en handhavingsbeleid).

Overview of regulatory bodies

Belgium is a federal state, where the decision-making power is shared between a federal government, three Regions (Wallonia, Flanders and the Brussels Capital Region) and three Communities (the Flemish, the French and the German-speaking Community). A federal regulator, CREG, oversees the transmission of high-voltage electricity and the import and export of electricity. Three regional regulators oversee suppliers and generators at a regional level (Table 16):

Table 16.- Regulators and operators at federal and regional levels

Region	Regulator	Operator
Federal	CREG	Elia
Flanders	VREG	Fluvius
Wallonia	CWaPE	ORES / RESA
Brussels	BRUGEL	Sibelga

The Flemish Energy and Climate Agency (VEKA) is an internal autonomous agency with goals:

- Ensures policy implementation and support for energy and climate policy in Flanders.
- Encourages the rational use of energy and environmentally friendly energy production.
- Provides advice and attestations on the rational use of energy and renewable energy sources in the context of tax deductions and other subsidies for companies.
- Ensures and evaluates the action plans on rational use of energy and use of renewable energy sources of the energy sector and other target groups.
- Represents the Flemish Government in Enover, the consultation forum between the regions and the federal level in which energy matters are discussed.
- Deals with the dossiers on the Energy Performance Regulations (EPB) and Energy Performance Certificates (EPC).

Definition of relevant figures and structures

As regards the relevant figures and structures to be defined, the respective legislation has been identified as follows:

- **Self-consumption:** Self consumption is allowed in Belgium and has been in place for several years under the name of “Prosumer or active consumers”, these are allowed to generate energy for self-consumption and injection to the grid with the installation of a reversible meter that posibilizes the concept of **net-metering**. Recently, a so called “prosumer tariff” has been introduced to “to eliminate an injustice in the charging of the costs for the use of the electricity distribution network”. The simple scheme is limited to 10kW, bigger installations are considered “large installations” and need to go through a network study and a permitting process explained later in this report. No supply license is needed for "behind-the-meter supply" or supply through a direct line, for Flanders, a notification to the VREG suffices, except where the line crosses the limits of its own property, in which case an authorization from the VREG is required.
- **Demand Aggregators:** In Flanders, the concept of aggregation is included under the simplified figure of “**energy sharing**” this posibilitizes the net-metering of consumptions in different supply points for the generation of a single installation and the energy can be either shared for free or sold at a mutually agreed price under the scheme of “**peer to peer trading**”. Normally, for the supply of electricity, a regional supply license is required for the supply of electricity via the public grid to end consumers at a distribution level. According to VREG, from July 2022 everyone - from citizens to local authorities and companies - can become a green electricity supplier. Buyers of such sales only need to notify Fluvius. Fluvius then takes over the practical arrangements and ensures that the information is passed on to the suppliers so that the electricity bill is adjusted automatically. The types of energy sharing are: (i) energy sharing in a communal building, (ii) energy community, (iii) energy sharing with yourself, (iv) peer-to-peer sales.
- **Closed distribution networks & renewable energy communities:** From 2023, energy sharing will be extended to create energy communities (differences exist between a citizens' energy community or a renewable energy community) and thus comply with the requirements of the European regulation.

- Anyone who joins an energy community can then invest in a renewable energy installation, a battery system, shared charging stations for EVs, etc. The cost of the investment and the resulting benefits are then shared among the members of the energy community or are spent on other ecological or social projects. To keep the new activities manageable and feasible, a phased approach is foreseen. A community can also act as a flexibility service provider or a participant in flexibility or aggregation. The regulations regarding flexibility on the distribution network are still being developed. In the initial phase, a number of conditions and restrictions will apply which will gradually disappear so that from 2024 onwards, these activities will be possible almost without limit according to VREG. The Flemish Energy and Climate Agency (VEKA), VREG and Fluvius are preparing the technical regulations and practical matters so that mutual energy exchanges can take place correctly and automatically. **The protocols are still under construction,** current information can be found under the dedicated VREG website.
- **Charging infrastructure** In Flanders, investments are being made to develop a network of charging points for electric vehicles. The operators, in this case Fluvius, have been given a legal obligation (“**openbaredienstverplichtingen aan de elektriciteits-distributienetbeheerders ter stimulering van de infrastructuur voor elektrische voertuigen”)** to install a certain number of charging points. Additionally, as discussed before, in 2023 the installation of charging points by third parties will be possible as part of the Energy Communities figure.
- **Power Purchase Agreements (PPAs)** or Bilateral off-exchange transactions. These transactions take place between known partners, such as a producer selling to a supplier. They form a substantial part of the whole market and Long-term Power Purchase Agreements (PPAs) are often used. Since 2019, various corporate PPAs (CPPAs) have been signed between generators and off-takers in Belgium, which still imposes requirements for Balance Responsible Parties and suppliers.

The detailed definitions according to the Energy decree can be found in the following links:

- Active customer Article 4.4.2 Energy Decree
- Energy community of citizens Article 4.8.1 Energy Decree , Article 4.8.4 Energy Decree
- Renewable energy community Article 4.8.2 Energy Decree , Article 4.8.4 Energy Decree
- Energy parts Article 7.2.1 Energy Decree
- Person-to-person sales (peer-to-peer trade of green energy) Article 7.2.2, §2 Energy Decree

Support schemes

Electricity generation from renewable energy in Belgium and specifically the Flemish Region is promoted primarily through green certificate programmes, as well as other support mechanisms in place to foster the addition of renewable energy capacity, the main applicable mechanisms are:

- **Tradeable Green certificates** to fulfil the suppliers’ mandatory quotas, these are issued by the regulator and can provide an income source additional to the energy sale prices. Prices for certificates have been adjusted numerous times to reduce the level of subsidies, in line with falling technology and deployment costs and so that certificate prices vary in line with electricity market prices. For medium to large-sized PV-installations and wind turbines, this system is planned to be modified to a tendering system supporting renewable energy installations.

- **Encouragement of small- and medium-sized PV installations and wind turbines** through calls for investment aid and grants, these calls include floating PV installations, PV installations on marginal land and small and medium-sized wind turbines as well as other PV installations. An application can be submitted by public and private companies in Flanders looking for funding for medium-sized solar energy installations and small and medium-sized wind turbines. The latest call (3rd) with a budget of 9,5M€ is due 30th of November 2022, nevertheless it is expected for more of these calls to follow.

Permitting, conditions and requirements

For **self-consumption**, in plants smaller than 10kW there is only an obligation to register the installation with Fluvius, this size limitation is considered too small for the potential applications within the ENROAD project. For installations larger than 10kW, a Grid connection study is necessary and needs to be requested with Fluvius. For large installations, Environmental permits are required for solar and wind installations. Since 2017, environmental and land use/building permits have been merged into an integrated environmental permit (omgevingsvergunning). Individual permits for projects greater than 25 MW capacity are required from the Federal Minister for Energy.

- Applications should be addressed to the FOD Economie, which submits the file to CREG for advice.
- The Federal Minister for Energy makes the final decision.

For **energy sharing**, the project needs to be registered with Fluvius and these conditions must be met:

- All relevant off-take points must have a digital meter.
- Anyone who wants to share must request 'metering regime 3' from their electricity supplier so that the digital meter can read quarter -hour values.
- The energy sharer must register via the Fluvius online customer portal, where the system and the steps to be taken are also explained.
- For the time being, the parties involved must have the same electricity supplier. It is expected that from 2023 this will no longer be necessary.

For **Energy Communities,** which will be possible as of 2023, the protocols and checklists are still under construction**,** current information can be found under the dedicated VREG website. The communities must be **registered legal entities** such as a company (e.g., cooperative company, private company, etc.) or an association (e.g. non-profit organization).

Currently it has already been defined who can take part and who can control energy communities. According to VREG and following the EU directives, a citizens' energy community or a renewable energy community are very similar but the main differences are in who can participate in and have control over the community and in the existence or not of geographical or technical proximity requirements. For the aims of the ENROAD project, have been identified to be more viable for the NRA as they allow entities such as the NRA to participate and do not require a geographical nor technical boundary.

Other Conditions

Additional conditions can apply depending on the municipality, as in the case of Antwerp. Relevant documents would be the *zoningplan*, which refers to the spatial implications and elevations of buildings.

Identified Key Opportunities

Under the current and foreseeable regulation, several opportunities were identified and discussed in the stakeholder workshops held in October 2022. The concepts of Energy sharing and Energy communities were discussed and some specific examples were proposed (Figure 40).

Energy sharing and Energy communities present several opportunities for linear infrastructures with decentralized consumptions and potential injection points such as those operated by the Flemish NRA:

- The volumes of energy generated by independent and decentralized installations such as PV on noise barriers or small-scale wind turbines can be aggregated under the Energy sharing figure and associated with the consumption of the NRA in other locations in Flanders such as offices, bridges and locks and do not need to be connected directly. While there are current limitations to the energy volumes that can be shared under this mechanism to be agreed with Fluvius, these are expected to be loosened in the foreseeable future. The upcoming Energy communities will allow the NRA to extend the pool of potential offtakers for the decentrally generated energy to include charging stations or other consumption installations owned by third parties such as resting stations provided a legal entity is formed to constitute the Energy community.

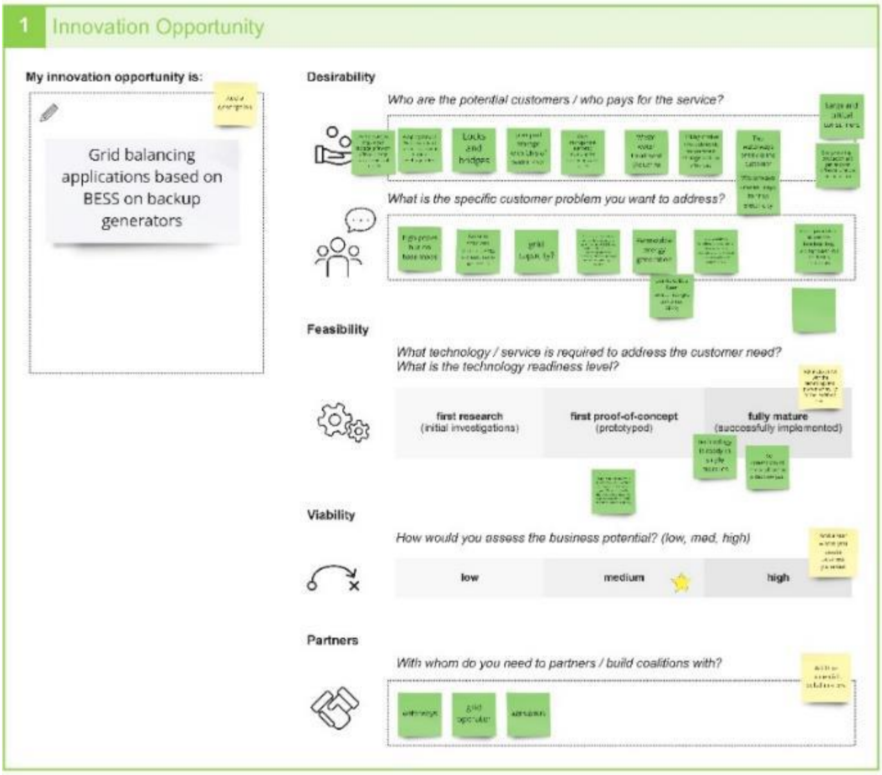

Figure 40.- Sample innovation worksheet from workshop held in October 2022

- In addition to the generic applications of the possibilities presented by Energy sharing and Energy communities described above, some applications specific to the Flemish case were discussed. These are related to the fact that the Flemish NRA also owns and operates waterways, locks and bridges, some of which are located in remote locations and operate for a couple of minutes at a time and accumulate only a few operating hours in total per year.
- The possibility of installing battery storage systems next to some of these consumers to make a better use of their grid connection, which is not utilized during most hours of the year, by storing the energy generated by the decentral installations and injecting it back to the grid in periods of unmatched energy consumption by the NRA.
- These batteries could also be charged by using the positive water level differences in the locks when moving from a higher to a lower level as well as when managing water levels due to precipitation for which there are reliable forecasts. While the technology needed to implement these concepts has been readily available for several year, without the extended offtake opportunities, and potentially also grid balancing opportunities, presented by the energy sharing and energy communities these were not economically viable.
- Lastly, for remote critical applications currently using back up diesel generators, battery storage systems powered by on- and off-site renewables can be deployed more viably through the opportunities presented by the described schemes.

Identified Key Challenges

In order to implement the opportunities described above, some current challenges have been identified that need to be overcome, mainly:

- The size limit for self-consumption renewable installations without the need of network studies is considered too low (10kW). By way of comparison, other EU countries have limits of up to 500kW.
- For self-consumption and energy sharing, some costs such as the grid fees, taxes and the so called “prosumer tariff” are applied to the self-consumed/shared energy. This makes the business cases less attractive.
- Environmental permits are required for solar and wind large installations. Additionally, individual permits for projects greater than 25 MW capacity are required from the Federal Minister for Energy. The permitting process has historically been the bottleneck for utility scale installations in Belgium.
- While not officially published, there are limits to the volumes of energy allowed under the energy sharing schemes to be agreed with Fluvius, these are expected to be partially lifted with the introduction of the Energy communities in 2023 but the details are still unknown.
- While expected to be open for all participants, for the consolidation of energy communities a legal entity needs to be formed and internal legal/organizational barriers may prevent the Flemish NRA from doing so. This needs to be investigated at legal level within the organisation.

Key Recommendations

The recommendations derived from this analysis are in line with the challenges identified for the further implementation of renewable energy projects, which are summarised below:

- Increase the size limit for self-consumption RE installations without the need of network studies.
- Freeing the shared energy from taxes and levies and the self-consumed energy on site and with direct connections from the network charges such as the "prosumer tariff".
- To mainstream, standardize and facilitate the environmental and zoning/special permitting process for large installations, Environmental permits are required for solar and wind installations.
- To lift or define generous limits to the volumes of energy allowed under the energy sharing schemes and energy communities.
- Conducting a legal review at organization level to evaluate potential issues preventing the Flemish NRA to form or take part on legal entities necessary for the consolidation of Energy communities.

4.3.2. UNITED KINGDOM

As of 31 January 2020, the UK left the EU, and therefore will not contribute to EU targets or be bound by the Effort Share Regulation after the Transition Period ends. However, UK has its own objectives. In the UK's British Energy Security Strategy and the Nationally Determined Contribution stated that all regions have high ambitions and works hard to reduce the GHG emissions along every sector with a global target of reducing UK GHG emissions around 68% by 2030, compared to 1990 and net zero by 2050.

Additionally, Climate change policy is devolved to Wales, Scotland and Northern Ireland, although the UK government retains control over many policy areas as defined in the UK's British Energy Security Strategy. The Environment (Wales) Act 201651 requires Welsh Ministers to reduce emissions in Wales by at least 80% in 2050. Wales has targets to produce 70% of the electricity used from renewable sources by 2030, and of 1GW of locally owned renewable energy capacity by 2030. Scotland's climate change legislation requires Scottish Ministers to reduce emissions in Scotland to net-zero by 2045, with interim targets of 56% reduction (from a 1990 baseline) by 2020, 75% reduction by 2030, 90% reduction by 2045 and annual targets for each other year to net-zero.

National Regulatory framework

Energy policy in the UK is the responsibility of the Department for Energy Security and Net Zero (DESNZ). Although there are numerous regulators for specific parts of the energy sector, much of the energy market is regulated by Ofgem (Figure 41). Historically, parts of energy generation, transportation and supply were run by the public sector. Most of the market is now privatized; generation and supply are competitive, and transportation through networks is regulated as the operators are monopolies.

The Government and Ofgem continue to regulate the market for customers, and deliver policy to meet Government's aims on energy. The energy policy of successive Governments has centered around three objectives: security, affordability and decarbonization, sometimes referred to as the energy 'trilemma'.

Electricity Act 1989 and Energy Act 2013 provide a complete framework for development of renewable energy technologies in UK, with a range of measures to support the sector and incentivize investment.

Additionally, Electricity Market Reform (EMR) is intended to provide a stable and predictable framework for investment in low carbon energy sources, while also ensuring that there is sufficient capacity to meet electricity demand. By providing financial incentives and support for renewable energy projects. The EMR made two significant changes to how the electricity market works, the capacity market and the Contracts for Difference scheme.

The Review of Electricity Market Arrangements (REMA) consultation, conducted between July and October 2022, analyzed various aspects of the UK energy market, aiming to balance the need for low-carbon electricity production with the need for reliable and affordable energy for consumers. A second consultation is planned for 2023 to deepen outstanding issues.

Figure 41.- Overview of main market players. Source: Arup.

National and Regional Climate and Energy plans

British energy security strategy: although the UK has now left the EU, the government remains committed to building on the policies set out in the UK's compromises relating to renewables and energy efficiency. (Secretary of State for Business, Energy, and Industrial Strategy, April 2022)

In December 2020, the UK Government launched its **Energy White Paper** building on the Prime Minister's Ten Point Plan for a Green Industrial Revolution by outlining plans for transformation of transport, energy and infrastructure in order to delivery significant decarbonization of power in the 2030s and net-zero by 2050. The publication provides a lot of detail for stakeholders in terms of how energy and electricity will be transformed in the UK over the next 30 years.

The **Road to Zero:** Sets out the UK's strategy for cleaner road transport in order to delivery zero-emission transport by 2030 and the development of required charging infrastructure and manufacturing capability.

The **Energy Digitalization Strategy**, developed by government, Ofgem and Innovate UK in coordination with the energy sector sets out a vision and suite of policies to digitalize the energy system. Digitalization will enable millions of low carbon assets, including solar PV, electric vehicles and heat pumps, to be optimized across our energy system.

Overview of regulatory bodies

- **Transmission Grid:** managed by the Transmission Network Operator (TNO), it comprises all the transmission lines and substations by means of which energy is distributed across the country. Transmission voltage is 275kV or 400kV. In Scotland, 132kV is also used. The transmission owners for the different regions are: National Grid Electricity Transmission (NGET) for England and Wales, Scottish Hydro Electric Transmission Plc for northern Scotland, and SP Transmission Plc for southern Scotland. The System Operator in England, Wales and Scotland is the National Grid Electricity System Operator (NGESO).
- **Distribution Grid**: managed by energy Distribution Network Operators (DNOs), there are six DNOs in GB and are responsible for the regional/local distribution of electricity (Electricity North West, Northern Powergrid, Scottish and Southern Energy, SP Energy Networks, UK Power Networks and Western Power Distribution). Distribution voltage is 132kV in lower in England and Wales, and less than 132kV in Scotland.
- **Suppliers/Retailers (liberalized):** licensed companies that supply electricity to retail customers, may have own generation or acquire in the wholesale markets.
- **Market operator:** the wholesale market is operated by Elexon, who administer the Balancing Settlement Code (BSC) in Great Britain.
- **Regulatory body:** Ofgem (Office of Gas and Electricity Markets), the government regulator for the electricity and downstream natural gas markets in Great Britain.

Definition of relevant figures and structures

As for the relevant figures and structures to be defined, the respective legislation has been identified as follows:

- **Self-consumption:** Self consumption is allowed in UK and has been in place for several years, this allows entities with their own generator source to self-consume and inject to the grid. The self-consumption installation has an electricity supply contract either through a supplier or aggregator. The simple scheme is limited to 11.04kW if connected to 400V and 3.68kW if connected at 230V. Bigger installations are considered "large installations" and need to go through a network study and a permitting process.
- **Demand Aggregators:** Aggregation contracts are currently possible in the UK and commonly used by consumers with supply points spread. Demand aggregator can deliver Demand response services by either reducing their demand or taking advantage of onsite generation.

- **Renewable energy communities:** According to Community Energy England, by 2020 there were 424 community energy organizations across UK, with 319 MW installed capacity. The Government has policies to support energy, including at local level. These include the Smart Export Guarantee, the Renewable Heat Incentive, and the Local Energy Programme.
- **Closed distribution networks:** A distribution exemption holder may apply to Ofgem for classification as a Closed Distribution System (CDS). Ofgem must agree to classify the distribution exemption holder if it considers that it meets the criteria laid down in regulations. Broadly, these criteria include: the distribution system is not used for the purpose of supplying electricity/gas to household customers (or supplies fewer than 50 employees of the exemption holder supplied from embedded generation); the distribution system is used for distributing electricity/gas within a geographically self-contained industrial, commercial or shared services site and is not integrated into the national transmission or distribution network; the distribution system is wholly or mainly used to supply integrated system users or the distribution exemption holder.
- **Charging infrastructure:** The market for EVs is immature yet growing. The latest data for Q3, 2022 shows that 14% of new car registrations in the UK were battery EV with a further 5% being plug-in hybrid electric vehicles. The Government has a variety of schemes to support the provision of charging infrastructure, including in homes and workplaces. The EV infrastructure strategy was published in March 2022 setting out the vision to charging infrastructure as both a perceived and real barrier to the adoption of electric vehicles. The provision of charging infrastructure was also included in amendments to the Building Regulations 2010 in June 2022.
- **Power Purchase Agreements (PPAs)**: They form a substantial part of the whole market and long-term PPAs are often used. The UK has a relatively healthy short-term PPA market or renewables which a number of policies have facilitated. Similarly, the Contracts for Difference scheme, based on wholesale market price, results in PPAs being signed that will provide revenues corresponding to market reference price for the CfD.

Support schemes

There are several government policies and initiatives that encourage the adoption of renewable energy and self-consumption in the UK, such as:

- **Smart Export Guarantee (SEG):** financial incentive to support distributed and small-scale renewable energy generation, up to a 5 MW capacity. The SEG scheme for generators opened on 1st January 2020. The SEG scheme replaces the Feed-in Tariff (FIT) scheme that closed on the 31st March 2019 but works differently to FITs. The SEG scheme obliges electricity suppliers to offer an export tariff rate to an eligible generating unit.

  The main financial benefit from a generation project under the SEG scheme is the export tariff, which is a guaranteed price for each unit of electricity exported to the grid. It is an obligation for licensed energy suppliers to offer eligible generation projects an export tariff rate. The electricity suppliers decide the SEG export tariff details i.e., the rate and the length of the contract. However, although wholesale electricity prices can fall below zero due to changes in demand, electricity suppliers must always offer a tariff which is greater than zero.

- **Contracts for difference (CFD):** this is the main financial incentive mechanism for larger schemes of low carbon generation, installed capacity of at least 1MW. It has replaced the Renewables Obligation (RO), which closed to new applications in March 2017. The application process for a CFD is much more complex than for the SEG scheme.

  A Contract for Difference is a bilateral contract between a generator and the Low Carbon Contracts Company (LCCC, the CFD counterparty), which is government owned. A generator with a CFD is paid the difference between the "strike price" and the "reference price" over a 15-year period. The strike price is an agreed price for electricity reflecting the cost of investing in low carbon generation. The reference price is a measure of the GB market price for electricity.

  CFDs require generators to sell electricity into the market as usual. But to reduce their exposure to market prices, the CFD provides a variable "top up" payment. When the strike price is higher than the reference (market) price, the generator receives a payment. At times when the market price exceeds the strike price, the generator is required to pay back the difference, thus protecting consumers from over-payment.

Permitting, conditions and requirements

For **self-consumption**, for capacities lower than 30MW, it is recommended to connect via a distribution network, as it may be more economical and efficient. All DNOs provide information on the feasibility of connection and associated cost, such as capacity network capacity maps, dedicated generation 'surgeries' or 'drop in' sessions. For capacities over 30MW, National Grid offers ConnectNow Research Assistant tool, created to help with the connection research. It shows the potential locations that could meet the needs and an estimated cost of the connection. As of April 2023, new connection applications are submitted via the Electricity System Operator portal. This replaces the previous connection application form process.

In the future, there is likely to be **a new requirement for Electricity Storage devices** operating in import mode to switch to export mode if the grid frequency falls below a defined threshold. Details are being considered by an industry working group (Energy Networks Association) and are not yet mandatory.

Other Conditions

Additional conditions can apply depending on each region within UK.

Identified Key Opportunities

Under the current and foreseeable regulation, several opportunities have been identified and discussed in the stakeholder workshops held in April 2023. The concepts of Energy sharing and integration of storage technologies were discussed and some specific examples were proposed (Figure 42).

Some trends and factors that will drive the development of solar self-consumption in UK:

- Cost reduction: costs of RETs and ESSs have decreased significantly in recent years and it is expected to keep dropping, which will make distributed energy generation more accessible and cost-effective. Recently, supply change constrains have stopped the price drop.

- Regulatory changes: although the regulation has evolved positively, there are still some changes required, especially those related to procedures and grid connection. A second REMA consultation is planned for 2023. Government plans to deepen consultation related to electricity market reform across several market dimensions.
- Environmental awareness: consumers are concerned about the environmental impact of their actions and are looking for ways to reduce their carbon footprint. Solar self-consumption is an effective way to reduce carbon emissions and contribute to the fight against climate change.
- BESS integration or flexible technologies: the entry of storage systems, mainly batteries, will take place in the next few years and allow a more efficient management of surpluses, displacement of consumption peaks and a greater penetration of renewables.
- Surplus management: new products to compensate the surplus are available in the market as the virtual batteries, and others, as the PPAs, onsite and offsite are becoming available for all scales.
- Technological advances: technology behind renewables and energy storage systems is constantly evolving, that will lead to better prices and to improve the grid stability. In UK, Ofgem provides funding mechanisms for electricity and gas distribution and transmission companies through the Network Innovation Allowance (small scale projects) and Network Innovation Competition (larger-scale innovation projects).

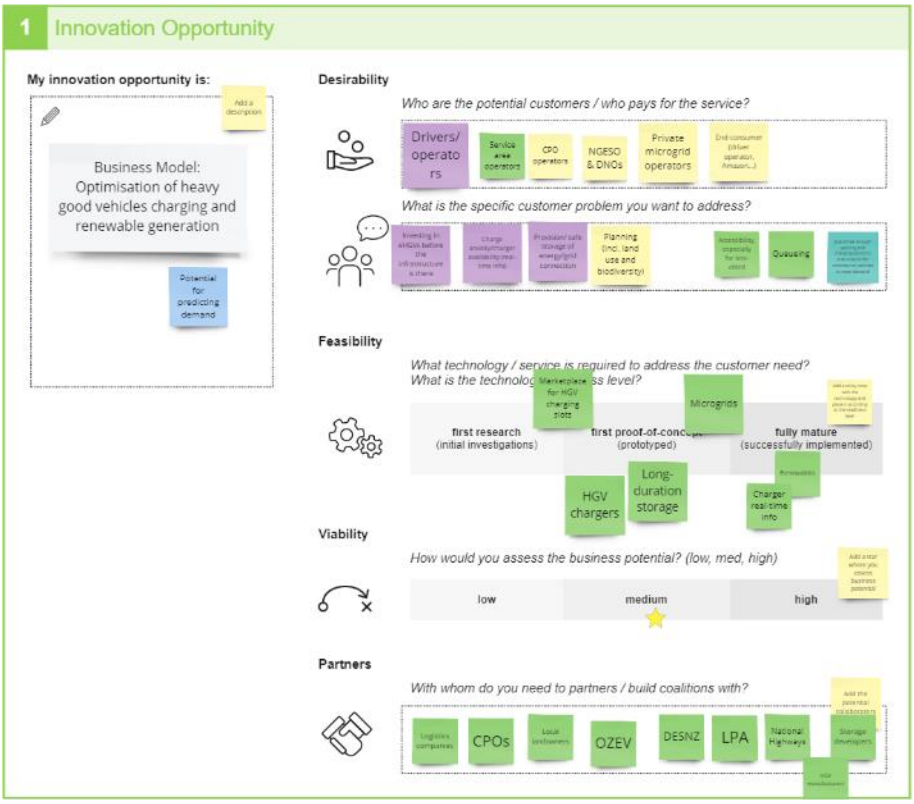

Figure 42.- Sample innovation worksheet from workshop held in April 2023. Source: Arup.

- Decentralised energy: self-consumption allows consumers to generate their own energy and reduce their dependence on electricity companies. As a more decentralised electricity grid develops, solar self-consumption could become a more important part of the UK energy system.
- Integration of electrical vehicles: EV charger are becoming more present with a high requirement of energy; ENA Low Carbon Technology Working Group has been looking at a way to simplify the V2G connection application, including considering a single process that combines the aspects of EV as demand and generation.
- "Call for inputs" and consultations from Ofgem have been recently launched in several topics around energy market and distributed energy being od special relevance Call for Input: The Future of Distributed Flexibility, Consultation: Future of local energy institutions and governance.

Identified Key Challenges

- Administrative and bureaucratic barriers: Although some administrative barriers were removed, there are still formalities and procedures that hinder the installation of self-consumption systems. This complexity can discourage consumers and delay the development of solar self-consumption.
- Access to the grid: Grid connectivity in the UK results in long delays for renewable energy projects. Investment in grid infrastructure is critical to address these challenges and improve throughput capacity for integrating RE projects. However, the swift progress of solar energy technology has not kept pace with requisite infrastructure construction, which requires significant investments and multiple permit approvals to install kilometres of transmission circuits.
- Complex stakeholders: the administrative procedures and project requirements involve a wide network of stakeholders. Moreover, if Energy Communities or other alternatives are considered, it significantly increases the number of stakeholders involved who have to be aligned.
- Renewable energy communities and self-consumers are possible under regulation, however, their support from the government is limited and the strategy for this segment is unclear.
- Low level of reward via the SEG.
- In the future, there is likely to be a new requirement for the Electricity Storage devices operating in import mode to switch to export mode if the grid frequency falls below a defined threshold. The details of these requirements are not yet mandatory.

Key Recommendations

The recommendations derived from this analysis are in line with the challenges identified for the further implementation of renewable energy projects, which are summarised below:

- Establishing likely hurdles and related costs related to planning permission and grid connection, which as highlighted, are common barriers to developing renewable projects.
- To explore the level of savings and revenues a project could generate through the various routes-to-market available to understand the strength of the business case.
- Engage with key stakeholders early on project development and maintain regular communication throughout to ensure project success.

- Increase the size limit for self-consumption RE installations with simplified connection procedures.

5. BUSINESS MODEL & ENVIRONMENTAL APPROACH

In the consideration that the general business model supports the decisions for the provision of RE at a cost-competitive price, in WP4 a preliminary estimation of revenue streams, costs, savings, and margins are estimated for the selected RE technologies along the road network, this helping to reach higher energy efficiencies and decarbonization goals. The model starts with the NRA's energy demand for one or more locations and the RE production for self-consumption. Alternatively, NRA's decision could be in the consideration of new activities like offering and selling all or a part of the energy.

While the renewable energy production depends on several variables and contextual factors, the decision-making analysis is based on economic criteria from the BM including the cost of installation, cost of maintenance and the life cycle cost, both individually and as a whole. Undoubtedly, the selection of the technologies and their CAPEX are directly connected to the operations and maintenance costs (and other OPEX), and if they are underestimated, this eventually results in negative margins. In brief, the operation of the BM in the GIS is a multistage process based on alternative scenarios that start with the NRA identification and energy necessities and uses, followed by the collection of energy market prices; the selection of feasible locations in terms of electricity production and storage by technology; CAPEX and OPEX estimation; the revenues and saving estimation; and the economic performance and financial assessment.

Business Models based on Renewables Energies

The business model is considered an essential tool that favours the energy transition to the renewable energies and their policies. There are different examples of applications, including the case of photovoltaic technologies, the implications of electric vehicles, the design of projects and applied studies in different countries, the optimisation of the design of the renewable energy system, the estimation of the costs of production, their effect on the reduction of greenhouse effect gases (GHG), and the use of software of support. Some authors highlight the generation and consumption of energy in the transition to green energies. On the one hand, the generation must evolve from the traditional sources to the green energies and on the other, the consumers can become producers. This means that now production is also located on the venue of consumption. Based on this distinction, they propose two generic business models in the value chain of the energy generation and consumption, a model of renewable energy business from the perspective of the client and a model of renewable energy business from the perspective of the producer.

Business Models based on the Energy Demand Response

The benefits of the demand response (DR) in the electric sector consists of balancing the fluctuations in the renewable generation and, in consequence, to facilitate a higher use of the renewable resources in the electrical system, as well as increasing the economic efficiency by the application of the fee in real time and the reduction of the requirements of generation capacity. It promotes the interaction and response capacity of the customers and determines the impacts at the short term in the electricity markets, what in turn generates economic benefits both for the customers and the public service company. In addition, improving the reliability of the energy system and, at the long term, reducing the peak demand, results in decreasing the general investments of the plant and capital costs, and postponing the need for actualisations of the network. In the literature there are references to three possible ways in which residential customers in DR may change their use of energy:

- Reducing their energy consumption by strategies of load reduction.
- Moving the consumption of energy to a different time interval.
- Using the energy on hold in the generation site, limiting its dependence on the main network.

The proposal of DR has gained attention since then with applications to the heating systems, helping to reschedule the time of switching on and off, or modifying their configuration. However, it has limitations due to it is based on the flexibility of the demands as general requirement when this is difficult to achieve in circumstances of non-automated consumption; that is to say, that part of the consumption may be adjusted, but to a point from which elevated rewards are needed or a substantial reduction of the fee to the consumer, what for example would remove part of the profitability in markets such as the residential. In this market, as the project AlpEnergy emphasised, in case it is assumed that the final users must react manually to the rate signals, the load change or the energy savings, then it is first needed that the user is at home and second, there is the will to consciously consider the options of response to the demand, what in both cases demands time.

The maximisation of the potential of direct consumption of energy generated by renewable sources requires to reconsider how to store energy without damaging profitability. The benefits of this option would be immediate, by rescheduling the productions of high energy consumption in the industry. In terms of the business model, the value proposition is based on the bulk supply of energy produced in an efficient and sustainable manner, with the effect of reducing unused energy.

Software for the simulation of costing of renewable energy

There exist different RE simulation and analysis tools with a variety of features: technology databases; weather databases; energy modelling tools; cost analysis (LCOE, LCC, target costing, etc.); sensitivity and Risk Analysis; environmental issues; planning, budgeting and control cycles; or customized reports. In *Deliverable 4.1* some of these tools are presented: RETScreen, HOME, Hybrid2, Insel, Pylon, Helioscope, windPRO, etc.

5.1. GENERAL BUSINESS MODEL DESCRIPTION

Most contemporary approaches in business strategy refer four essential dimensions. On the one hand, there is quality, time and also efficiency. Innovation is subordinated to the first three. While quality and time are important, to improve these aspects without the respective increase in the value appropriation and, in consequence, of the profitability, can make any effort or sacrifice useless, even disastrous for the survival of the company. As a result, the improvement of efficiency is a permanent concern for good managers. In the application of these dimensions to the production of RE, quality refers to the continuity to the extent that there is sufficient primary energy (wind, solar radiation, etc.) and power to offer the service. Time is interpreted in the sense that there is demand when energy is available. The design of the infrastructure and minimisation of idle or unused capacity, will have repercussions on a satisfactory cost for investors and on a higher substitution of conventional energies so the GHG emissions are reduced.

While RE production depends on several variables, the principal one is the geographical place (location) where the renewable energy technology (RET) can be installed due to the connection with the quality and time strategy dimensions. There are also other contextual factors (social and environmental) that limit or promote certain technologies within the countries' legislative and regulatory frameworks.

Thus, the definition of the NRA assets is cornerstone for the assessment of the performance. The RES data from the renewable energy resources (wind and solar) are transformed in parameters (wind turbines and PV-panels) in the evaluation of the generation technology and doing so, the outcomes in terms of annual data are the potential energy generation and the levelized cost of the energy.

With the aim of providing the economic and financial approach to this analysis, the design of the general BM is considering the following steps (Figure 43):

1. RETs screening and assessment of their applicability involves further definition of the general data strategy and detailed technical analysis of the facilities. Then, the search for data sources, proper data collection and selection will support the construction of BM datasets following the GIS-based project approach.
2. For each RET there must be a basic analysis and further modelling for the estimation of available energy in $kWh/m^2/year$, which should come from considering the energy resources location, the potential nominal power of the technologies as estimated with climate datasets, and the sequence of power losses because of technical considerations of the components.

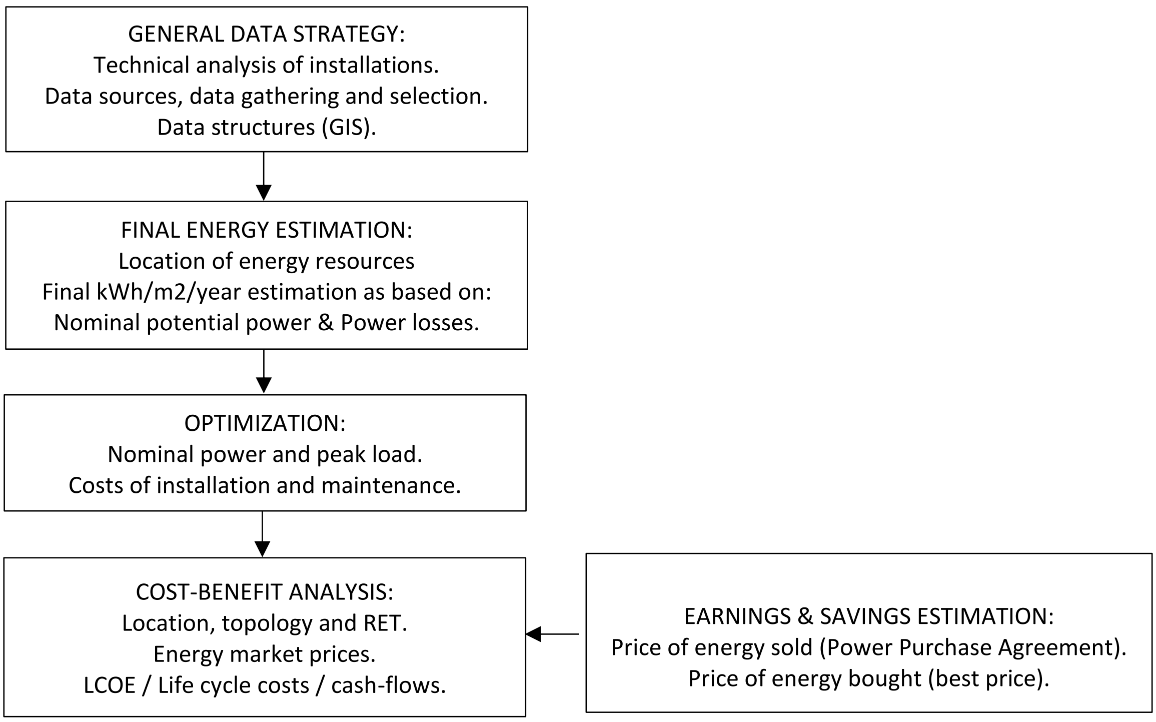

Figure 43.- Steps in the design of the General Business Model

3. Listing/ranking of technologies under cost optimization and/or maximum profit criteria according to the RET's nominal power, peak load, cost of installation and cost of maintenance.

4. The BM Cost-Benefit analysis explains the economic and financial results of the match-up between location and technologies selection, including the installation's life cycle costs (that are related to the specific climate characteristics, technical parameters and road topologies) and the market prices. Hence, the energy market prices and purchase agreements are crucial in power network-connected facilities, as the provision of energy should be competitive in economic terms, in the consideration of the best-selling price in the country's market for electricity surpluses. When the installation is for self-consumption and non-connected, the BM provides the best price for purchasing the electricity.

Prior to the approval for the implementation of the GIS, the model was tested through simulations to assess the efficiency of RET selection based on the life cycles of the installations.

While the BM is part of the decision-making approach, it is necessary to identify the whole design of the BM and its operation into the decision-making framework to explain the interactions between them. The general scheme is thus summarized in the next section.

5.2. BUSINESS MODEL: DESIGN AND APPLICATION

The Cost-Benefit analysis or BM application within the ENROAD Methodology is linked to the GIS general database and supplied with the detailed information in WP2 of the different RETs, and the barriers and recommendations for the NRAs to act as an electricity producer/retailer in WP3. Hence, the outcome from the GIS application should be affected by the country-based legislative and regulatory framework. The operation of the BM in the GIS is a multistage process based on alternative scenarios and the steps are expected to be as follows (Figure 44):

1. NRAs identification: Selection of NRAs, electricity uses (consumption, selling, and storage), and load necessities (road lighting, tunnel lighting, etc.). First approximation to optional locations.
2. Energy market prices: Selection of country's market prices (purchase-sale) for savings estimation and profits from selling the energy.
3. RET electricity output: Optimal location of the installation in terms of electricity production. The nominal power and kWh/m^2/year estimation by RET depends on the technology selection and its configuration. The estimation follows a three-step process:

    3.1. Primary energy resource estimation: it depends on the technology. For instance, the wind turbines performance is based on the wind speed distribution approximated by the Weibull distribution; likewise, calculation of the solar panels is based on European solar radiation statistics or the local solar irradiation (kWh/m^2/year).

    3.2. Performance corrections: depending on the technical configuration of the installation (connected or non-connected), this considers the losses of power from the production to the consumption or connection to the network.

    3.3. Determination of kWh/m^2/year: it is the estimation of the final energy production for the available area of the selected location, in square meters.

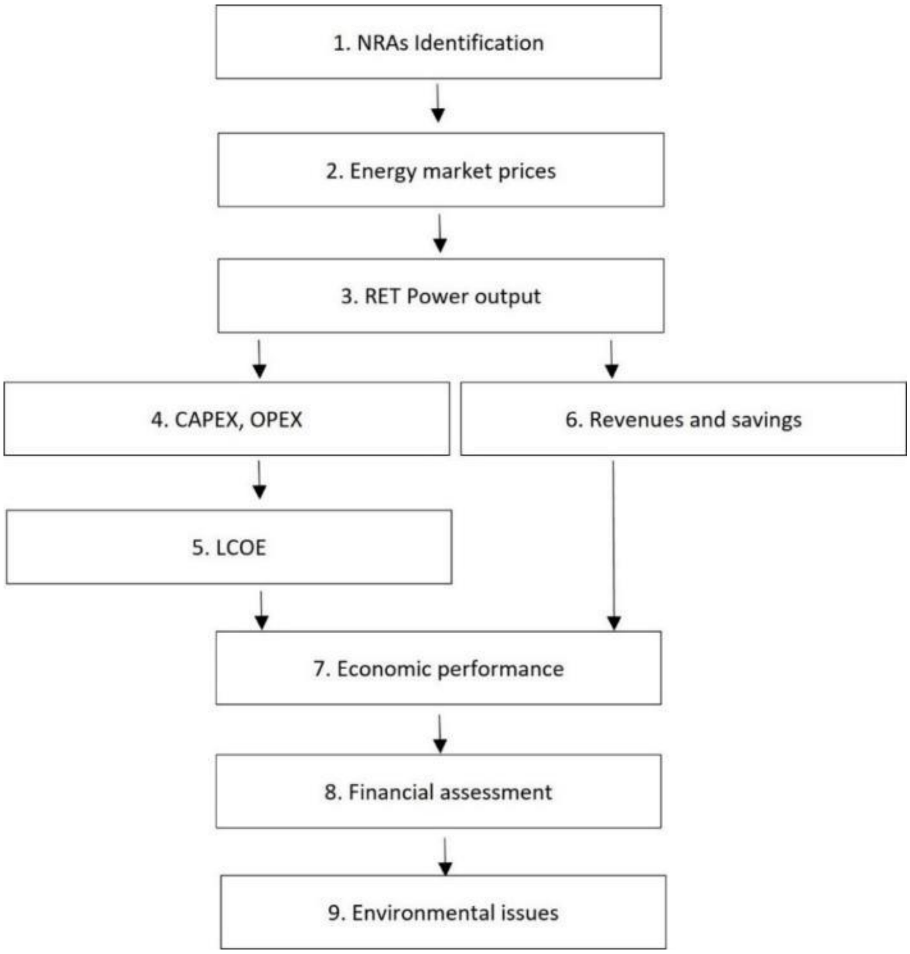

Figure 44.- Business Model application

4. CAPEX and OPEX estimation: initial investment and investment scaling (modules, structures, connections, transformers, inverters, BOS, batteries and financing) and annual operation costs (manpower, maintenance, insurance, communications, security, monitoring, etc.). The sum of both per kWh has to be considered for each technology configuration and technical life-cycle of the installation.
5. Levelized cost of the energy: in the situations in which two different sources are installed a cost by-source analysis is recommended. Then, the same CAPEX and OPEX overhead costs should be allocated. Anyway, in both situations with a unique source or two sources, the MB offers a final LCOE for the facility.
6. Revenues and saving estimation: estimation of annual revenues and savings, and tax aids and incentives along the life cycle of the installation.
7. Economic performance: annual profit-losses determination or savings estimation (energy and maintenance) by technology (results of Cost-Benefit analysis).
8. Financial assessment: cash-flow analysis for the life cycle of the installation (NPV, IRR and payback analysis).
9. Environmental analysis: estimation and assessment of economic-related environmental issues (e.g., CO_2 savings per year and square meter) and contrast with current regulatory barriers.

As another important outcome, the BM can simulate an if-then analysis to benchmark countries, needs and technologies, thus identifying barriers and obstacles for the NRAs to become active in the market.

DEFINITION OF THE NRA LAND/ASSETS

First for the RET electricity production estimation, there are two approximations for the definition of the NRA land locations. In fact, it is interesting that the proposal uses the term location in the sense of an area. Hence, the estimation considers the number of panels or turbines that the NRAs can deploy in that area. As soon as the area is determined, the next phase is the estimation of RET electricity production.

RET ELECTRICITY PRODUCTION

The outcome of the estimation of the electricity production is in kilowatts per hour, square meter, and year (kWh/m2 year). Due to the particularities of the technologies, models are presented in separate subsections.

COST ESTIMATION MODEL

Cost estimation models are a metric of efficiency and must be properly defined, measured and assigned (Mowen et al. 2014) so that the energy production is related to the inputs used to calculate the global financial effect of any modification in the BM. Thus, the cost is closely linked to the quality of service for the correct operation of the facility for as long as circumstances allow, minimising unused capacity.

Intermittence in the production and non-used capacity

The main problem in the use of renewable sources is their intermittence, what affects in a conclusive way the installation´s efficiency, both from the perspective of the idle time of the installation and the variations of primary energy coming from the wind and the solar radiation. This is due to the structure of the costs of the installations is based primarily on the fixed costs assigned to the kWh, the estimation both to tackle the decision to carry out the investment and the estimation of results not free from difficulties due to the differences between expected and real costs for this variation in productivity resulting from the idle capacity. The idle capacity is a basic element in the business model of RE from the producer perspective.

Classification of costs

The elaboration of the cost accounting has the purpose of answering three questions in this order: 1) what costs are involved during the consumption of good and services in energy production (renewable or not); 2) where (in what departments or sections) are the costs produced; 3) for what services are those costs produced and what is the operating results achieved with these services (Figure 45).

The first issue is the classification of costs. In fact, the first step of the cost analysis is the classification of costs on a functional basis: equipment (wind turbines, PV panels, connections, transformers, converters, etc.), labour, administration and financial costs. The analysis is a preliminary assessment of whether the site is likely to merit further attention through the application of more sophisticated analyses.

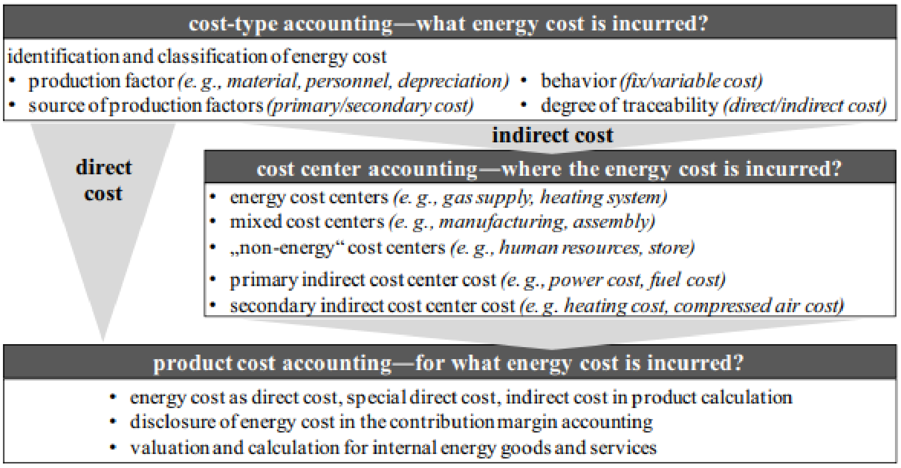

Figure 45.- Basic structure of the energy's cost accounting (Bierer and Götze, 2012)

In general, energy costs are classified according to the basis of the production factors, i.e., material costs (e.g., the fuel in a thermal station), personnel costs (e.g., wages of the maintenance team when they are hired by the own company), external services costs (e.g., security service) and depreciation costs (e.g., solar panels). These costs are conformed as costs of the activity of energy production, or operating costs. The operating costs become operating expenditures or expenses of operating operations (OPEX) when the suppliers of the services are identified and the decision horizon incorporates the corresponding payments according to the conditions agreed or to be agreed.

One of the OPEX is the depreciation designed as an exception in the sense it is an expenditure that does not entail a future payment. On the contrary, payment will be made in part or in full before the start of the economic activity, in order to make the necessary facilities available to the company. These decisions of capital investment (or capital expenditures) also known as CAPEX consist of the process of planning, objective and priorities setting, provision of funds, and the use of criteria to select the assets that will be used for longer than a year, in the long term, and which bestow stability to the company.

Due to the exploratory nature of the Business Model, a third group of development costs was created. Although initially identified with CAPEX, it was included in a third group of development and engineering costs. The aim of this group is to gather all the sunk costs derived from the preliminary studies before the decision (or not) of investment. This Business Model determines the benefit margins by an accumulative process of the costs but with the consideration of the effects on the liquid assets; that is to say, that depreciations are incorporated at the end because they do not imply cash outflows. This way, the determination of margins facilitates the understanding of the cash-flows and explains the final balance in cash and banks. Alternatively, for a BM based on self-consumption, it is explained where and how much money is being saved.

CAPITAL EXPENDITURES (CAPEX)

The outcomes of the model are the estimated cost per typology, the average cost per kilowatt and square meter, and finally the LCOE for the facility life. Most of costs are fixed and proportional to the power of the installation. The facility affects the capital costs (CAPEX) in three levels:

- The RET configuration in terms of power.
- The number of turbines or panels that require specific configurations of rectifiers and inverters.
- The number of battery modules in the Energy Storage System (ESS).

There is no relevant effect of changes in the daily level of activity. In fact, the behaviour of the unit cost decreases rapidly in the short run and tends to minimum cost (shows the level of economic efficiency) in the long run. The BM does not include sales or income taxes due to the differences between countries.

Capital expenditures (CAPEX) are the most important decisions that an organization makes as they commit financial and human resources in the long-term in the expectation of future benefits. In the economic valuation of CAPEX decisions, investments are included in necessary engineering, purchasing and installation of the power system. This includes the equipment in the energy production facility: the power sources (turbines and panels) and their specific structures and elements (for instance, the balance of solar PV systems or BOS), the substations, inverters and transformers, grid connection, the batteries, and the construction of buildings and yards (displayed in Table 17 for illustration purposes).

Regarding the useful life of the facility elements, life expectancy and the depreciation are estimated based on how much of their value has been used. There are many types of depreciation. For this project, the annual depreciation has been estimated based on the life of the element on a straight-line basis, then the cost of the element is divided by its life in years. As the useful life of the installations generally coincides with that of the component with the shortest service life, if replacement is not considered for the calculation of the costs of a complete cycle, it is necessary to amortise the remaining years of the components still in use. If the decommissioning costs are also taken into account, both types of costs have to be periodised by dividing them by the years of useful life, giving rise to a second amortisation item for these costs in the OPEX (end-of-cycle depreciation and decommissioning).

OPERATIONS EXPENDITURES (OPEX)

The OPerations and maintenance EXpenditures are the annual costs associated to the operations aimed at producing the renewable energy: manpower, maintenance, insurances, communications, monitoring, security, energy and other general and administrative costs. When the NRAs are assumed the owners of the installations' land, the cost estimation includes the property taxes; otherwise, the land rentals are incorporated (Table 18). When the financing of the long-term investments is fully or partially based on loans, the assessment includes the debt leverage and the debt payments (yearly annuities), which are constant over the debt term. Then, the estimations of loan's debt term and interest rate are necessary.

DEVELOPMENT AND ENGINEERING COSTS (DEC)

In addition to the CAPEX costs, a more detailed analysis following the RETScreen costing model suggests the incorporation to the *Detailed Feasibility Study* of other important costs such as the site investigation, resource assessment, environmental assessment, preliminary design, project management or travel and accommodation expenditures (Table 19). These are also initial costs; however, difficulties in the basis of estimation suggest that a general valuation of the net margin should be proposed.

Table 17.- CAPital EXpenditures

Facility elements	Cost	Years	Annualized (Facility depreciation)
Power sources			
Structures			
Inverters			
Transformers			
Grid connection			
Batteries			
Yard & building constructions			

Table 18.- OPeration EXpenditures

Annual costs
Manpower
Maintenance
Insurances
Communications
Security
Monitoring
Energy
Other general and administrative costs
Interest

Other costs under this approach are the *Development Costs*, which include the contract negotiations, the permits and approvals, the GHG validation and registration, the detailed project financing analysis, the legal and accounting issues, and the project management. Finally, *Engineering Expenditures* are related to the site and building design, mechanical and electrical design, civil design, tenders, contracting, and construction supervision. As with CAPEX, these costs are annually considered; i.e., they are depreciated during the project life.

Table 19.- Development and Engineering Costs (DEC)

Detailed Feasibility Study (DFS)	
Site investigation	GHG Baseline
Resource assessment	Report preparation
Environmental assessment	Project management
Preliminary design	Travel and accommodation
Development Costs (DS)	
Contract negotiations	Project financing
Permits and approvals	Legal and accounting
GHG validation and registration	Project management
Engineering Expenditures (EE)	
Site and building design	Tenders and contracting
Mechanical design	Construction supervision
Civil design	
Development and Engineering Costs Depreciation **DEC Depreciation = [(DFS) + (DS) + (EE)] / Years**	

COST ANALYSIS STRUCTURE, MARGINS AND LEVELIZED COST OF ENERGY

In Table 20, the yearly cost structure is displayed for illustration purposes. The annual cost per kWh is calculated by dividing the Annual Net Margin before DEC by the electricity produced in the period. The Levelized Cost of Energy is estimated over the annual net margin before DEC during the facility life:

$$LCOE = \frac{\sum Annual\ Margin\ Before\ DEC}{\sum kWh}$$

Table 20.- Complete annual cost structure and margins

	Electricity production (kWh year)	Unit Price (€/kWh)	Total (€)	%
Energy revenues or savings				100
Expenditures:				
Manpower				
Maintenance				
Insurances				
Communications				
Security				
Monitoring				
Energy				
Other general and administrative costs				
Interest				
ANNUAL NET MARGIN BEFORE DEPRECIATIONS				
Facility depreciation End-of-cycle depreciation and dismantling				
ANNUAL NET MARGIN BEFORE DEC				
DCE depreciation				
ANNUAL NET MARGIN AFTER DEC				

The order in which the expenditure is presented is based on prudence. The higher up the list, the lower the risk of estimation error. First, personnel and maintenance costs are the most important among the OPEX, then the amortisation of the CAPEX and, finally, the development and engineering expenditures. Thus, the BM offers a maximum spending limit on the latter item that provides an adequate margin. However, if the BM has a negative margin for these expenses, the investment is not advisable.

CASH BUDGET AND CASH-FLOW MANAGEMENT

Knowing the liquid assets, collections and payments flows is essential for the proper management of any business. The cash-budget is an accounting document that shows the initial availability of liquid assets and collections for a period or the life cycle of the RE facility (shown in Table 21 for illustration purposes only). Together they constitute the cash available from which payments are deducted or disbursed to determine the expected ending balance.

Table 21.- Cash budget (investment cycle in years)

	Year 1	Year 2	…	Year n
Beginning cash balance				
Cash inflows (or non-outflows): Energy revenues (or savings)				
Total cash available				
Payments or cash outflows for:				
Total CAPEX payments:				
- Property, Plant & Equipment (PP&E)				
- Dismantling costs				
- Developing and engineering costs (DEC)				
Total OPEX payments:				
- Manpower				
- Maintenance				
- Insurances				
- Communications				
- Security				
- Monitoring				
- Energy				
- Other general and admin costs				
- Interest				
Total disbursements				
Excess (deficiency) of cash available over needs (Net cash flow)				
Financing (borrowing, repayments, NRAs equity).				
Ending cash balance				

The cash-budget is an estimation of collections and payments to be included in the BM. When as a result of the analysis of all the information the NRA favourably decides to carry out the investment in RE, the collections and real payments are collected in an accounting document called statement of cash flows, which would gather all the collections and cash payments coming from the operations, the investments and the funding operations.

RE INVESTMENT FINANCIAL ASSESSMENT

Although there are different models to assess the investment decisions in capital, two types of models are here followed based on the classification by Mowen et al. (2014):

- Models without financial discount: Payback period, and Accounting Rate of Return.
- Models with financial discount: Net Present Value (NPV), and Internal Rate of Return (IRR).

Payback Period

The payback period is the time required for the NRA to recover the original investment. It is determined adding the yearly cash flows up to the moment when the original investment is recovered. One way of apply it is to consider a maximum recovery period, above which the investment would be rejected. This approach would be interpreted as a risk measure because the longer the time to recover the investment the greater the risk assumed. The formula for its calculation is as follows:

$$\text{Payback period (in years)} = \frac{\text{Original investment}}{\text{Annual cash flow}}$$

Accounting Rate of Return (ARR)

The accounting rate of return measures the performance of a project in terms of margin or benefit. It is calculated by dividing the average annual profit (which is calculated from the accumulation of all the benefits and losses of the investment period) by the value of the initial investment. In application of the data in Table 24, this would imply the calculation of the ARR before or after the DEC. In the case of a final ARR, the calculation would be:

$$\text{ARR}_{\text{AFTER DEC}} = \frac{\text{Average Annual Net Margin after DEC}}{\text{Initial investment}}$$

Net Present Value (NPV)

The Net present value is the difference between the discounted or present value to the type of interest agreed or requested of the cash inflows and the cash outflows of a project. The interest rate requested is the minimal accepted and a positive NPV implies that the investment will result in net value contribution to the NRA, i.e., the investment will have been recovered and the minimum rate will have been reached. The formula is as follows:

$$\begin{aligned} \text{NPV} &= \left[\sum \frac{\text{CF}_t}{(1+\text{i})^t}\right] - \text{I} \\ &= \left[\sum \text{CF}_t \, \text{df}_t\right] - \text{I} \\ &= \text{P} - \text{I} \end{aligned}$$

Where: *I* is the present value of the project's cost (usually the initial cost outlay); CF_t is the cash inflow to be received in period t, with t = 1 … n; *i* is the required rate of return; *t* is the time period; P is the present value of the project's future cash flows; and df_t is the discount factor $1/(1+i)^t$.

Internal Rate of Return (IRR)

The Internal rate of return is the type of interest that matches the discounted value or current value of the cash flows of the RE project to the initial investment value. The IRR is the most widely used valuation method for an investment because the IRR is comparable to other profitability rates, either of financial or banking products or as profitability from comparable or benchmark business activities. The formula is as follows:

$$\boldsymbol{I = \sum \frac{CF_t}{(1 + IRR)^t}}$$

5.3. ANALYSIS OF FINANCIAL VIABILITY OF A PROJECT OF RE FACILITY IN ROADS

As other tools available in the market, the Business Model helps to estimate the power and quantity of yearly electricity produced and its average cost per hour in different locations for a RET list. What makes the ENROAD tool different from others and gives it added value is the analysis of the long term effects in the financial result, individually or as a whole, of the loss of the RET technical efficiency, as well as of the macroeconomic variables (interest rates and inflation). For this, a financial dashboard is provided with four Key Performance Indicators (KPIs):

- Energy Average Prices.
- First Year Total Cost (FYTC): mean cost EU/MWh of each RET in the first year.
- Levelized Cost Of Energy (LCOE): mean cost EU/MWh of the energy produced by each RET.
- Cost Gap (LCOE – FYTC): effect of the efficiency loss, the interest rates (general of the economy and specific of the potential debt of the project funding), and the inflation (above OPEX) on the long-term cost increase.

The model is designed to, in an automatic and recurrent manner:

1. Determine the peak power and quantity of energy produced in the first FYTC year, based on the location, solar and wind resources, and no. of units that can be installed for a given list of RETs.
2. Determine yearly productions along the facility life based on an estimation of performance losses.
3. Estimate the mean cost of the standard MWh produced for the first year of operation, FYTC and the LCOE for each RET. This is done according to the data introduced of real or estimated costs of the facility (CAPEX), of the operations (OPEX) and of the engineering and development (DEC).
4. Finally, with the information provided and the required calculations made, the Business Model offers estimations of Starting Total Investment, Total Energy Revenues, Debt over Investment, Payback Period (in years), Net Present Value (NPV), Internal Rate of Return (IRR), and Average Anual Net Margin After DEC (ARR).

5.4. BUSINESS MODEL SCHEME AND SPREADSHEET STRUCTURE

The BM was designed as in Figure 46, where the numbers of the sheets in which the Excel spreadsheet is organised are also shown. It should be noted that the structure of this spreadsheet has evolved with the project time to finally become the excel Template used for the ENROAD GIS-based tool. Therefore, some changes can be noticed between this structure and the original one in *Deliverables 4.1 and 4.2.*

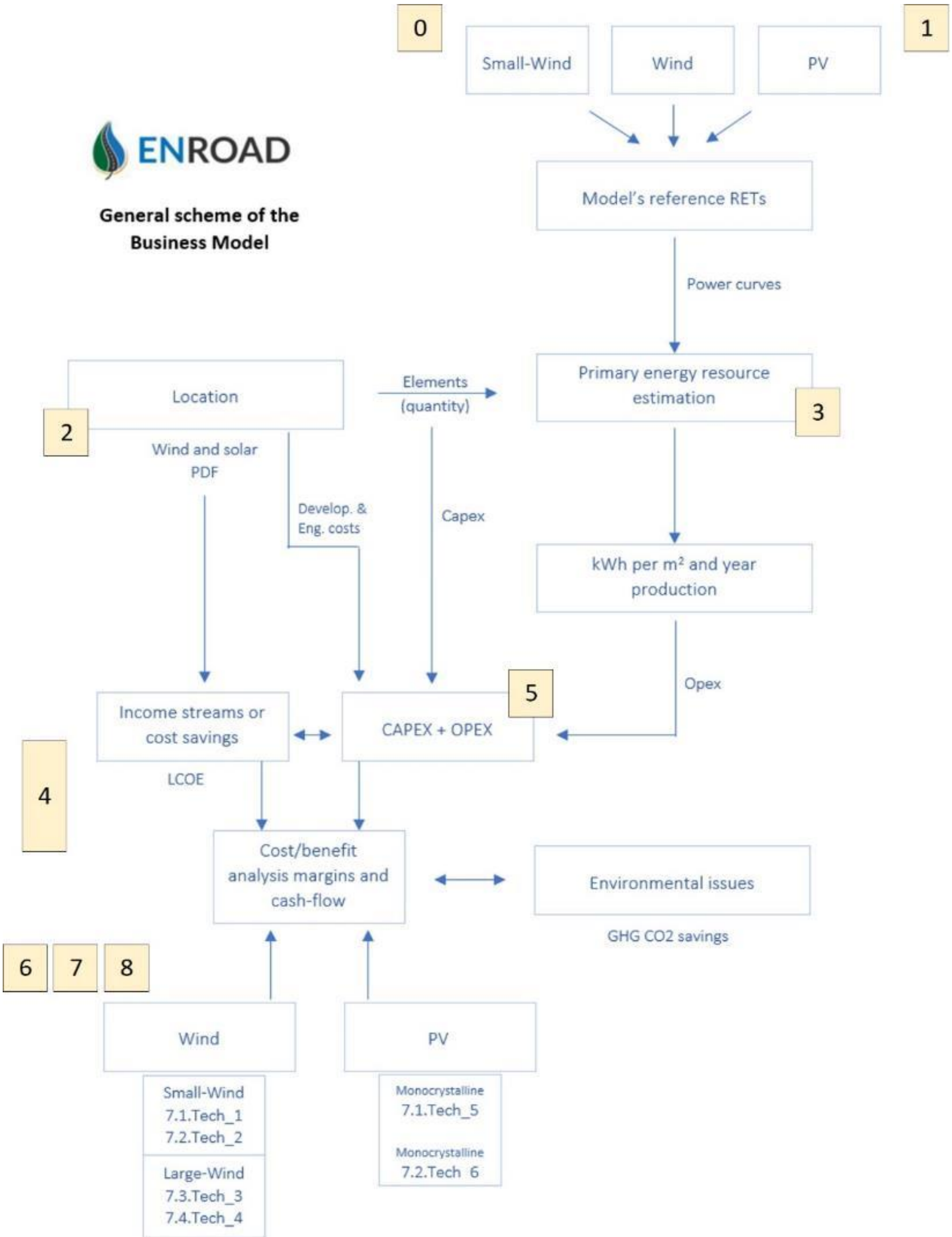

Figure 46.- BM general structure

The BM was designed to include a double approach:

- Supply model: the BM is applied to a business consisting of the production and sale of energy to an electric operator.
- Demand model: starting from the supply model, the energy needs of the NRAs are collected and the percentage of coverage is estimated. This model is not fully developed because the current version does not incorporate neither the potential uses' curves of electricity consumption nor the cost of purchasing the energy from the energy trading company.

Additionally, according to the connection or not to the grid, two scenarios are presented: connected and isolated. In the second one, energy storage systems (ESS) technologies and their costs are incorporated into the model, even for large wind, since the ESS is a complementary electricity supply system. The description of the dataset conforming the structure of the Excel file with their respective sheets and, in due case, the referenced numbers in Figure 46, is as in Table 22.

Table 22.- Description of the organization of the Excel file in sheets or datasets

Reference number & type of dataset (group)	Dataset (Excel file)	Brief description
General description	Sheet Codes	ENROAD Sheet names and links
General description	Disclaimer	Project Aim and Disclaimer
General description	Summary	General presentation of inputs such as location, starting year, NRAs equity, demand of energy by NRA, interest rates, government subsidies, inflation or date of analysis; and provides a summary of most important outcomes.
1: General configuration	1.1_Config_TC	List of RETs with technical features (rotor diameter, nominal power, module length, module width, etc.) and main costs. In this section, costs by default per component (CAPEX) are included as well as the engineering and development costs (DEC) for each RET.
1: General configuration	1.2_Config_WNP	Table with the wind speed in m/s and nominal power in kW for small and large wind turbines.
1: General configuration	1.5_Config_ESS	Five configurations and costs of ESSs are considered. The information on batteries does not consider their renovation at the end of their lifetime, which is lower than that of the facility. It is advisable to use a multiple to adjust the estimate.
1: General configuration	2.2_Input_PRO	Project data by NRAs with the configuration of connection to the grid, energy demand, storage capacity, peak power for using the energy stored, financing, etc.
1: General configuration	EU_LaborCost	Labour cost levels by NACE Rev. 2 activity in the project countries.

2: Location	2.1_Input_LOC	Input from the GIS-based tool of location (Longitude, Latitude and Altitude), area and project starting date. The First Year of Exploitation is the second year of Project, since the first year, totally or partially in months, is for installation operations.
3: Production data	3.1_Out_Prod&Costs	Starting from the number of RETs units estimated by the GIS-based tool for the selected area, the losses are introduced according to the prices in 1.1_Config_TC.
4: Income Streams and Cost Savings	1.4_Config_Prices_IR	Financial parameters: yearly country's forward prices and interest rates.
5: CAPEX + OPEX	3.2_Out_CapEx_OpEx	Determination of the tables 4, 5 and 6 of Deliverable 4.1: estimations for the first year of exploitation of each RET with CAPEX, OPEX and DEC costs.
6: Cost/benefit analysis, Margins	3.3_Out_Margins	Analytical Profit and Looses Statement for each RET. Net margins before DEC, after DEC and net yearly margin after DEC per kilowatt hour. Besides, the initial total costs are gathered per kWh as well as the total initial CAPEX per KWh.
7: Cash Flow (Cash Budget)	4.1_Tech_1 4.2_Tech_2 4.3_Tech_3 …	Cash Budget Statement (Table 8 in Deliverable 4.1) for a RET. In case government subsidies are available, these are deducted from the payments for Property, Plant & Equipment (PP&E) in the first year, the one of the installations. The Cash Flow Statement is accompanied by the yearly data, for the whole project term, of the energy prices, costs of energy production and the production itself.
7: Cash Flow (Debt repayment and amortization schedule)	4.1_Tech_1 4.2_Tech_2 4.3_Tech_3 …	The difference between NRAs equity and the total of the investment is completed by a bank loan with an amortization period equivalent to the length of the project applying the French amortization method.
8: Performance (Financial assessment)	4.1_Tech_1 4.2_Tech_2 4.3_Tech_3 …	A chart with the revenues, costs and net margins is offered. In this section, the Payback Period, NPV, IRR and AARR are determined. Similarly, the LCOE is determined for the RET.
8: Environmental performance	3.4_Out_Env	Estimated environmental impact, GHG/MWh and CO2 Annual Savings.

The LCOE is estimated based on the following formula:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{C_t + M_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{Q_t}{(1+r)^t}}$$

where C_t are the yearly costs of Facility Depreciation, End-of-cycle Depreciation and Dismantling and DCE Depreciation (all of them are CAPEX); M_t are the yearly operation costs (OPEX); Q_t is the yearly energy production; t is the year; r is the interest rate (IR); and T is the length of the project as a whole.

5.5. ENVIRONMENTAL APPROACH

Literature search and review were conducted to attain overview on the availability of information on the environmental impact the of RETs from a life cycle assessment (LCA) perspective. Life cycle assessment evaluates environmental impact of the whole life cycle: raw material extraction, materials processing, production, transport, use and end-of-life processing. The method includes all resources that are needed to satisfy a specific need or function. LCA is most often based on a functional unit (FU). For the electricity market, FU would be the environmental impact per kWh in order to compare different technologies. For this project, the life cycle energy is a variable within the ENROAD GIS-based tool and therefore, the total emissions related to the selected technology are needed. In the ENROAD tool the impact is presented per kWh/MWh for comparison purposes.

The literature review was used to find guiding values for the technologies considered. Thus, a search in Scopus was performed for all RETs mentioned in *Deliverable 2.1*, but the main focus was on wind energy and solar PV technologies. The search for the literature review of wind technologies returned 52 articles, 11 of which were decided to be relevant after evaluating the tittles and abstracts. The search for the literature review of solar PV resulted in 63 papers, but after carefully evaluating titles and abstracts 14 papers were defined as relevant for the GIS-based tool.

Furthermore, research of available data in the EcoInvent database was used to support the information in the literature review. The results of the literature review and available data in Ecoinvent were used to evaluate the potential environmental impact of the RE technologies aimed at creating a site-specific dynamic approach to an environmental impact calculator. The aim of the environmental calculator is to support decisions along with the technical, economic and financial information provided by the ENROAD tool. As the target users of the calculator are CEDR members and other NRAs, a European electric mix is used by default for calculating emissions and for comparison purposes.

The results presented in the environmental calculator are not absolute numbers but an indication of the magnitude of the environmental impact, only for comparison purposes within the context of the final ENROAD GIS-based tool. This is because of the high uncertainty of the required input data: suppliers, transport distances, construction work needed for installation and removal as well as materials and work needed for maintenance.

The sustainability of large-scale PV power plants is questioned in the literature as potentially resulting in problem shifting between the different sustainable development goals, i.e., due to the toxicity in the production and waste handling. However, solar PV plants do not produce noise unlike the wind farms, nor bad smell unlike biowaste plants. Besides, visual impact does not seem to affect nearby residents. The life cycle stages included are based on the European standard EN 15804 (European Committee for Standardization, 2013) and are actually focused on A1-A5 (production and installation), and B1 (use, energy production).

For the estimation of the environmental impact of wind turbines, two sizes have been included from the Ecoinvent database that offer a good estimate: 2 MW and 3.3 MW onshore turbines. The dataset used has been adjusted mostly to represent the European situation instead of the global market. Regarding the estimation of the environmental impact of PV panels, ground-mounted silicon PV panels have been selected from the Ecoinvent database due to their slightly higher technological and market readiness level. Like with wind turbines, the dataset has been adjusted to represent the European situation rather than the global market.

Preliminary results obtained with the model for different simple study cases show that for the life-cycle analysis of wind power, potential energy generation, number of turbines and wind conditions are crucial. Likewise, the location of the wind turbines is very relevant for the environmental assessment of the technology for important reasons such as the transportation distance or the construction work that is required for the installation of the infrastructure. As for the solar PV plants, the energy harvested largely depends on the existing solar radiation, which is highly affected by location and angle, as well as by the efficiency of the PV panel. Therefore, their life-cycle impact per MWh varies highly between locations.

6. ENROAD GIS-BASED TOOL

The ENROAD tool developed by the University of Cantabria is aimed at providing NRAs with an **easy-to-use tool** for the pre-feasibility evaluation of renewable energy projects within the road infrastructure. Therefore, the GIS-based tool has been carefully designed in order to become a user-friendly tool and at the same time provide:

1. A preliminary estimation of power and potential energy generation in a specific location.
2. An economic and financial pre-feasibility study of the renewable energy installation.
3. A preliminary environmental impact assessment mainly associated with the core technology.

As this tool is intended for decision-making purposes at a very early stage of the project investment, the solution provided by the tool to an initially proposed study case shows the potential utilization of a specific location to fulfil the energy requirements of a road infrastructure, also allowing the comparison between different renewable generation alternatives.

It should be noted that this tool is intended to help technicians and managers of NRAs in their decision-making process, but in no case can it be taken as a design software nor can it be used as a substitute for the professional advice that is mandatory when dealing with this type of projects and investments.

6.1. TECHNICAL FEATURES

As a first step for the development of the ENROAD GIS-based Tool, a UX Design process was approached with the help of Arup's Digital Advisory team following the Design Council's double diamond framework (Figure 47). As a result of the workshops celebrated (further information in *Deliverable 5.1*), a design was set by the University of Cantabria with improved user interaction, flexibility and general advantages:

1. A more fluent interaction of the user with the application.
2. A more straightforward response to the user aspiration.
3. Wider scope while keeping the convenience of the results provided.
4. Greater versatility, being adaptable by the end-user.

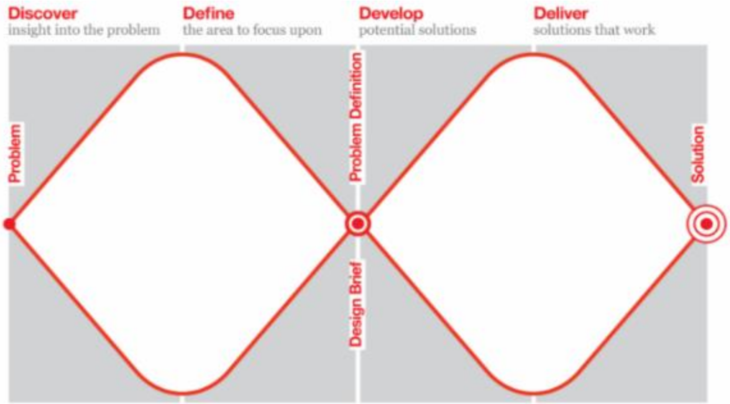

Figure 47.- Design Council's double diamond framework.

All the technical features of the ENROAD GIS-based tool on its actual form are detailed in *Deliverables 5.1. and 5.2.* A summary of the most important characteristics is listed below.

GIS-based tool

The solutions provided by the ENROAD tool are all based on the location of the RET that is planned to be installed. For this reason, a Geographical Information System (GIS) is needed to run behind the tool that is able to deal with the information contained in the different geodatabases used. In order to select the **QGIS software** for the management of the geo-referenced data instead of the more commercial ArcGIS, several aspects were taken into account such as the functionality, compatibility and handling capacity. ArcGIS, by ESRI, consists of several tools. Based on users' experience, the ArcGIS Model builder is more stable and its export to Phyton script is easier as only the ArcPy module is necessary. On the other hand, QGIS is an open-source software, operating under GNU and GLP licenses that manages georeferenced data through GDAL library. The fact that the QGIS is progressively developed by its end users can make things challenging sometimes, especially when looking for a specific feature, but it is also true that all the required functionalities for the ENROAD tool can be found in QGIS, including a good connection to Python. Finally, the fact that the QGIS is non-profit makes it potentially reachable to any professional or organization with the required skills.

Road-focused

The ENROAD tool is aimed at fostering the use of RETs along the road network and the NRAs lands. Thus, in order to help the end user to find the right place for the renewable technologies, different free open-source databases have been incorporated to the tool: EsriSatellite, OpenTopoMap and OpenStreetMap (Figure 48). As requested by the PEB, end users are allowed to upload their own geodatabases such as parcels, points for connection to the grid, land uses, etc., which definitely helps the users to be more accurate when selecting the location of the RET. For the vector data (e.g., shapefile) to be valid for the tool they must be converted to a GeoJSON format (with EPSG:3857 or EPSG:4326 projection coordinate system), which can be done with the QGIS software itself or any of the converters that can be found in the internet (e.g., MyGeodata Converter or Mapsharer).

Web Map Service (WMS)

The operation of the tool by the end user simply by clicking on a link or entering a web site (no need of complex installations or configuration) is key in terms of a proper UX. In short, Web Map Services allow the dynamic consultation of cartographic information generated from one or several sources and loaded from one or several servers. For the purpose of the ENROAD project, raster maps with the information from the energy resources are stored in the external server not to have them locally consuming resources and making the processes slower. Geoserver, an open-source server for sharing geodata that is installed in the external server with the maps, is used to supply the energy layers to Leaflet, an open-source library responsible for the management of the raster maps, through WMS connections. Finally, the refinement of energy databases for a correct visualization is performed from Geoserver by cubically interpolating the raster maps -both in colour gradient and numerical pixel value - when zooming in and out them.

Languages and open-source tools

Different programming languages, libraries and free databases have been used for the development of the ENROAD GIS-based tool. More specifically, HTML, CSS and JavaScript have been used for the FrontEnd web development, while Java and Node.js have been used for the BackEnd development.

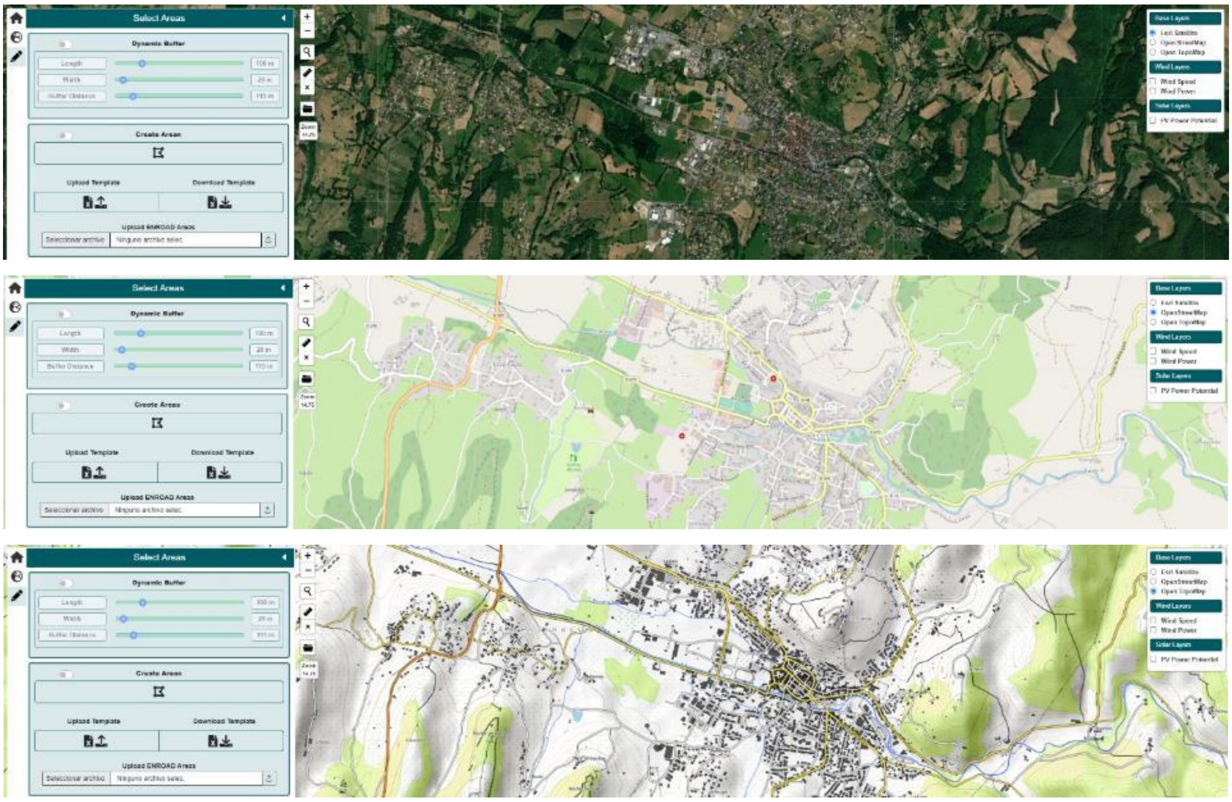

Figure 48.- Different databases for the location of the RETs

Renewable Energy Sources (RES)

The decision about the RE sources that can be exploited by NRAs for electricity generation in their lands and assets has been made based on the study carried out by the University of Cantabria and SINTEF Energi during the first part of the project. The resolution for both the wind and solar resource is of 250 m, very suitable for the purpose of the tool (Figure 49). On the other hand, this high resolution makes the maps extremely heavier, resulting in a slower and more difficult management of the georeferenced data and hence, in worse user experience. For this reason, energy layers were decided not to be stored in local, but in a more powerful external server.

Although the ENROAD tool was initially designed for the calculation of renewable energy production using solar and wind data from an average of recent time series - the small differences in these time series seem to guarantee a good accuracy of the calculations provided by the tool - for this version of the tool, wind and solar data that are updated over time (PVGIS, https://re.jrc.ec.europa.eu/pvg_tools/es and NEWA, https://map.neweuropeanwindatlas.eu) have been used to provide a little more accuracy.

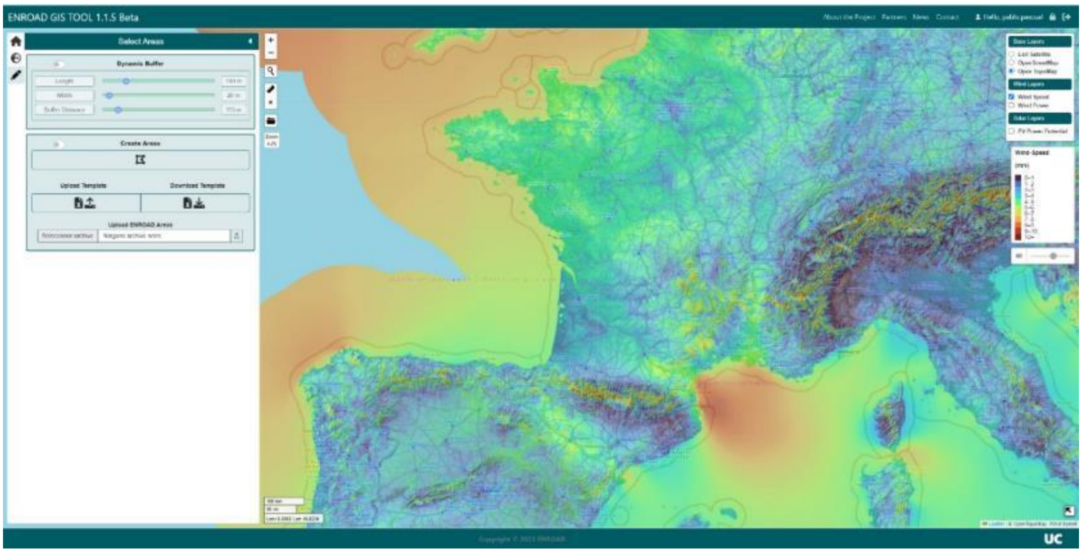

Figure 49.- Screenshot of the wind speed layer in the ENROAD tool

6.2. MODULES INVOLVED & OPERATION

Inputs & Outcomes

The type of user dealing with the ENROAD tool defines the amount and complexity of the input data that must be introduced: from basic *Location*, *RET*, *Area*, *Available financing* or *Starting year of investment* to more specific *Energy demand for storage*, *Inflation rate*, or *OPEX standards*. Further information about the inputs can be found in the next section (User Guide).

In terms of the outcomes, the ENROAD tool allows the user to start making decisions based on a set of results that depend on the inputs provided. The results can be classified intro three groups or modules: 1) power capacity and energy production, also based on the energy resources on site; 2) an economic and financial assessment, which depends on the amount of electricity that can be produced; and 3) a preliminary environmental assessment associated to the technology implemented.

Excel Template

While the GIS-based tool helps the user to make the most important decisions, the location and *selection of the RET* and the *area available*, and provides the *number of elements* (PV panels, small turbines or large turbines) that fit the area selected and *the total capacity (MW)* obtained, the potential *energy production* (MWh) and the remaining technical, financial and environmental outcomes are detailed and presented in an excel file that can be later used to further analyse those results. Likewise, important inputs such as the *interest rates* or the *financing by NRAs* have to be uploaded into the tool through the same template.

Thus, the ENROAD tool is built up of two elements: an Excel file or ***template*** where inputs and outcomes are displayed in the form of a complete study case for a specific location, which will change every time a new simulation is carried out; and the tool itself (the ***web service***), which makes use of the input data in the template and allows the user to select location and area for the different RETs, and calculate the total capacity of the new renewable energy installation. Those data are then written back on the excel template and the rest of the outcomes are calculated accordingly.

The information in the Template is split in 4 different types of sheets, each with a colour (Figure 50):

- Configuration (1.X_Config_XXX): main parameters of RETs, ESS, standards and prices.
- Input data (2.X_Input_XXX): input data to be entered by the user or the GIS tool itself.
- Out (3.X_Out_XXX): energy, economic and environmental outcomes.
- Technology (4.X_Tech_X): financial analysis per RET.

Some of these sheets have been hidden/blocked to prevent misuse by the user that would cause the tool to malfunction (e.g., cells automatically filled by the tool are highlighted and blocked).

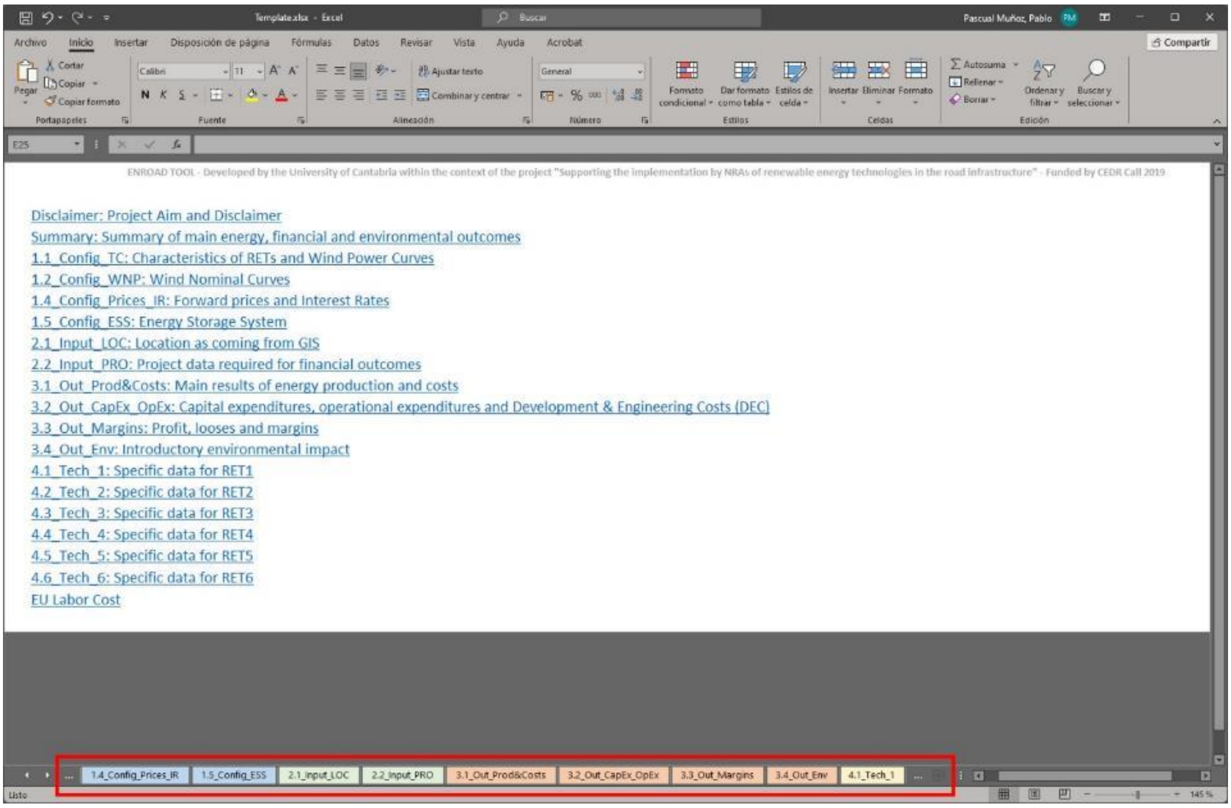

Figure 50.- List of contents and codes of the Template for the ENROAD tool

Renewable Energy Technologies (RETs)

In line with the energy sources, the decision on the renewable energy technologies to be included in the ENROAD GIS-based tool has been made based on the study carried out by the University of Cantabria and SINTEF Energi during the first part of the project.

In addition to the technical criteria such as the maturity of the technology (TRL), performance, ease of integration or accuracy of the models developed, the scope and results of the survey conducted (see section 2.3) were considered relevant and therefore, taken into account for the decision. According to the study carried, the three main types of RETs (two models each) in Table 23 were initially incorporated into the tool.

Table 23.- RETs initially included in the tool

RET type	Rotor Architecture - Reference	Manufacturer	Nominal Power
Small Scale Wind Turbine	HAWT - Bornay 6000	BORNAY	6 kW
	Darrieus - Aeolos-V 3kW	Lotus Energy Tech	3 kW
Large Scale Wind Turbine	HWAT - V90-2.0 MW	VESTAS	2000 kW
	HWAT - NWB 54-750	NORWIN	750 kW
RET type	**Cell type - Reference**	**Manufacturer**	**Nominal Power**
PV Module	Monocrystalline A-330M GS PERC	ATERSA	330 kW
	Polycrystalline LX-330P/156-72+	LUXOR	330 kW

However, based on the feedback provided by several experts from the energy industry (10 professionals were consulted on the RE technologies included in the tool, the calculations made, the prices and costs given by default, etc.) who were shown the ENROAD tool for validation purposes, it was decided to update the RET list and replace the 750 kW wind turbine and the polycrystalline PV module with a more modern and cost-effective 3.3 MW turbine and a 530 kW monocrystalline module (Table 24).

Table 24.- RETs finally included in the tool

RET type	Rotor Architecture - Reference	Manufacturer	Nominal Power
Small Scale Wind Turbine	HAWT - Bornay 6000	BORNAY	6 kW
	Darrieus - Aeolos-V 3kW	Lotus Energy Tech	3 kW
Large Scale Wind Turbine	HWAT - V90-2.0 MW	VESTAS	2000 kW
	HWAT – V112-3.4 MW	VESTAS	3300 kW
RET type	**Cell type - Reference**	**Manufacturer**	**Nominal Power**
PV Module	Monocrystalline JAM60S10-330/PR	JA SOLAR	330 kW
	Monocrystalline JAM72S30-530	JA SOLAR	530 kW

Maintenance and updating (change of RETs by users)

In order to facilitate upgrading and maintenance to a certain extent, the tool has been designed so that a user with some energy knowledge and access to certain technical data is able to modify the parameters of each of the six technologies initially incorporated into the tool (two small wind turbines, two large wind turbines and two types of PV panel), and even replace each of the technologies completely as long as they are replaced by the same type of technology (i.e. small wind turbines, large wind turbines and PV modules can only be replaced by other small turbines, large turbines and PV modules, respectively).

In order to replace a technology only the *Excel Template* needs to be modified. Particularly, the following information has to be updated: 1) Reference, manufacturer and technology characteristics in the sheet **1.1_Config_TC**; 2) Wind nominal curves in the sheet **1.2_Config_WNP** (only in case of change of the wind turbines); and 3) Individual figures of environmental impacts in **3.4_Out_Env sheet**, if required. Once this information is updated and the template is uploaded into the ENROAD GIS-based tool, the new data is read by the application, the reference names and other necessary data are changed (and shown in the screen), and the calculations are made according to the new models defined.

Type of users & Modes of operation

As a main conclusion from the workshops with Arup's UX team, the tool was thought to be used by 2 types of users with different profiles and knowledge. A *basic user*, with a more executive profile, whose aim should be to obtain a global vision of the opportunities for the installation of RETs; and an *advanced user*, with a more technical profile, whose aim is to get as much as information as possible at this first level of the decision-making process. The main difference between these 2 types of users lies in the level of outcomes they are interested in, one more focused on the summary of results provided in the Excel Template and the other more into detailed results) and the number and quality of inputs they enter.

CALCULATION OF ENERGY GENERATION AND STORAGE

The model developed for the estimation of the energy production of the RE technology (Small Wind, Large Wind and solar PV) for the location and the existing energy resource, is based on the theoretical development carried out by SINTEF Energi, as presented in *Deliverable 2.2.*, and the needed adjustments incorporated by the University of Cantabria during the coding of the tool.

In short, the Total Annual Energy Production (MWh/Year) of the turbines depends on the wind resource at the selected site, the type and power of the turbine, its geometry, the number of turbines arranged in the chosen area and its layout (number of rows and number of turbines per row). As for the PV plants, the Total Annual Energy Production depends on the solar resource at the selected location, the type and power of the module, the total number of modules and the plant layout. Also, an initial approach to the need of storage (technology and cost) is provided that considers the *NRAs renewable energy demand for storage* (kWh/day) and *NRAs renewable peak power demand for using the energy stored* (kW).

In order to gain precision in estimating the location of the elements of the PV systems and their overall performance, two functionalities were added to the ENROAD GIS-based tool that makes use of the API of the PVGIS online service. The first functionality makes use of the *Grid-connected* API to determine the optimal elevation and azimuth angles of the PV arrays, thereby obtaining the greatest possible energy production for the irradiance conditions at the selected location. For this, the API takes into account the location where the PV system is installed and the shading effects due to the local orography. The second functionality is based on the *Horizon Profile* API, through which the optimal distance between rows and arrays is calculated. Defining this spacing is crucial to avoid shading effects between adjacent rows, as this would decrease the energy production and the PV plant lifetime, and to avoid those effects it is necessary to know the position of the sun as determined by elevation and azimuth angles at the winter solstice (when shading effects are maximum). With angles provided through the *Horizon Profile* (Figure 51), the distance between arrays is calculated according to Ma et al. (2015) and Sánchez-Carbajal and Rodrigo (2019).

Figure 51.- Determination of solar winter elevation and azimuth

ECONOMIC AND FINANCIAL ASSESSMENT

The purpose of the model is to provide the NRAs with an estimation of the energy generated by the RET selected, as well as the corresponding estimated cost of investment (CAPEX, OPEX and Development and Engineering costs) and a financial assessment (LCOE and payback period) of the solution proposed that is based on parameters such as the type of RE technology and the renewable energy resource. For this, the model has been designed with a bottom-up approach, i.e., the calculations are made considering the disaggregated data from the RETs manufacturers, the locations selected and the energy resources (wind speed and solar radiation). Thus, ENROAD not only provides the user with an accurate estimation of the energy production, but also an effective analysis of the cost structure and the economic and financial picture associated to the solution proposed, all offered in an intuitive and understandable way. It should be noted that by-default estimations are given at a European level, however, due to the changing nature of the figures referred, the tool allows the user to change different economic and financial parameters in order to adjust that estimation to the particularities of the country where the analysis is based.

The ENROAD tool provides these economic and financial results depending on the type of user accessing the tool. Thus, a **basic user** enters or modify default values of: *location, starting year of the investment, interest rate percentage or available financing*; and obtains the following outcomes for each RET: *total annual energy production, total installed peak capacity, Levelized Cost of Energy (LCOE), starting total investment, total energy revenues or savings, project duration and loan repayment, debt over investment, payback period, Net Present Value (NPV), Internal Rate of Return (IRR), Average Accounting Rate of Return (AARR) and CO2 savings*. On the other hand, an **advanced user** enters or modifies the same default values plus: *RETs configuration and CAPEX, OPEX and DECs standards*; and obtains the same outcomes for each RET plus: *annual net margin before DECs per kWh, annual net margin after DECs per kWh, annual cash budget and cash-flow.*

PRELIMINARY ENVIRONMENTAL ASSESSMENT

As a result of the Life Cycle Assessment (LCA) carried out by SINTEF AS, main outcomes of the ENROAD GIS-based tool are the Life Cycle Inventory for the four large scale technologies that can be selected by the user, including (among others) GHG emissions (kg CO_2 eq/MWh) and annual CO_2 savings (Tonne CO_2/MWh), the latter based on the values of GHG emissions by a combined cycle gas turbine (US DOE, 2022 and Hou et al., 2016). The results obtained derive from a cradle-to-gate approach involving mainly extraction, manufacturing, construction and connection to grid of the technologies. Transport is partially included, as only the transportation of materials to the manufacturing plant is considered. It should be noted that the extraction, manufacturing and construction (installation) phases together account for the vast majority (85-90%) of the energy consumption and emissions (Schultz and Carvalho, 2022; Thompson and Garrison, 2015; and Khoie et al., 2020).

6.3. SECURITY FEATURES

To allow access only to authorized users and to secure the information uploaded through the template, the ENROAD GIS-based application has been provided with an authentication layer by means of user and password (Figure 52). Once on the ENROAD website, users must enter their username and password to log in. The password can be changed anytime. Two types of profiles have been considered: administrator and user. In addition to accessing the application, the administrator can register new users. Additionally, an access audit has been included to record all accesses to the application.

Other protection measures have been added to secure the server on which the ENROAD tool is hosted and protect it against misuse, corrupted files, excessive file size, etc. An extra validation has been added in the configuration of the write microservice to prevent the system from uploading templates higher than 10MB. Also, a service has been added to automatically notify the administrator when the tool stops working. Finally, a new validation process has been set up to prevent users from uploading templates with empty or misspelled mandatory cells.

6.4. USER GUIDE

Even though the ENROAD GIS-based tool has been designed to be very user-friendly, a basic user guide is required for novel users. This chapter presents in an orderly and comprehensible manner the steps to be taken by the user to run the tool and take advantage of all its functionalities.

STEP-BY-STEP GUIDE FOR NOVEL ENROAD GIS-BASED TOOL USERS

1.- If you are a basic user who just want to look around and find spots for potential energy generation, simply access the website and select a location and area to obtain a number of elements (solar PV panels and/or turbines) that match the selected area and the total capacity (MW) of the RET. Several graphs show the kWh/m2 available from solar (global irradiation) and wind resources.

If you are **a more advanced user** who want to go deeper into the results, you should start by opening the template, check the default data set and make the necessary changes. Once the template has been adjusted with the new entries, it should be uploaded so that the new data can be read by the GIS-based tool and used for its calculations. Main data to be examined in the template are:

- **2.1_Input_LOC**:
    - Set the **UTC zone** of the country you are assessing.
    - The other important data are automatically imported by the GIS-based tool.
- **2.2_Input_PRO**:
    - **Connected to the grid?**: "Yes" to activate the use of batteries and have it considered for results.
    - **NRAs Renewable energy demand**: estimation of energy demands by the NRA to be covered with RETs.
    - **NRAs Renewable energy demand for storage**: need of energy storage by the NRAs.
    - **Financing (NRAs equity)**: NRA's own public funds for investing in RETs.
    - **Government subsidy**: non-repayable grants (no reimbursement) complementary to NRAs equity.
    - **Average HICP**: measure the changes over time in prices of goods and services acquired by households.
    - **Debt Interest Rate**: estimated interest rate in case it is possible to borrow from third parties (banks).
    - **Price per square meter**: NRAs is considered the owner of the land and therefore this is zero.
- **1.1_Config_TC:** check the standards defined by default (wages, civil works, O&M, etc.).
- **EU_LaborCost:** check and select the weight based on the labour cost levels (countries).

* Notes regarding the font colour in the "Config" and "Input" sheets:

- ***Cells in blue font*** *are costs, prices, efficiencies, etc., related to RETs, energy market, project data, etc. Users are encouraged to check and update these data in order to obtain more accurate estimations.*
- ***Cells in black font*** *are technical features of the different RETs and ESSs, and data related to energy sources that are imported from the GIS platform, given by default or automatically calculated via formulas. These cells can be modified, but some knowledge is required not to corrupt the calculations or the template.*
- ***Cells with a blue dot pattern*** *applied are imported from the GIS platform and cannot be altered in any way. They are blocked to prevent misuse by the user.*

In case one would like to adjust or replace any of the six RETs considered, go to the end of this guide.

2.- Enter the site and log in with user and password (Figure 52).

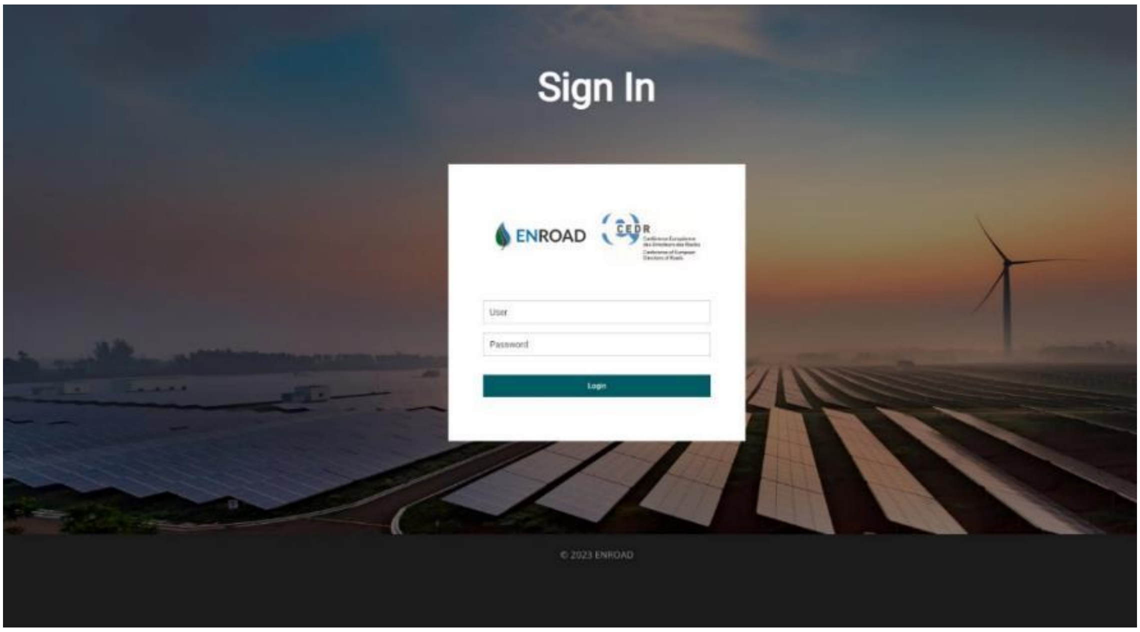

Figure 52.- Authentication screen of the ENROAD GIS-based tool

To change the password, first log in and then click on the lock icon at the top right part of the screen.

3.- Upload the template to the server via the ENROAD application (Figure 53). By doing this, the inputs in the template (see Step 1) are read and used by the tool for its calculations, and the data provided by the tool (location, area geometry, power capacity, etc.) are eventually exported to that template at the end of the simulation, this resulting in all the outcomes in the template being updated.

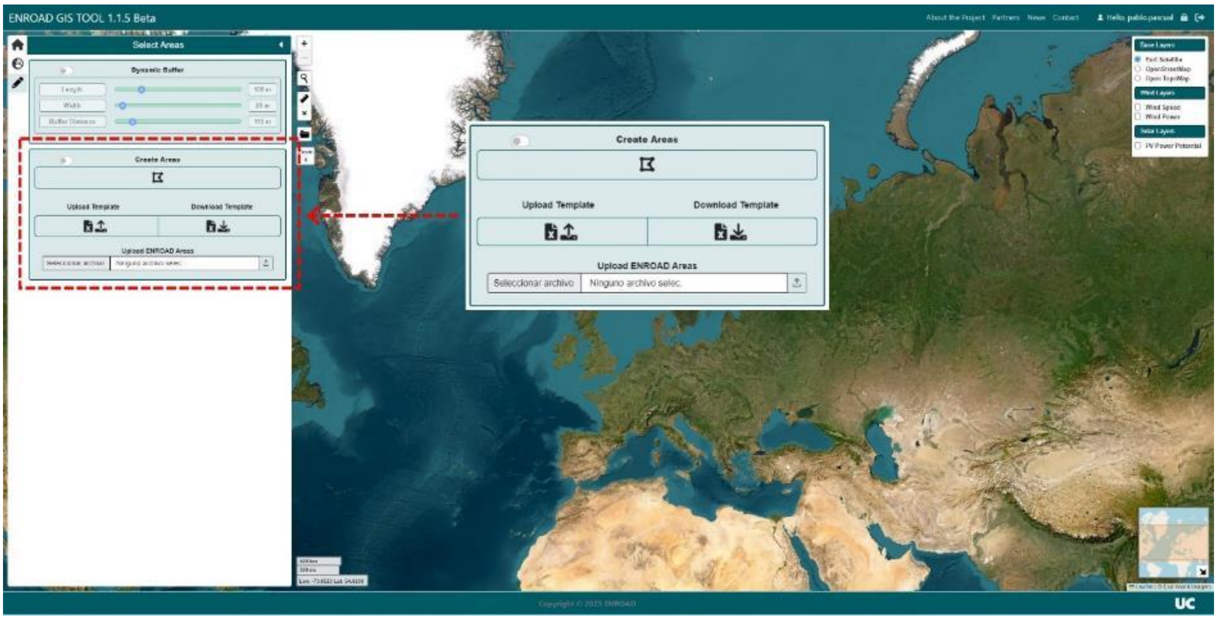

Figure 53.- Loading of the excel file in the ENROAD application

4.- Next step is selecting the country of interest (i.e., where the area for the installation of the RET is to be defined). It can be done manually, simply zooming in and out with the mouse, or with the function offered by the application (Figure 54).

Figure 54.- Selection of the country in the ENROAD application.

5.- In case you are clear about the location you want to jump to, simply use the *Magnifying glass* button and select the place, as in Figure 55.

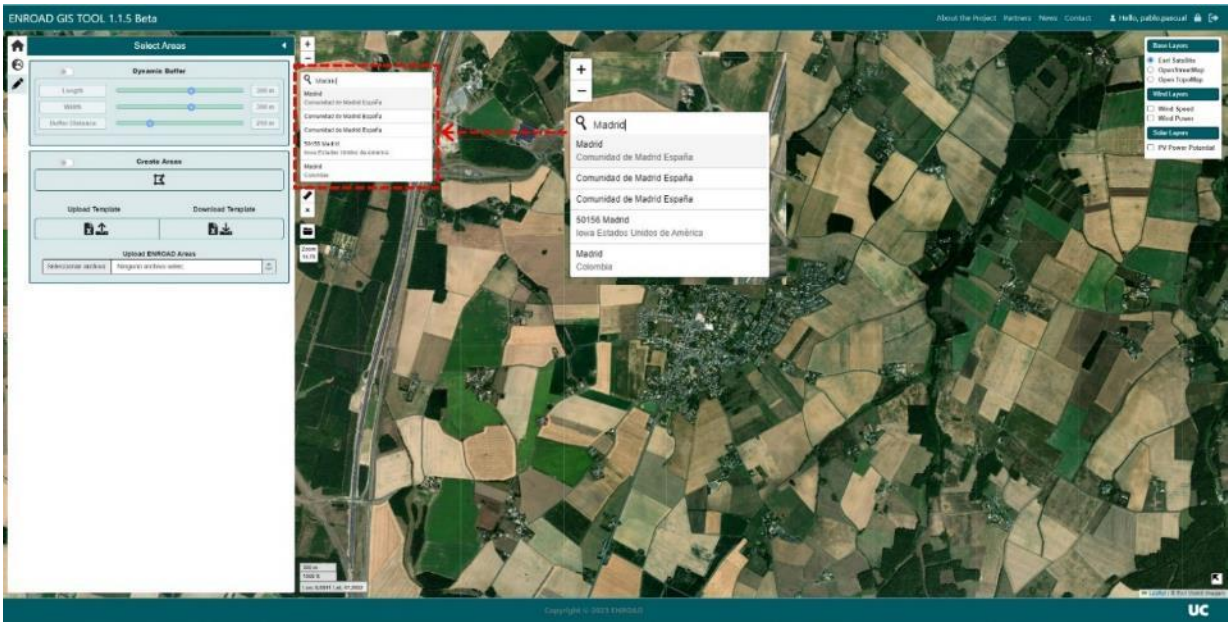

Figure 55.- Use of the “"Magnifying glass” button to jump to a specific place.

6.- Now the road can be displayed on the map (optional operation) but first the user can customize the map by switching from the *Esri Satellite* view (by default) to the *Open StreetMap* or *Open TopoMap* view (Figure 56). To do this, select the desired option from the menu at the top right of the screen.

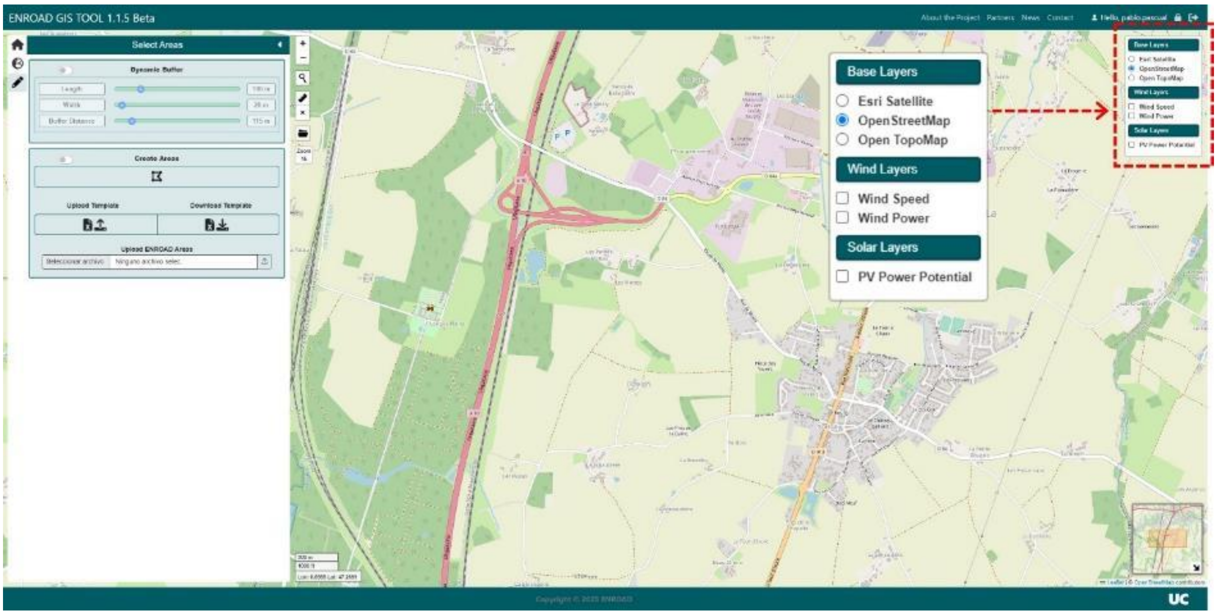

Figure 56.- Selection of Open Streetmap view from the menu at the top right of the screen.

7.- In order to help you to select an adequate location for the RE installation, the *Dynamic Buffer* can be used. Activate this menu to define a sliding polygon with a given length and width, and a buffer to check the distance of the potential location to a specific spot (building, road, etc.) on the map (Figure 57).

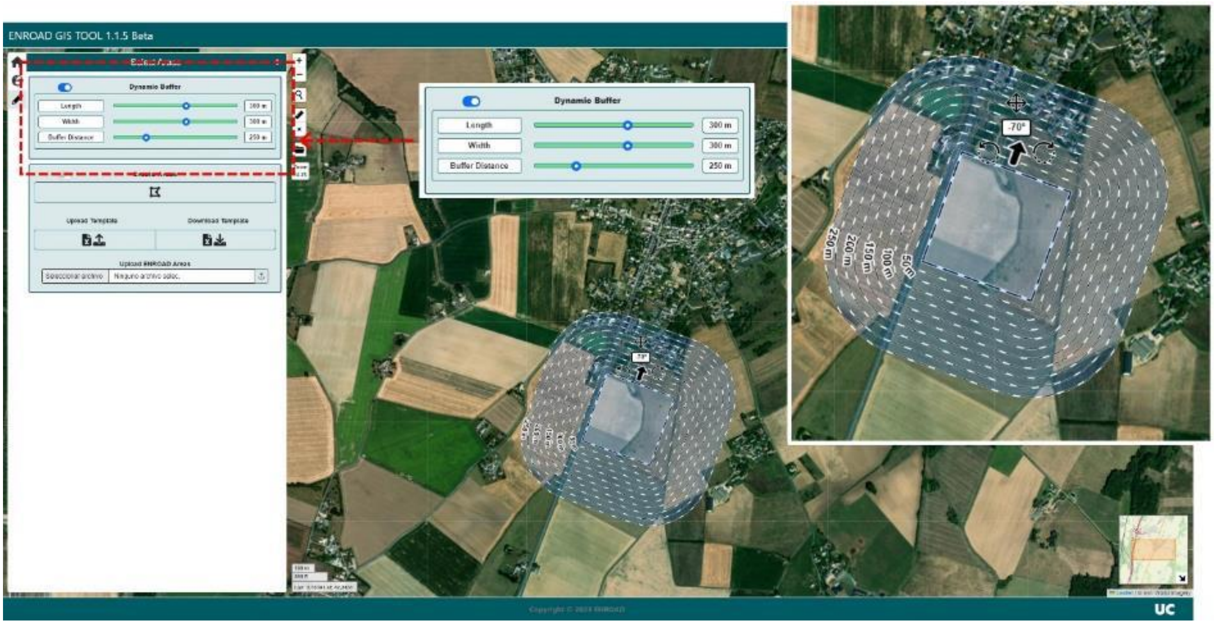

Figure 57.- Activation of dynamic buffer to help the user to set the location.

8.- For more manual measurements, use the *Ruler* button and find out the distance between a potential location for the RE facility and any specific spot (road, building, yard, etc.) in the map (Figure 58).

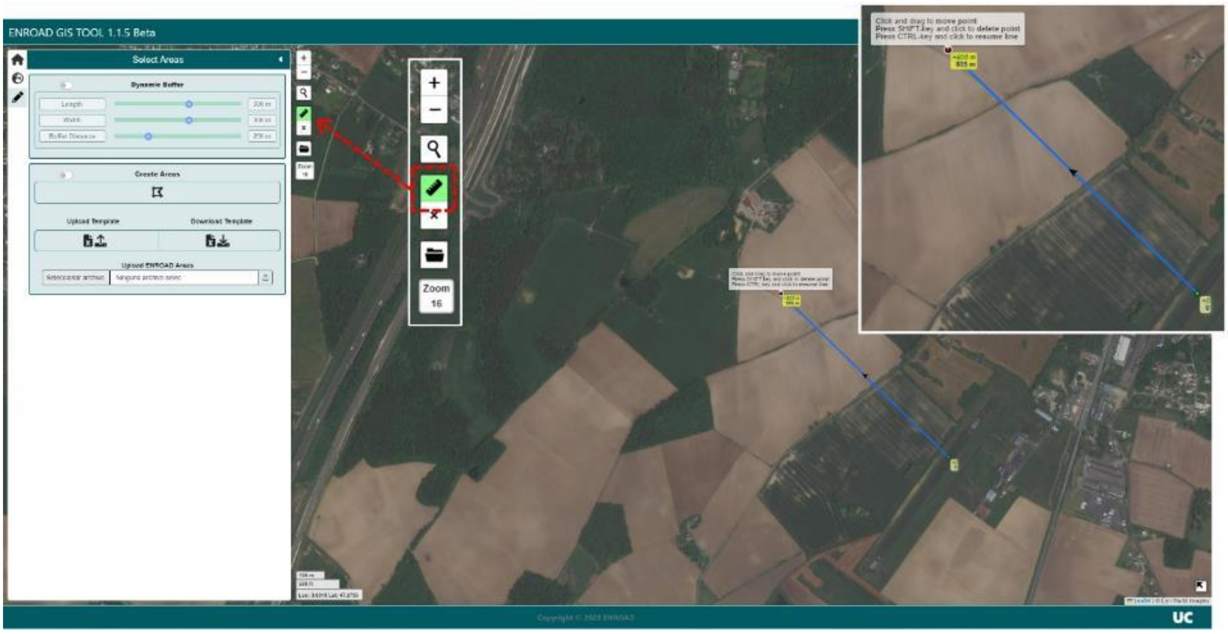

Figure 58.- Use of Ruler button to make simple measurements.

9.- The energy layers (wind and solar resource) can be easily activated by selecting them from the menu at the top right of the screen. This is very valuable information for a basic user looking for opportunities within a large area of land (Figure 59).

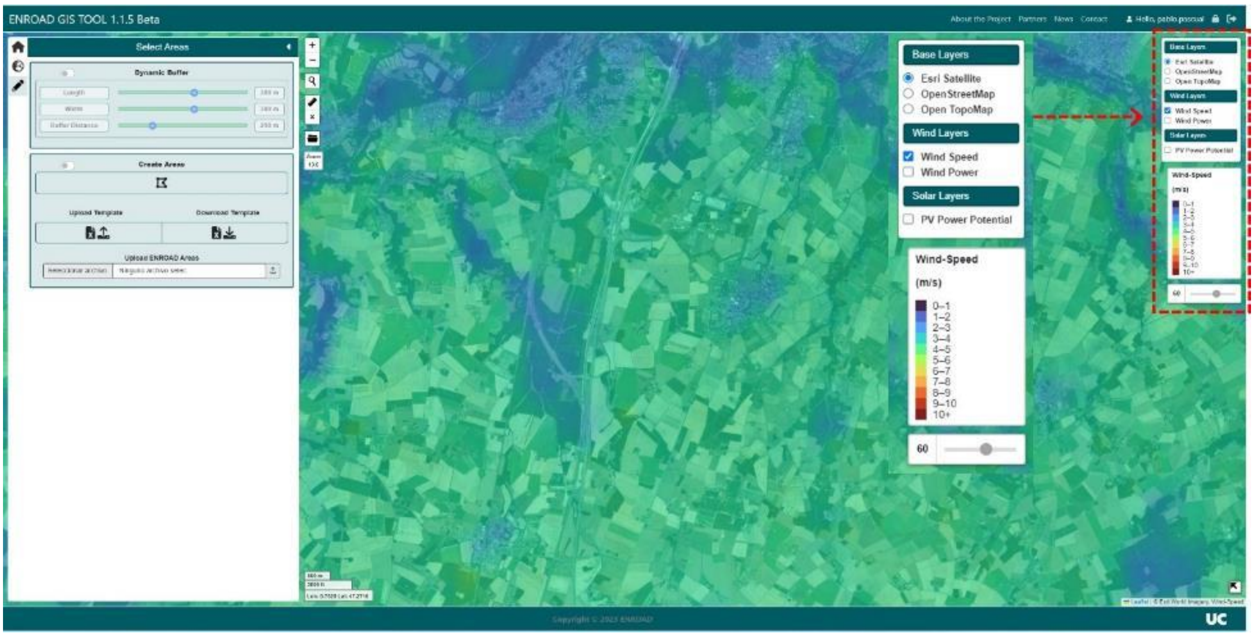

Figure 59.- Activation of the wind speed layer.

10.- External geodatabases -GIS layer- can be uploaded to help you to decide on the location of the area for the installation of the RET (e.g., boundaries of NRA assets, airports, transmission lines, etc.). To do so, simply click on the button shown in Figure 60 and select the file. Note that this file should be previously converted to a GeoJSON format.

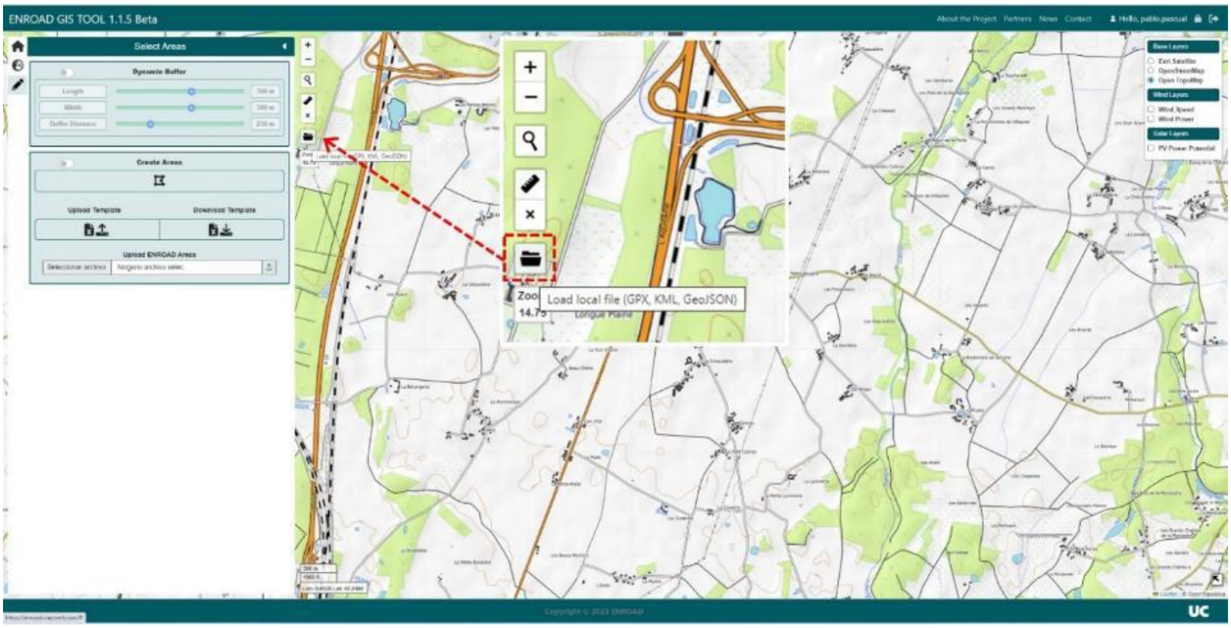

Figure 60.- Button to upload a GIS layer by the user.

11.- Once the location is decided, activate the menu and click on button *Create Areas* to start drawing the polylines that allows you to define the area boundaries (Figure 61).

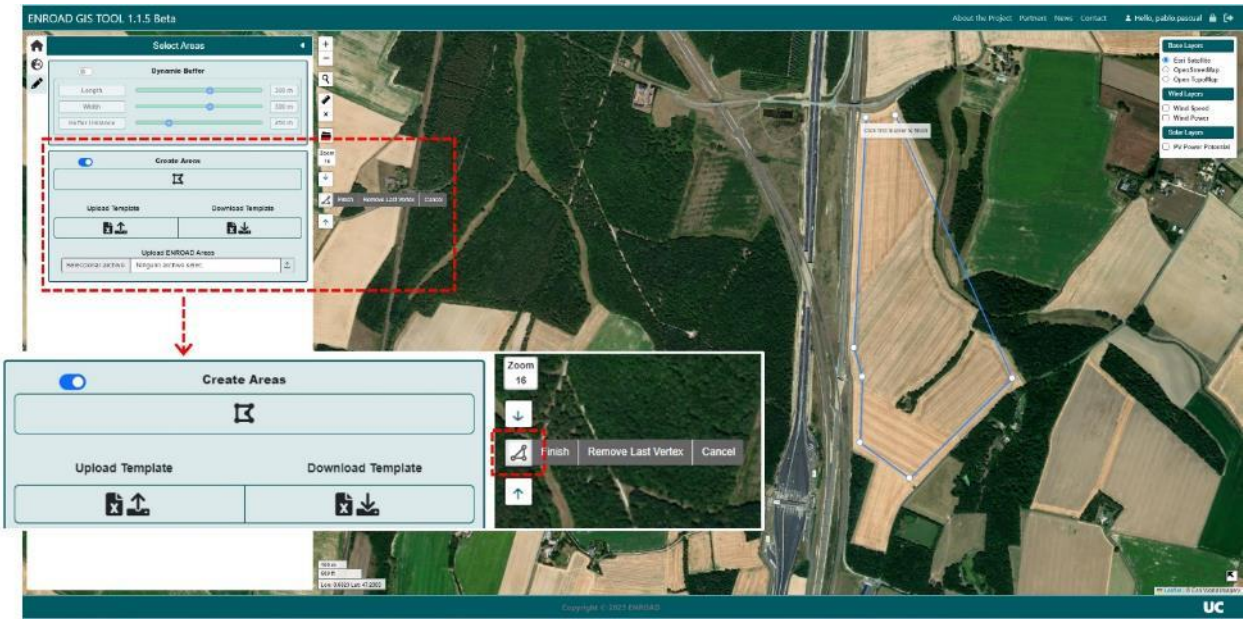

Figure 61.- Definition of an area for the installation of the RETs.

** The *Area Settings*, a new panel with sliders and buttons appear (Figure 62): a first slider to adjust the *buffer area ratio*; a second slider to adjust the opacity of that buffer; a *Fly to location* button that lets the user easily jump to the area; a button to delete the area; a button to easily adjust its geometry; a button to display the dimensions of the area; and a button to download (save) the area with its characteristics.

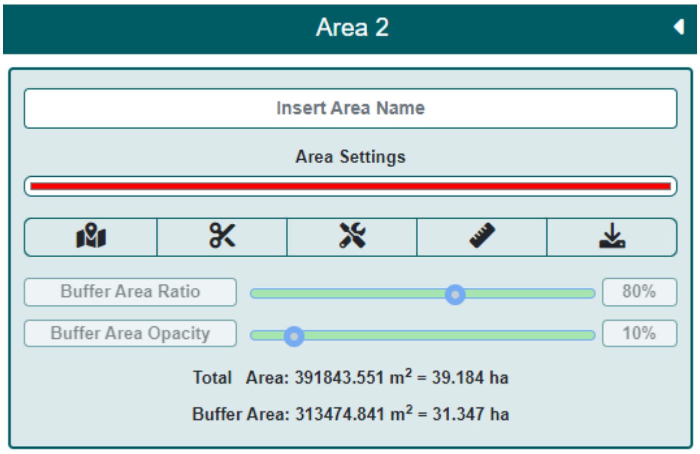

Figure 62.- Panel of buttons and sliders to edit the new area generated.

12.- To check on the suitability of the location and area in terms of its distance to a specific element in the surroundings, the Buffer Zones menu can be activated and the required distance set (Figure 63).

Figure 63.- Activation of *Buffer Zones*.

13.- With the area created, the number of elements for the different RETs that fit that area and the total capacity (MW) are calculated based on certain parameters, some of which can be manually changed. For the case of wind turbines (Figure 64), the spacing between them and wind direction are set by default, which can be adjusted by means of three sliders. When adjusted, the number of elements and the total capacity (MW) of the facility are automatically recalculated (Figure 65).

Figure 64.- Calculation by the ENROAD tool of the number of wind turbines in the area defined.

Figure 65.- Recalculation of the number of wind turbines after adjusting spacing and wind direction.

** Calculations for wind technologies are based on the information in PVGIS and NEWA databases, on the basis of which the following data is calculated and plotted for the selected location: average speed, Weibull parameters and two wind roses, one with the distribution of wind speeds and the other with the distribution of energies. The latter is used to establish the optimal angle at which the turbines have to be oriented (Figure 66).

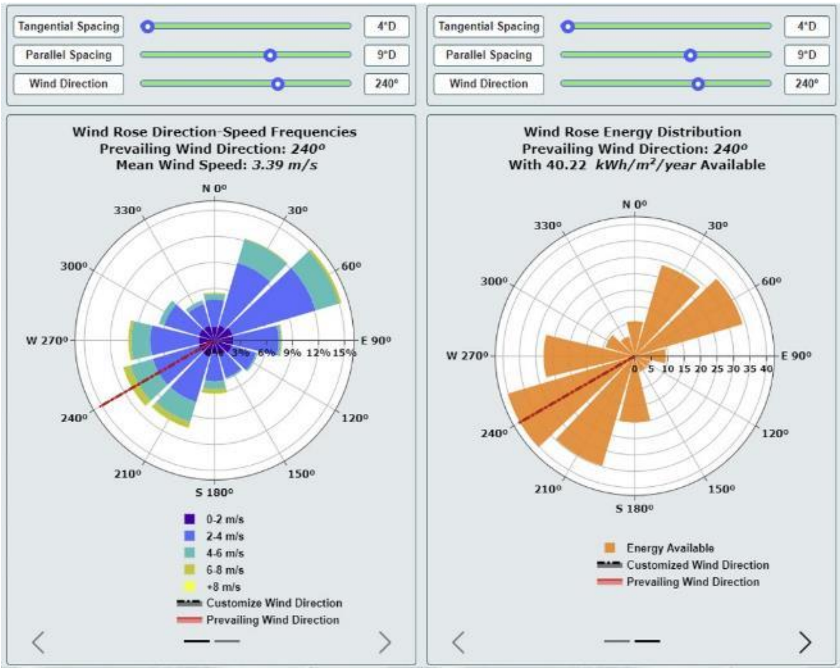

Figure 66.- Wind roses provided by the tool with speed and energy distributions for the area selected.

14.- Finally for this simulation, click on button *Write Template* to export the results to the excel template (Figure 67), and click *Download Template* to find the detailed list of results.

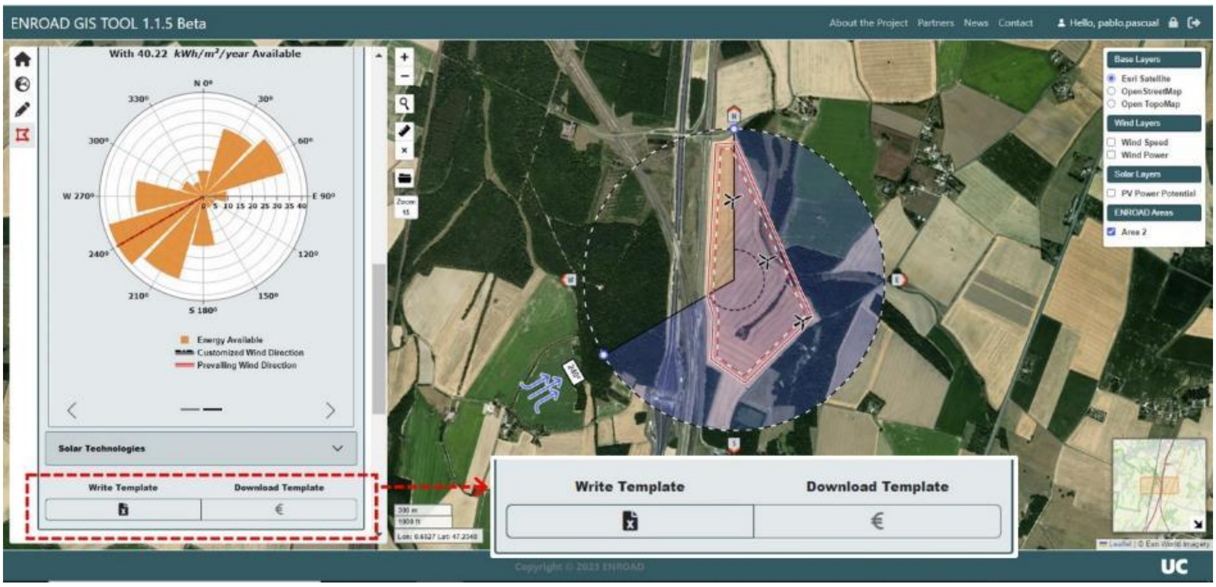

Figure 67.- Exporting results to the excel template and downloading it.

15.- Click the *Download* button in the *Area Settings* panel (Figure 62) to save a local copy of the defined area and its characteristics (location, geometry, number of RETs, etc.) for further simulations (Figure 68).

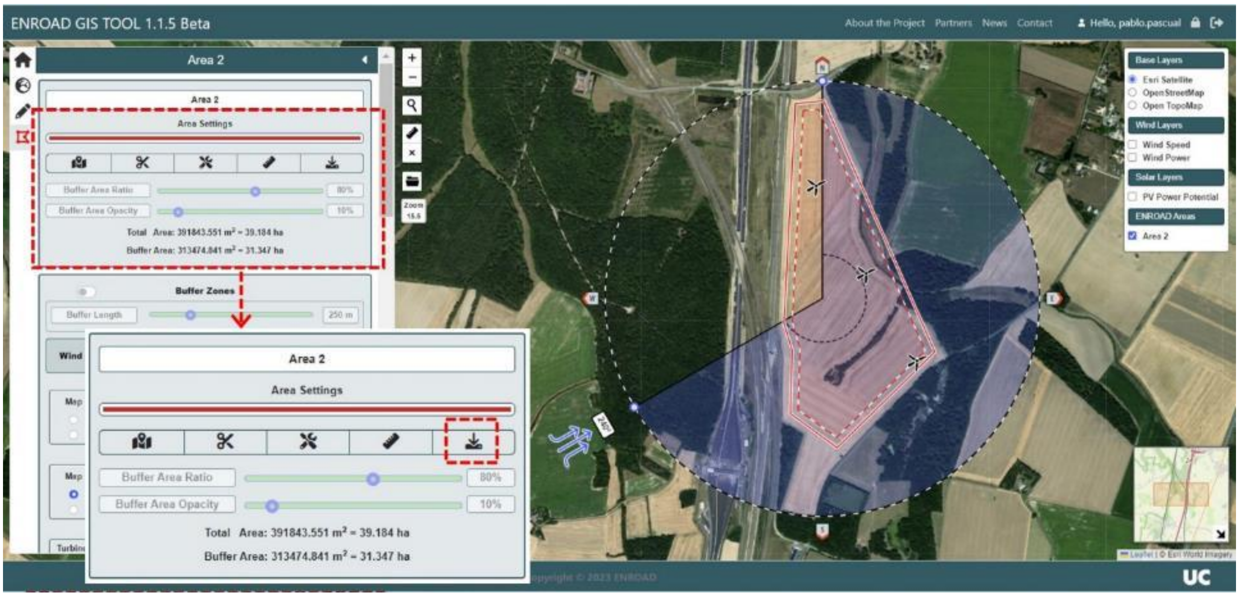

Figure 68.- Download button to save the area defined and its characteristics.

16.- Previously saved areas with its characteristics can be easily uploaded (Figure 69). For this example, a new area is uploaded in the same session.

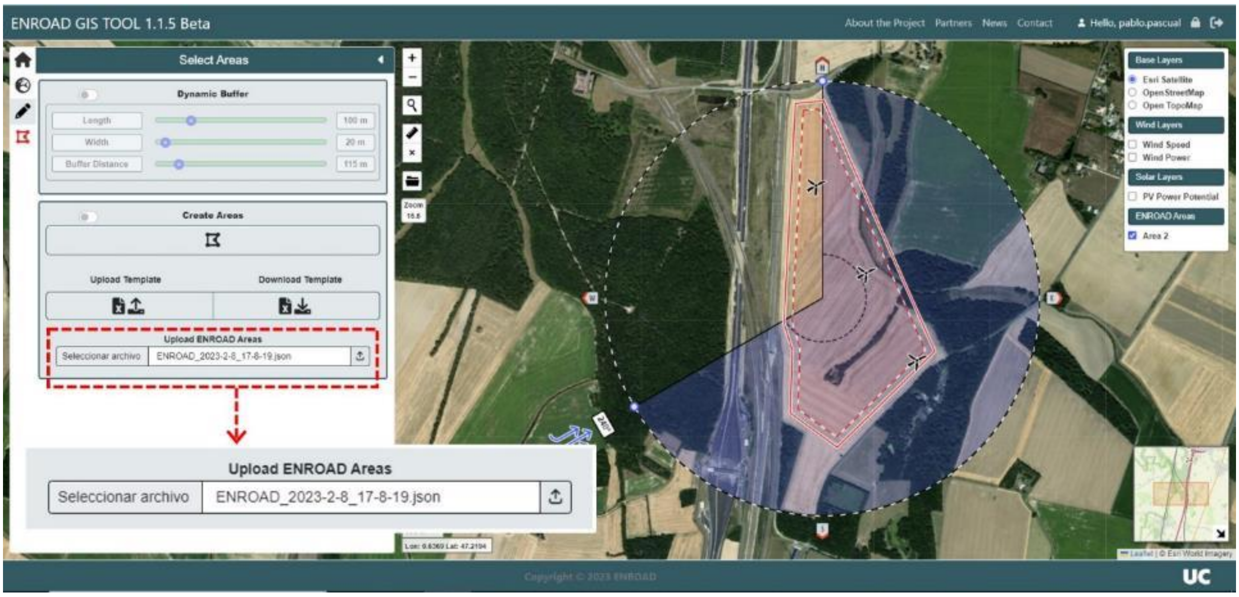

Figure 69.- Upload of a previously saved area and related features.

17.- For a solar farm, optimal solar azimuth and panels elevation are set by default. For this, the location of the PV system and the shading effects due to the local orography are taken into account. Both angles can be manually adjusted by means of two sliders. Given the dimensions and power output of the PV panels (defined in the template), the tool calculates the number of modules and total capacity (MW). If adjusted with the sliders, these values are automatically recalculated (Figures 70 and 71).

** As of version 1.1.10 of the ENROAD tool, the range of tilt and azimuth angles of the panels have been expanded to address the peculiarities of their location next or aside the road.*

Figure 70.- Calculation by the ENROAD tool of the number of PV modules in the area defined.

Figure 71.- Recalculation of the number of PV modules after adjusting azimuth and tilt.

The calculations for the solar PV technologies are based on the information in PVGIS, whose data for a selected area - global horizontal, direct and diffuse irradiation - and a monthly distribution of the energy that can be extracted, are graphically provided by the ENROAD tool (Figure 72).

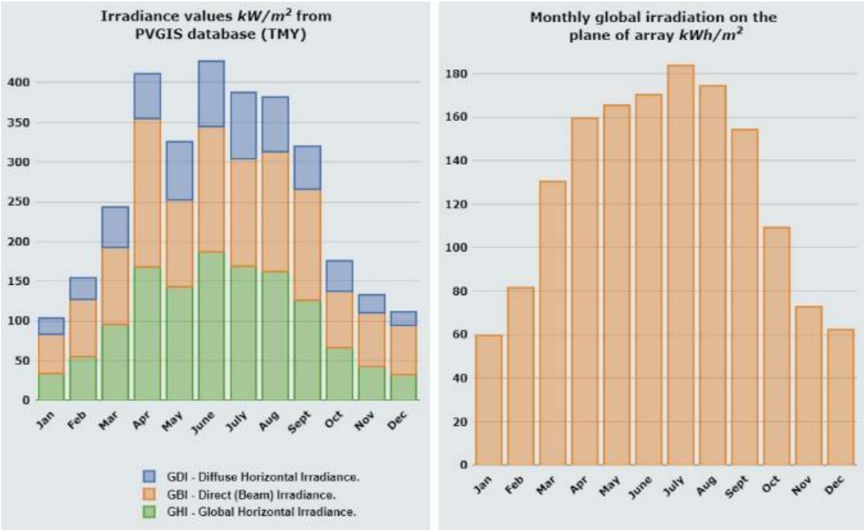

Figure 72.- Data of monthly Irradiance (kW/m²) and Irradiation (kWh/m²) on site.

18.- With the *Inter Row Factor* slider, the number of solar panels can be slightly increased by reducing the vertical distance considered by default. Likewise, with the button *Strings Config*, the configuration of the strings can be swapped from 2x12 to 3x8 (rows x columns) (Figure 71).

19.- Finally for this simulation, click on button *Write Template* to export the results to the excel template (Figure 73), and click *Download Template* to find the detailed list of results.

* Visualization: when the area defined is smaller, panels and turbines fitting that area are more nicely displayed. The colours of the areas (simulations) created in each session can also be changed by clicking on the colour bar in the Area Settings panel (Figure 73).

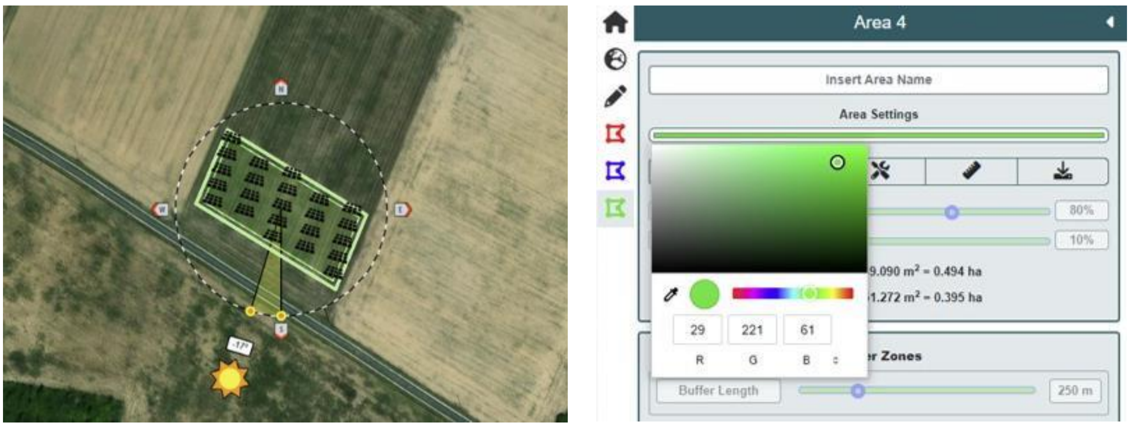

Figure 73.- Visualization of the PV panels in the ENROAD tool.

20.- A complete list of results in the template is ready for further analysis. A complete summary is shown in the *Summary* sheet (Figure 74), including: Total Annual Energy Production (MWh), total installed peak capacity (MW), LCOE (€/MWh), NPV (€) or CO2 emissions savings (Ton CO2/kWh year).

RESULTS FOR THE DIFFERENT TECHNOLOGIES		*Tech_1* HWAT Bornay 6000	*Tech_2* DARRIEUS Aeolos-V 3kW	*Tech_3* HWAT V90-2.0 MW	*Tech_4* HWAT V112-3.3 MW	*Tech_5* Monocrystalline JAM60S10-330	*Tech_6* Monocrystalline JAM72S30-530
		Small Wind	Small Wind	Large Wind	Large Wind	PV	PV
Number of turbines/modules	No.	754	1.517	4	2	115.440	72.744
Total Annual Energy Production	MWh year	1.051,0	369,2	15.589,6	16.149,9	68.471,2	69.341,7
Energy Production per m2	kWh/m2 year	2,10	0,74	31,17	32,29	136,91	138,65
Covered demand for energy	%	32%	11%	475%	492%	2084%	2111%
Total installed peak capacity	MWp	1,5	1,4	7,6	6,6	38,1	38,6
Yearly efficiency looses	%	0,00%	0,00%	0,00%	0,00%	0,30%	0,30%
First Year Total Cost (FYTC)	EUR/MWh	1.080,78	3.791,66	70,46	50,31	37,19	31,93
LCOE	EUR/MWh	1.193,66	4.181,79	86,83	63,14	45,98	39,95
LCOE's best technology (LCOE)	EUR/MWh						39,95
Starting total Investment	EUR	12.162.049	15.126.439	11.237.485	7.627.909	30.992.922	25.708.596
Total Energy Revenues	EUR	1.456.386	511.633	30.751.567	31.856.893	129.562.398	131.209.654
Project Duration (and loan repayment)	Years	20	20	30	30	30	30
Debt (bank loan) over Investment	EUR	11.951.532,30	15.234.600,13	11.243.936,35	7.209.888,86	33.178.964,10	27.374.442,85
Payback period	Years	34	34	34	34	13	9
NPV	EUR	-25.679.877	-32.932.184	-13.152.427	-3.315.437	6.117.963	18.087.302
IRR	%	negative	negative	negative	negative	5,04%	9,28%
AARR	%	-7,66%	-7,92%	-1,36%	1,85%	5,98%	8,41%
Sales for Break-even Point Based on First Year Production	EUR YR	1.135.949,08	1.400.017,21	1.098.517,37	812.528,55	2.546.169,43	2.213.900,93
CO2 Emissions Savings	Tonne CO2/kWh year	-	-	7.090	7.363	28.976	29.347

Figure 74.- Summary of the results obtained after the simulation with the ENROAD tool.

Only for advanced users. In case a more expert user wants to adjust or replace any of the six RETs here considered, the following parameters in the **Template** have to be changed. Then, the **Template** must be uploaded so that the new entries are read and updated by the GIS tool and used for its calculations.

<u>WIND TURBINES</u>

In 1.1_Config_TC:

- Nominal and Peak Power (kW)
- Rotor Diameter (m)
- Expected life time (years)
- Tower Height (m)
- General, Tower and Converter Cost (EUR)

** Other parameters such as Nominal Wind Speed, Cut-in Wind Speed or Cut-out Wind Speed (m/s) should be also changed for the purpose of a proper description of the new turbine, but the values are not used by the algorithm.*

In 1.2_Config_WNP:

- Power curves: Wind Speed (m/s) and related Power (kW)

This information can be obtained directly from suppliers or websites such as **The Wind Power**, where all these parameters (except for the prices) can be found: www.thewindpower.net/index.php.

SOLAR PV PANELS

In 1.1_Config_TC:

- Module Length and Width (mm)
- Number of Cells (no.)
- Expected lifetime (years)
- Cost per module (EUR)
- STC and NMOT Conditions:
  - Maximum Power MPP (W)
  - MPP Voltage (V)
  - MPP Current (A)
  - Open Circuit Voltage (V)
  - Short Circuit Current (A)
- Thermal Coefficients:
  - Current [Isc] (%°C)
  - Current [Voc] (%°C)
  - Power [Pmax] (%°C)
  - Tcell [NOCT] (°C)

** Other parameters such as Module Thickness or Module Weight should be also changed for the purpose of an adequate description of the new panel, but their values are not used by the algorithm.*

This information can be obtained directly from the websites of solar panels suppliers such as Canadian Solar (www.csisolar.com/), JA Solar (www.jasolar.com/), Mitsubishi (www.mitsubishi-pv.de) or AE-Solar (https://ae-solar.com/) to name a few, from which full datasheets can be downloaded.

7. STUDY CASE: EV CHARGING STATION IN GERMANY

7.2. TECHNICAL STUDY WITH ENROAD

A) CASE CANVAS AND DESCRIPTION

The business case selected for this Final Programme report is a charging station for EVs (customer-side or demand model) in Germany. The roll-out strategy consisted of offering a series of charging stations with specific agreements for parcel and logistics companies. In other words, the NRA (or company on its behalf) builds a charging station in plots located next to the highway network, close to companies that can make use of those charging points at night schedule, with the installation including batteries for such schedule. The energy is certified free from GHG. If the business consolidates, a restaurant could be included in the future as the location is close to towns (which eliminates the large wind option). On the other hand, there is an opportunity to develop software for the management of charging stations, which would help to reserve them in advance. The advertising of the facility in the highway itself with panels would help to achieve a good occupancy rate of the facility. The Canvas for this case is presented in the following figure (Figure 75).

<table>
<tr><th colspan="10">ENROAD'S BUSINESS MODEL CANVAS. CASE 3 – ELECTRIC CAR CHARGING STATION</th></tr>
<tr>
<td colspan="2" rowspan="2">KEY PARTNERS

Logistic companies with electric vehicles</td>
<td colspan="2">KEY ACTIVITIES

Energy production
Energy storage
Restaurant & bar (franchises)</td>
<td colspan="2" rowspan="2">VALUE PROPOSITION

Scheduling in advance
Fast charging
Certified Free GHG emissions electricity</td>
<td colspan="2">CUSTOMER RELATIONSHIPS

On road direct advertising based on panels</td>
<td colspan="2" rowspan="2">CUSTOMER SEGMENTS

Electric car owners and drivers
Logistic companies with electric vehicles</td>
</tr>
<tr>
<td colspan="2">KEY RESOURCES

Staff
Fast charging equipment</td>
<td colspan="2">CHANNELS

Online scheduling</td>
</tr>
<tr>
<td colspan="4">COST STRUCTURE

See costs list from ENROAD's Software
Network connection cost (eletricity tolls)
Restaurant and bar (or franchises) costs</td>
<td colspan="6">REVENUE STREAMS

Electricity sales
Restaurant and bar (or franchises) sales</td>
</tr>
</table>

Figure 75.- Business Case Canvas

This business case has an added value, as different GIS plots are used to make the aggregated estimates in a single spreadsheet.

B) CONFIGURATION OF STANDARDS AND PRICES

The data relative to the technologies are shown in sheet 1.1_Config_TC. Cost data are weighted based on Eurostat LCI. For the simulation, users are encouraged to enter updated values of financial inputs such as the forward prices or the annual interest rates in the template. With regards to the charging prices at stations in Germany, 490.00 €/MWh seemed a feasible price based on own market tracking and Statista (Figure 76), while the market price of the electricity considered was 122.71 €/MWh[1]. Also, Figure 77 shows the electricity price as well as the annual interest rate to apply in the cash flows analysis.

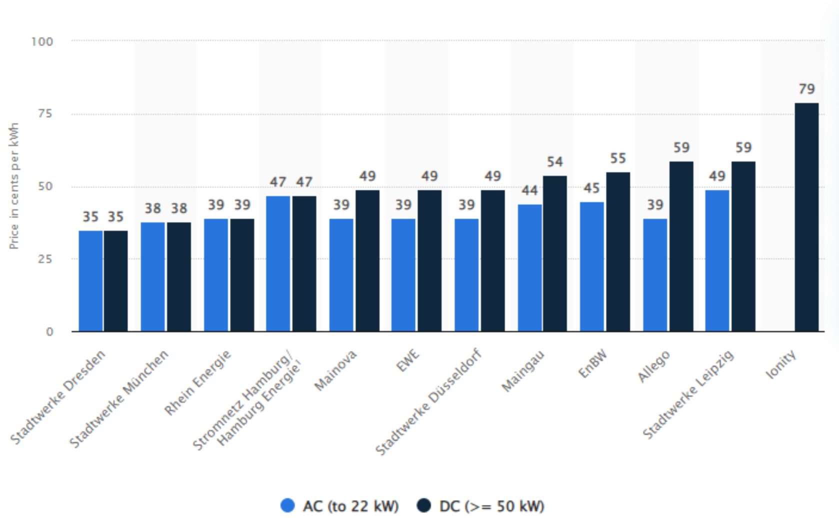

Figure 76.- Electricity prices for charging stations in Germany in 2021, by provider (in cents per kWh). Source: Statista.

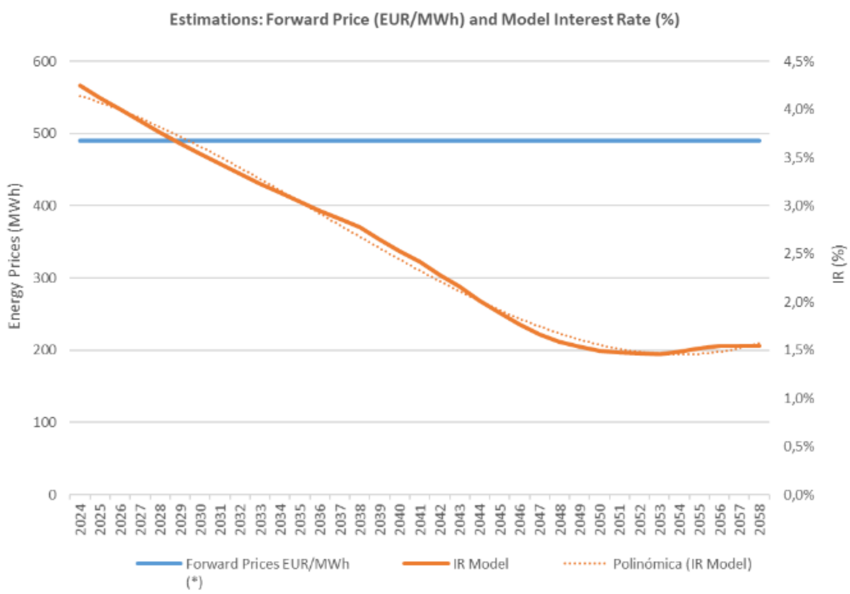

Figure 77.- Charging prices at stations in Germany and Model Interest Rate.

[1] Energy spot price in Germany in October 11th 2023 was 122.71 €/MWh.

C) ROAD SELECTION

An important point is the selection of the installation spot, which must fulfil three requirements:

1. Good productivity in terms of primary energy.
2. An adequate level of traffic to help maintain a good level of facility usage and achieve the level of profitability. In this sense, it is important that it is located near a town with a shopping centre that helps to take advantage of the waiting times.
3. The plot, which is assumed to be NRA-owned and its value enhanced with the new use.

As for the first point, in the ENROAD GIS-based TOOL (Figure 78) it can be seen that the availability of the primary energy is quite uniform both for wind (Figure 79) and photovoltaics (Figure 80). The use of small wind technology is discarded beforehand.

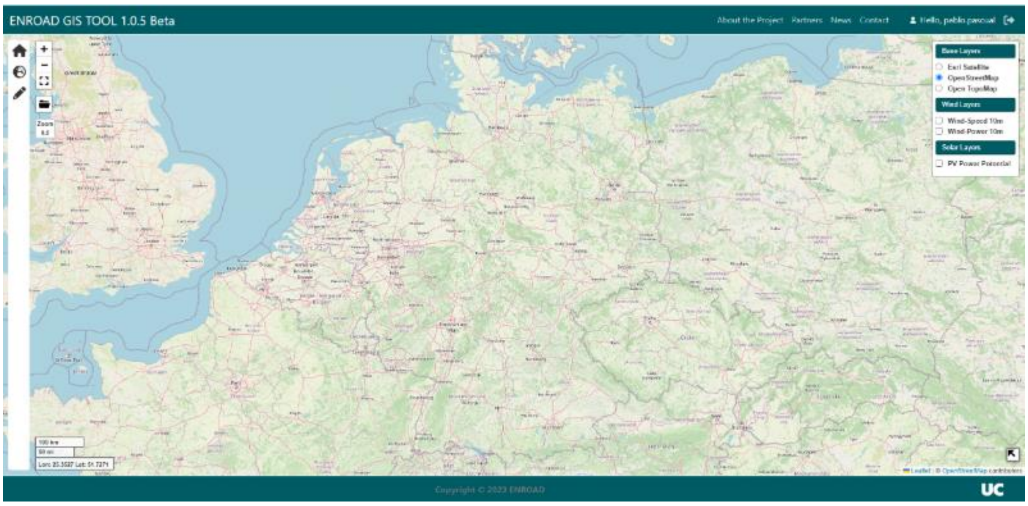

Figure 78.- OpenStreet Map of Germany

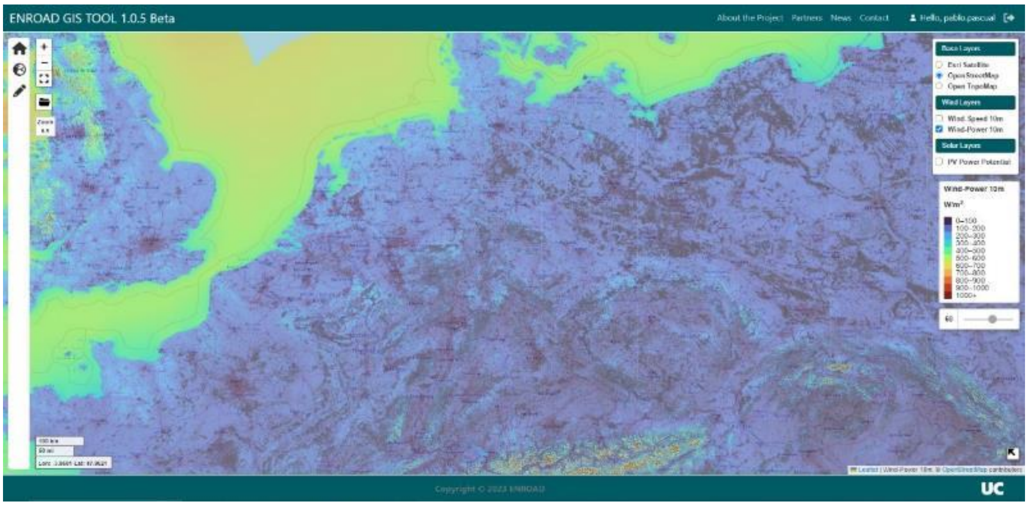

Figure 79.- Wind Power Map of Germany

Figure 80.- PV Power Potential Map of Germany

Next, the best highways in terms of traffic have been analysed according to the information from BAST (https://www.bast.de) and Mcloud (https://mcloud.de). Based on the information from BAST, a location that gathers the conditions described (Figure 81) has been found. This is a connection between the A6 Ludwigshafen-Nord 23 and the B9 (Longitude 8.3878 and Latitude 49.5414) highways where five areas of available plots have been selected to install solar PV panels due to the impossibility of using large wind. The existence of charging points has been verified in Electromaps (Figure 82), amounting a total of 13.

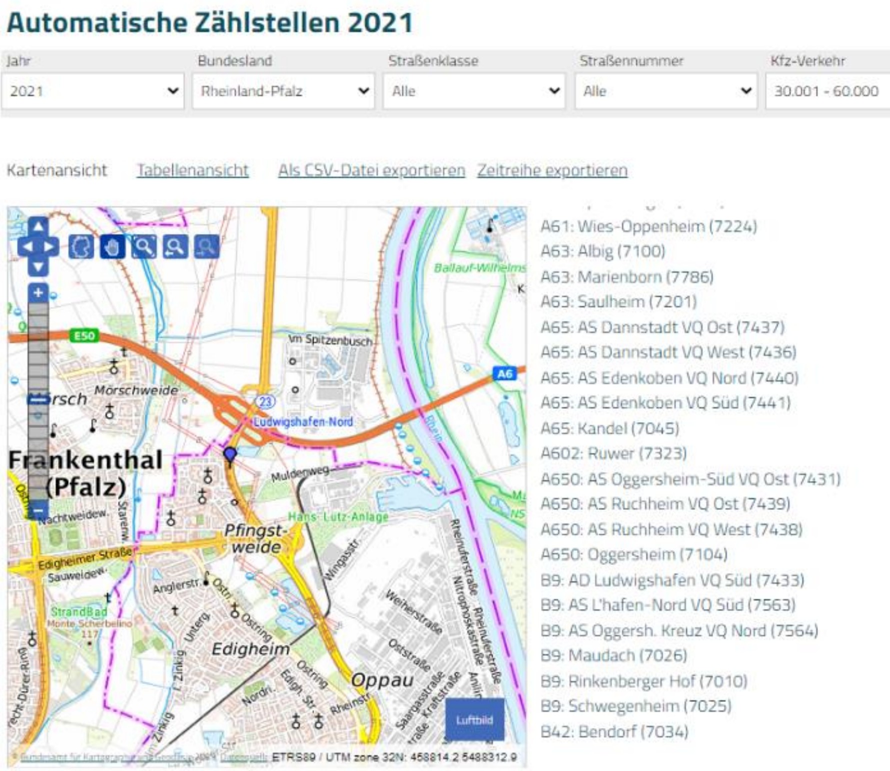

Figure 81.- BAST.DE: AS L'hafen-Nord VQ Süd (7433)

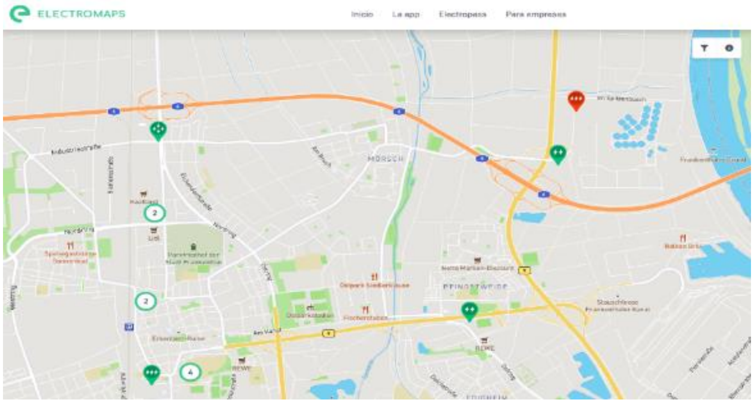

Figure 82.- Recharging points availability in the area (Electromaps)

D) AREA SELECTION AND CONFIGURATION

Figure 83 shows an aerial image of the area that is divided into two locations. The first is the connection between both highways, which results in 4 islands. The two oriented to the South, next to the vegetated areas, on the side that includes a flooded zone, are used in this case. In addition, it is assumed that the vegetation line 1100 meters to the east on the bank of the Rhine River (Figures 83 and 84), with nearby transmission lines for connection to the grid, is available for the NRA. To the south, there is a commercial centre that is surrounded by business facilities.

Figure 83.- Aerial view of the selected area

Figure 84.- Location of the selected spot as seen from the road

In order to show the possibilities of the tool, the sun orientation and the optimal arrangements of the PV panels have been included (Figure 85).

Figure 85.- Configuration of the areas and amount of solar PV panels

The starting parameters for this location are shown in Figure 86. The maximum peak power radiation is produced in April, with 455 kW/m2, whereas in July the energy production reaches 178 kWh/m2.

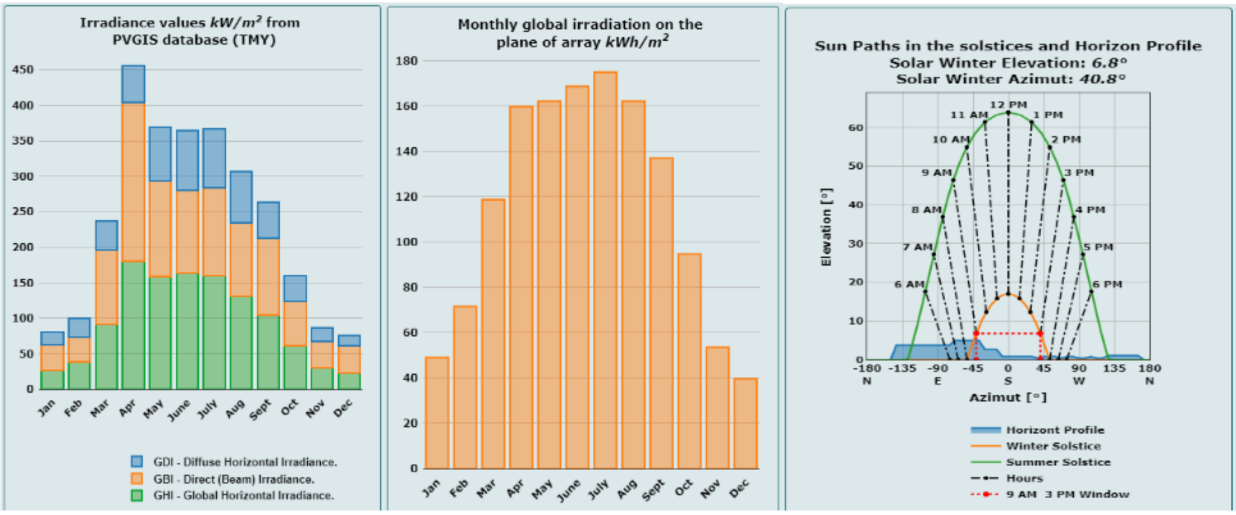

Figure 86.- Energy parameters of the PV and sun paths in solstices and horizon profile according to location

The data aggregated for the six RETs that ENROAD GIS-based tool offers are shown in Table 25, together with the surfaces (m2) of the three areas. It is important to highlight that in the tool configuration, 80% of the available space is considered for the setting of the elements (as set with the *buffer area ratio*).

Table 25.- Selection of areas for the location of RETs

AREA	NAME	m2	HAWT Bornay 6000 No. Units	Darrieus Aeolos-V 3kW No. Units	HWAT V90-2.0 MW No. Units	HWAT V112-3.3 MW No. Units	Monocrystalline JAM60S10-330/PR No. Modules	Monocrystalline JAM72S30-530/MR No. Modules
1	A6 Ludwighafen-Nord 23 / B9: AREA 1	28577	50	102	1	1	3504	2208
2	A6 Ludwighafen-Nord 23 / B9: AREA 2	15816	29	56	1	1	1824	1320
3	A6 Ludwighafen-Nord 23 / B9: AREA 3	13631	24	49	1	1	1632	1080
		58024	103	207	3	3	6960	4608

The aggregated area has been entered in the template as if it were a single area with the total of the elements (RETs) with which the economic and financial analysis is carried out, which is presented below.

E) ECONOMIC AND FINANCIAL ASSESSMENT

With solar PV energy as the most suitable energy source, the charging station was designed to have an initial charging capacity given by 8 charging points connected to 6,960 modules with 330W maximum power or 4,608 modules with 530W maximum power. On the other hand, if electric charging of high-end vehicles is considered, each of those charging points should be able to supply 250 kWp. In that case, the total peak power required for the two potential arrangements (2,000 kWp) would be less than the 2,296 kWp and 2,442 kWp available (Table 26).

Table 26.- Capacity analysis of energy production and consumption (kWp)

	Monocrystalline JAM60S10-330/PR	Monocrystalline JAM72S30-530/MR	
Maximum Power (at STC)	330	530	W
Total DC	2,297	2,442	kWp
Average consumption	250	250	kWp
No. Chargers	8	8	
Total consumption	2,000	2,000	kWp

The ENROAD tool estimates yearly productions of 2,418,727 kWh and 2,570,891 kWh, respectively. Based on the standard of one hour of occupation of the charging point by each vehicle, thereby enabling 9,675 and 10,283 operations per year, respectively (26 charging operations per day for this simulation), the annual energy demands total are 2,372,500 kWh in both cases (Tables 27 and 28).

For the ESS configuration, recharges in darkness during winter are estimated. If the energy autonomy of one day is considered, then 26 recharging operations with 250 kWh are the target that equals 6,500 kWh (see the NRAs renewable energy demand for storage in 2.2_Input_PRO of the template).

Revenues for price of 0.49 EU/kWh amount to 1,162,525 EU and 1,215,024 EU, respectively (Table 28). Installation costs are estimated at 35,738 EU and connection costs at 13,808 EU; the costs of permits, approvals, and licenses are budgeted at 2,640 EU (Table 29). Therefore, total recharging station costs amount to 417,485 EU for both PVs, JAM60S10-330/PR and JAM72S30-530/MR.

Table 27.- Simulation of the daily occupancy rate (number of vehicles).

	No. Recharger point								
Hour	1	2	3	4	5	6	7	8	Sum
0									
1									
2									
3									
4									
5									
6									0
7									0
8	1								1
9	1	1							2
10	1	1							2
11	1	1	1						3
12	1	1	1	1					4
13	1	1	1	1					4
14	1	1	1	1					4
15	1	1	1						3
16	1	1							2
17	1								1
18									0
19									0
20									0
21									0
22									0
23									
24									
No. recharges	10	8	5	3	0	0	0	0	26
Darkness recharges	3	1	0	0	0	0	0	0	4

Table 28.- Estimation of annual revenue

	Monocrystalline JAM60S10-330/PR	**Monocrystalline JAM72S30-530/MR**	
Energy production	2,418,727	2,570,891	kWh/Year
Average car charge	250	250	kWh
No. charging operations	9,675	10,284	operations
Charging duration	60	60	Min
Energy consumption	2,372,500	2,372,500	kWh
Charging price	0.49	0.49	EU/kWh
Revenues	1,162,525	1,215,024	EU

Table 29.- Simulation of the daily use of the RET Monocrystalline (number of vehicles)

	Monocrystalline A-330M GS PERC	Monocrystalline JAM72S30-530/MR	
For each charger			
Recharging point cost	35,738	35,738	EU
Connection point cost	13,808	13,808	EU
Permits, approvals, assessments	2,640	2,640	EU
Total cost per charger	52,186	52,186	EU
No. Recharging points	8	8	
Recharging station total costs	**417,485**	**417,485**	EU

The location of the station remains a decision of the NRA, although it would be interesting if it could be located close to the dwellings in the south-west of the selected area. CAPEX, OPEX and DEC weighted with Eurostat's LCIT and the investment on the station are shown in Tables 30, 31 and 32.

Table 30.- CAPEX

CAPital Expenditures - Investments

Facility Investments		**Small Wind HAWT Bornay 6000**	**Small Wind Darrieus Aeolos-V 3kW**	**Large Wind HWAT V90-2.0 MW**	**Large Wind HWAT V112-3.3 MW**	**PV Monocrystalline JAM60S10-330/PR**	**PV Monocrystalline JAM72S30-530/MR**
Power sources	EUR	1.030.000,00	1.035.000,00	4.800.000,00	6.300.000,00	1.557.691,83	1.267.405,01
Structures	EUR	257.500,00	496.800,00	618.000,00	810.000,00	0,00	0,00
Inverters/Converters	EUR	195.700,00	248.400,00	810.000,00	1.125.000,00	0,00	0,00
Transformers	EUR	296.640,00	356.040,00	1.245.600,00	1.647.000,00	311.538,37	253.481,00
Land & building constructions	EUR	438,73	406,76	1.360.800,00	2.245.320,00	14.864,02	15.825,72
Grid connection	EUR	2.947,11	2.799,68	35.685,91	56.484,26	15.300,00	16.141,97
Batteries	EUR	1.477.100,00	1.477.100,00	1.477.100,00	1.477.100,00	1.477.100,00	1.477.100,00
Government subsidies	EUR	-500.000,00	-500.000,00	-500.000,00	-500.000,00	-500.000,00	-500.000,00
Total CAPEX	EUR	2.760.325,84	3.116.546,44	9.847.185,91	13.160.904,26	2.876.494,22	2.529.953,70
Years	Years	20	20	30	30	30	30
Annualized CAPEX (Facility depreciation)	EUR	89.161,29	106.972,32	295.669,53	406.126,81	63.313,14	51.761,79
End-of-cycle depreciation and dismantling	EUR	81.508,15	90.413,66	258.679,65	341.522,61	6.752,99	6.059,91
Annualized EoC (Dismantling depreciation)	EUR	4.075,41	4.520,68	8.622,65	11.384,09	225,10	202,00

Table 31.- OPEX

OPerational Expenditures

Annual Costs		**HAWT Bornay 6000**	**Darrieus Aeolos-V 3kW**	**HWAT V90-2.0 MW**	**HWAT V112-3.3 MW**	**Monocrystalline JAM60S10-330/PR**	**Monocrystalline JAM72S30-530/MR**
Manpower	EUR	0,00	0,00	0,00	0,00	0,00	0,00
Land lease	EUR	0,00	0,00	0,00	0,00	0,00	0,00
Maintenance	EUR	614,22	569,46	54.432,00	89.812,80	20.438,03	21.760,36
Insurances	EUR	12.875,00	15.318,00	165.240,00	272.646,00	7.432,01	7.912,86
Communications	EUR	2.000,00	2.000,00	23.328,00	38.491,20	1.783,68	1.899,09
Security	EUR	3.000,00	3.000,00	31.104,00	51.321,60	2.378,24	2.532,11
Monitoring	EUR	5.000,00	5.000,00	7.776,00	12.830,40	594,56	633,03
Energy purchased	EUR						
Other general and administrative costs	EUR	2.000,00	2.000,00	15.552,00	25.660,80	1.189,12	1.266,06
Interest	EUR						
Total OPEX	EUR	25.489,22	27.887,46	297.432,00	490.762,80	33.815,64	36.003,50

Table 32.- DEC.

Development and Engineering Costs (DEC)

Detailed Feasibility Study (DFS)							
Site investigation	EUR						
Resource assessment	EUR						
Environmental assessment	EUR						
Preliminary design	EUR	0,00	0,00	24.300,00	24.300,00	8.100,00	8.100,00
GHG Baseline	EUR						
Report preparation	EUR						
Project management	EUR						
Travel and accommodation	EUR						
Development costs (DS)							
Contract negotiations	EUR						
Permits and approvals	EUR						
GHG validation and registration	EUR	0,00	0,00	40.500,00	40.500,00	24.300,00	24.300,00
Project financing	EUR						
Legal and accounting	EUR						
Project management	EUR						
Engineering expenditures (EE)							
Site and building design	EUR						
Mechanical design	EUR						
Civil design	EUR	0,00	0,00	81.000,00	81.000,00	32.400,00	32.400,00
Tenders and contracting	EUR						
Construction supervision	EUR						
TOTAL DEC	EUR	0,00	0,00	145.800,00	145.800,00	64.800,00	64.800,00
Years	Years	20	20	30	30	30	30
DEC Depreciation = [(DFS) + (DS) + (EE)] / Years	EUR	0,00	0,00	4.860,00	4.860,00	2.160,00	2.160,00

The estimation of benefits (or losses) and margins for each RE technology is shown in Table 33. Revenues are calculated over the whole energy production.

Table 33.- Profit & Looses, Margins

Facility Investments	Unit	Date	HAWT Bornay 6000	Darrieus Aeolos-V 3kW	HWAT V90-2.0 MW	HWAT V112-3.3 MW	Monocrystalline JAM60S10-330/PR	Monocrystalline JAM72S30-530/MR
Electricity production	MWh year	-	**14.789,92**	**9.704,35**	**29.567,04**	**59.043,67**	**2.418,73**	**2.570,89**
Unit Price	EUR/MWh	2024	**490,00**	**490,00**	**490,00**	**490,00**	**490,00**	**490,00**
ENERGY REVENUE OR SAVINGS	**EUR**		**7.247.059,43**	**4.755.129,86**	**14.487.847,66**	**28.931.396,15**	**1.185.176,14**	**1.259.736,61**
EXPENDITURES:	**EUR**		**-25.489,22**	**-27.887,46**	**-297.432,00**	**-490.762,80**	**-33.815,64**	**-36.003,50**
Manpower	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Land lease	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Maintenance	EUR		-614,22	-569,46	-54.432,00	-89.812,80	-20.438,03	-21.760,36
Insurances	EUR		-12.875,00	-15.318,00	-165.240,00	-272.646,00	-7.432,01	-7.912,86
Communications	EUR		-2.000,00	-2.000,00	-23.328,00	-38.491,20	-1.783,68	-1.899,09
Security	EUR		-3.000,00	-3.000,00	-31.104,00	-51.321,60	-2.378,24	-2.532,11
Monitoring	EUR		-5.000,00	-5.000,00	-7.776,00	-12.830,40	-594,56	-633,03
Energy	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Other general and administrative costs	EUR		-2.000,00	-2.000,00	-15.552,00	-25.660,80	-1.189,12	-1.266,06
Interest	EUR		0,00	0,00	0,00	0,00	0,00	0,00
ANNUAL NET MARGIN BEFORE DEPRECIATIONS	EUR		7.221.570,21	4.727.242,40	14.190.415,66	28.440.633,35	1.151.360,50	1.223.733,11
Facility depreciation	EUR		-89.161,29	-106.972,32	-295.669,53	-406.126,81	-63.313,14	-51.761,79
End-of-cycle depreciation and dismantling	EUR		-4.075,41	-4.520,68	-8.622,65	-11.384,09	-225,10	-202,00
ANNUAL NET MARGIN BEFORE DEC	EUR		7.128.333,51	4.615.749,39	13.886.123,47	28.023.122,45	1.087.822,26	1.171.769,32
DCE depreciation	EUR		0,00	0,00	-4.860,00	-4.860,00	-2.160,00	-2.160,00
ANNUAL NET MARGIN AFTER DEC	EUR		7.128.333,51	4.615.749,39	13.881.263,47	28.018.262,45	1.085.662,26	1.169.609,32
ANNUAL NET MARGIN AFTER DEC PER KILOWATT HOUR	**EUR/kWh**		**0,48197**	**0,47564**	**0,46948**	**0,47453**	**0,44886**	**0,45494**
FIRST YEAR TOTAL COSTS	EUR		-118.725,92	-139.380,47	-606.584,19	-913.133,70	-99.513,88	-90.127,29
FIRST YEAR TOTAL COST PER KWH	EUR/kWh		0,008027	0,014363	0,020516	0,015465	0,041143	0,035057
FIRST YEAR CAPITAL COST	EUR		-93.236,70	-111.493,01	-304.292,19	-417.510,90	-63.538,24	-51.963,79
FIRST YEAR CAPITAL COST PER KWH	EUR/kWh		0,006	0,011	0,010	0,007	0,026	0,020

As it may be observed, for the selected location only the solar PV technology is feasible since there is not enough wind energy for Small Wind turbines and a Large Wind facility is not functional. Anyway, they are profitable in the Electricity Charger price.

With the aim to demonstrate the flexibility of the ENROAD tool, the sale of the electricity to the network (without ESS) is now estimated (Tables 34 and 35). This analysis helps to measure the effect of a much lower price on the net margins.

Table 34.- CAPEX (selling energy)

CAPital Expenditures - Investments

Facility Investments		Small Wind HAWT Bornay 6000	Small Wind Darrieus Aeolos-V 3kW	Large Wind HWAT V90-2.0 MW	Large Wind HWAT V112-3.3 MW	PV Monocrystalline JAM60S10-330/PR	PV Monocrystalline JAM72S30-530/MR
Power sources	EUR	1.030.000,00	1.035.000,00	4.800.000,00	6.300.000,00	1.557.691,83	1.267.405,01
Structures	EUR	257.500,00	496.800,00	618.000,00	810.000,00	0,00	0,00
Inverters/Converters	EUR	195.700,00	248.400,00	810.000,00	1.125.000,00	0,00	0,00
Transformers	EUR	296.640,00	356.040,00	1.245.600,00	1.647.000,00	311.538,37	253.481,00
Land & building constructions	EUR	438,73	406,76	1.360.800,00	2.245.320,00	14.864,02	15.825,72
Grid connection	EUR	2.947,11	2.799,68	35.685,91	56.484,26	15.300,00	16.141,97
Batteries	EUR	0,00	0,00	0,00	0,00	0,00	0,00
Government subsidies	EUR	-500.000,00	-500.000,00	-500.000,00	-500.000,00	-500.000,00	-500.000,00
Total CAPEX	EUR	1.283.225,84	1.639.446,44	8.370.085,91	11.683.804,26	1.399.394,22	1.052.853,70
Years	Years	20	20	30	30	30	30
Annualized CAPEX (Facility depreciation)	EUR	89.161,29	106.972,32	295.669,53	406.126,81	63.313,14	51.761,79
End-of-cycle depreciation and dismantling	EUR	44.580,65	53.486,16	221.752,15	304.595,11	3.798,79	3.105,71
Annualized EoC (Dismantling depreciation)	EUR	2.229,03	2.674,31	7.391,74	10.153,17	126,63	103,52

Table 35.- Profit & Looses, Margins (selling energy)

Facility Investments	Unit	Date	Small Wind HAWT Bornay 6000	Small Wind Darrieus Aeolos-V 3kW	Large Wind HWAT V90-2.0 MW	Large Wind HWAT V112-3.3 MW	PV Monocrystalline JAM60S10-330/PR	PV Monocrystalline JAM72S30-530/MR
Electricity production	MWh year	-	**14.789,92**	**9.704,35**	**29.567,04**	**59.043,67**	**2.418,73**	**2.570,89**
Unit Price	EUR/MWh	2024	**122,71**	**122,71**	**122,71**	**122,71**	**122,71**	**122,71**
ENERGY REVENUE OR SAVINGS	**EUR**		**1.814.870,74**	**1.190.820,38**	**3.628.170,99**	**7.245.248,21**	**296.801,97**	**315.474,04**
EXPENDITURES:	**EUR**		**-25.489,22**	**-27.887,46**	**-297.432,00**	**-490.762,80**	**-33.815,64**	**-36.003,50**
Manpower	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Land lease	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Maintenance	EUR		-614,22	-569,46	-54.432,00	-89.812,80	-20.438,03	-21.760,36
Insurances	EUR		-12.875,00	-15.318,00	-165.240,00	-272.646,00	-7.432,01	-7.912,86
Communications	EUR		-2.000,00	-2.000,00	-23.328,00	-38.491,20	-1.783,68	-1.899,09
Security	EUR		-3.000,00	-3.000,00	-31.104,00	-51.321,60	-2.378,24	-2.532,11
Monitoring	EUR		-5.000,00	-5.000,00	-7.776,00	-12.830,40	-594,56	-633,03
Energy	EUR		0,00	0,00	0,00	0,00	0,00	0,00
Other general and administrative costs	EUR		-2.000,00	-2.000,00	-15.552,00	-25.660,80	-1.189,12	-1.266,06
Interest	EUR		0,00	0,00	0,00	0,00	0,00	0,00
ANNUAL NET MARGIN BEFORE DEPRECIATIONS	EUR		1.789.381,52	1.162.932,92	3.330.738,99	6.754.485,41	262.986,33	279.470,54
Facility depreciation	EUR		-89.161,29	-106.972,32	-295.669,53	-406.126,81	-63.313,14	-51.761,79
End-of-cycle depreciation and dismantling	EUR		-2.229,03	-2.674,31	-7.391,74	-10.153,17	-126,63	-103,52
ANNUAL NET MARGIN BEFORE DEC	EUR		1.697.991,19	1.053.286,29	3.027.677,72	6.338.205,43	199.546,56	227.605,22
DCE depreciation	EUR		0,00	0,00	-4.860,00	-4.860,00	-2.160,00	-2.160,00
ANNUAL NET MARGIN AFTER DEC	EUR		1.697.991,19	1.053.286,29	3.022.817,72	6.333.345,43	197.386,56	225.445,22
ANNUAL NET MARGIN AFTER DEC PER KILOWATT HOUR	**EUR/kWh**		**0,11481**	**0,10854**	**0,10224**	**0,10727**	**0,08161**	**0,08769**
FIRST YEAR TOTAL COSTS	EUR		-116.879,55	-137.534,09	-605.353,27	-911.902,78	-99.415,41	-90.028,82
FIRST YEAR TOTAL COST PER KWH	EUR/kWh		0,007903	0,014172	0,020474	0,015445	0,041102	0,035019
FIRST YEAR CAPITAL COST	EUR		-91.390,32	-109.646,63	-303.061,27	-416.279,98	-63.439,77	-51.865,31
FIRST YEAR CAPITAL COST PER KWH	EUR/kWh		0,006	0,011	0,010	0,007	0,026	0,020

F) PRELIMINARY ENVIRONMENTAL ASSESSMENT

In addition to the financial analysis, the ENROAD GIS-based TOOL offers a preliminary estimation of the environmental impact for the PV technologies in the 3.4_Out_Env sheet (Tables 36 and 37).

Table 36.- CO2 Emissions Savings for Monocrystalline JAM60S10-330/PR

GHG Emissions		
Total installed peak capacity	kWp	2293,83
Reference PV plant	kWp	570
Equivalent no. of PV plants	-	4
Lifespan (operation)	years	30
Total Annual Energy Production	MWh/year	2.418,73
Total Energy Production	MWh	72561,80451
GHG / MWh	**kg CO2 eq/MWh**	**71,27**
CO2 Annual Savings *	**Tonne CO2/MWh**	**952,33**

Table 37.- CO2 Emissions Savings for Monocrystalline JAM72S30-530/MR

GHG Emissions		
Total installed peak capacity	kWp	2442,24
Reference PV plant	kWp	570
Equivalent no. of PV plants	-	4
Lifespan (operation)	years	30
Total Annual Energy Production	MWh/year	2.570,89
Total Energy Production	MWh	77126,73124
GHG / MWh	**kg CO2 eq/MWh**	**71,39**
CO2 Annual Savings *	**Tonne CO2/MWh**	**1011,94**

G) SUMMARY ANALYSIS

The financial dashboard for this business case, the electric car charging station, is provided with four Key Performance Indicators (KPIs). Based on the results obtained for this analysis the most efficient RET is the "Monocrystalline JAM72S30-530/MR", but just in this case the financial KPIs of the "Monocrystalline JAM60S10-330/PR" are shown (Figure 87):

- Energy Average Prices (2023-2057): 490.00 EUR/MWh.
- First Year Total Cost (FYTC), in the first year, 41.14 EU/MWh.
- Levelized Cost Of Energy (LCOE): 98.02 EU/MWh.
- Cost Gap (LCOE – FYTC): 56.88 EU/MWh.

Energy average price	Recommended RET
490,00	**Monocrystalline JAM60S10-330/PR**
EUR/MWh	-
First Year Total Cost (FYTC)	COST GAP (LCOE - FYTC)
41,14	**56,88**
EUR/MWh	EUR/MWh
LCOE for selected RET (LCOE)	COST GAP (LCOE - FYTC)/ FYTC
98,02	**138%**
EUR/MWh	-

Figure 87.- LCOE Dashboard (without efficiency loses)

The LCOE is so high relative to the Total First Year Cost because: (1) the investment in batteries increases the cost of electricity, and (2) the inflation in 2024 is 4.25% and decreases very slowly throughout the investment period. Taking the LCOE Renewable Energy Technologies report (2021) as a reference, the estimated LCOE is higher than that of utility-scale PV (Figure 88). The full list of results is presented in the Summary sheet (Table 38). The starting total investment for the selected RET is 2.529.954 EU.

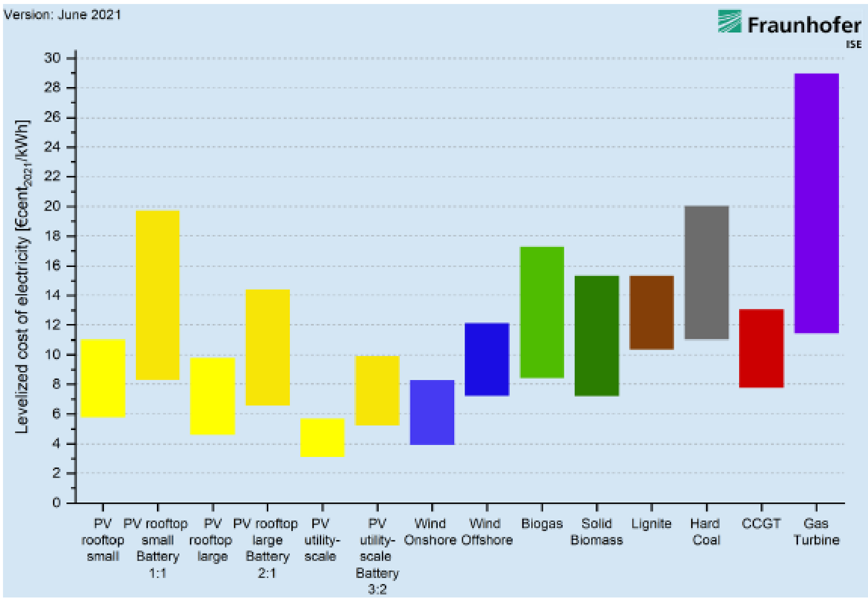

Figure 88.- LCOE of RETs and conventional power plants at different locations in Germany in 2021

Table 38.- Case summary (car electric charging)

RESULTS FOR THE DIFFERENT TECHNOLOGIES		Tech_1 HAWT Bornay 6000	Tech_2 Darrieus Aeolos-V 3kW	Tech_3 HWAT V90-2.0 MW	Tech_4 HWAT V112-3.3 MW	Tech_5 Monocrystalline JAM60S10-330/PR	Tech_6 Monocrystalline JAM72S30-530/MR
		Small Wind	Small Wind	Large Wind	Large Wind	PV	PV
Number of turbines/modules	No.	105	210	3	3	6.960	4.608
Total Annual Energy Production	MWh year	14.789,9	9.704,3	29.567,0	59.043,7	2.418,7	2.570,9
Energy Production per m2	kWh/m2 year	78,47	51,49	156,88	313,28	12,83	13,64
Covered demand for energy	%	507%	332%	1013%	2022%	83%	88%
Total installed peak capacity	MWp	0,3	0,3	6,0	9,9	2,3	2,4
Yearly efficiency looses	%	0,00%	0,00%	0,00%	0,00%	0,30%	0,30%
First Year Total Cost (FYTC)	EUR/MWh	8,03	14,36	20,52	15,47	41,14	35,06
LCOE	EUR/MWh	ND	ND	38,26	28,18	98,02	83,64
LCOE's best technology (LCOE)	EUR/MWh						83,64
Starting total Investment	EUR	2.760.326	3.116.546	9.847.186	13.160.904	2.876.494	2.529.954
Total Energy Revenues	EUR	144.941.189	95.102.597	434.635.430	867.941.884	34.008.629	36.148.142
Project Duration (and loan repayment)	Years	20	20	30	30	30	30
Debt (bank loan) over Investment	EUR	1.470.061,57	1.864.542,29	9.611.940,95	13.504.054,83	1.605.382,67	1.226.856,25
Payback period	Years	0	0	0	0	3	3
NPV	EUR	99.709.130	63.024.005	254.465.281	523.382.128	16.772.212	18.830.669
IRR	%	248,89%	141,88%	132,13%	199,58%	35,76%	44,38%
AARR	%	754,86%	434,25%	412,10%	622,10%	112,06%	136,93%
Sales for Break-even Point Based on First Year Production	EUR YR	118.725,92	139.380,47	606.584,19	913.133,70	99.513,88	90.127,29
CO2 Emissions Savings	Tonne CO2/kWh year	-	-	13.629	27.235	952	1.012

H) CASE CONCLUSIONS

In this case, two PV options have been configured in three areas taking advantage of the spaces along the highway. The very significant productions achieved would supply energy to eight recharging points, with enough power to provide service to high powered vehicles as well as small transport vans. Because of the high price per kWh, both options are very cost-effective. However, due to the higher production of the Monocrystalline JAM72S30-530/MR modules, the analysis has been based on it.

Alternatively, once the firm makes the investment in batteries, the option of selling energy in the market with the future prices from EEX - https://www.eex.com/en/ can be also considered. The results show that the profitability appears soon for both PV solutions (Figure 89 and Table 39).

Energy average price 2024-2044	Recommended RET
122,71	**Monocrystalline JAM72S30-530/MR**
EUR/MWh	-
First Year Total Cost (FYTC)	COST GAP (LCOE - FYTC)
35,06	**48,58**
EUR/MWh	EUR/MWh
LCOE for selected RET (LCOE)	COST GAP (LCOE - FYTC)/ FYTC
83,64	**139%**
EUR/MWh	-

Figure 89.- LCOE Dashboard (electricity sale)

Table 39.- Case summary (electricity sale)

RESULTS FOR THE DIFFERENT TECHNOLOGIES		Tech_1 HAWT Bornay 6000	Tech_2 Darrieus Aeolos-V 3kW	Tech_3 HWAT V90-2.0 MW	Tech_4 HWAT V112-3.3 MW	Tech_5 Monocrystalline JAM60S10-330/PR	Tech_6 Monocrystalline JAM72S30-530/MR
		Small Wind	Small Wind	Large Wind	Large Wind	PV	PV
Number of turbines/modules	No.	105	210	3	3	6.960	4.608
Total Annual Energy Production	MWh year	14.789,9	9.704,3	29.567,0	59.043,7	2.418,7	2.570,9
Energy Production per m2	kWh/m2 year	78,47	51,49	156,88	313,28	12,83	13,64
Covered demand for energy	%	507%	332%	1013%	2022%	83%	88%
Total installed peak capacity	MWp	0,3	0,3	6,0	9,9	2,3	2,4
Yearly efficiency looses	%	0,00%	0,00%	0,00%	0,00%	0,30%	0,30%
First Year Total Cost (FYTC)	EUR/MWh	8,03	14,36	20,52	15,47	41,14	35,06
LCOE	EUR/MWh	ND	ND	38,26	28,18	98,02	83,64
LCOE's best technology (LCOE)	EUR/MWh						83,64
Starting total Investment	EUR	2.760.326	3.116.546	9.847.186	13.160.904	2.876.494	2.529.954
Total Energy Revenues	EUR	36.297.415	23.816.408	108.845.130	217.357.446	8.516.732	9.052.528
Project Duration (and loan repayment)	Years	20	20	30	30	30	30
Debt (bank loan) over Investment	EUR	1.470.061,57	1.864.542,29	9.611.940,95	13.504.054,83	1.605.382,67	1.226.856,25
Payback period	Years	2	4	4	3	18	13
NPV	EUR	21.456.130	11.678.604	42.559.856	100.219.218	96.716	1.106.103
IRR	%	59,07%	31,83%	27,12%	43,46%	3,34%	6,34%
AARR	%	181,41%	100,82%	89,72%	140,27%	20,96%	26,84%
Sales for Break-even Point Based on First Year Production	EUR YR	118.725,92	139.380,47	606.584,19	913.133,70	99.513,88	90.127,29
CO2 Emissions Savings	Tonne CO2/kWh year	-	-	13.629	27.235	952	1.012

7.2. BUSINESS CASE VS. CURRENT REGULATORY FRAMEWORK BARRIERS

7.2.1. NATIONAL LONG-TERM STRATEGIES

As set out in the Climate Action Plan 2020, Germany is committed to achieving a 65% reduction in GHG emissions by 2030, 88% to 90% reduction by 2040 (compared to 1990 levels), and to achieving climate-neutral economy by 2045.

The government announced plans to phase out coal-fired power plants by 2038, to expand support for electric vehicles and charging infrastructure, and to increase funding for energy-efficient buildings and industrial processes. The government also introduced a new carbon pricing scheme, which puts a price for sectors not covered by the EU Emissions Trading System.

A climate strategy for transport will address emissions from cars, light and heavy commercial vehicles and issues related to GHG-free energy supply, the requisite infrastructure, and the interlinking of sectors (through electric mobility). The energy supply for roads and rail transport will be based on biofuels and as far as possible on electricity from renewable sources and other GHG-neutral vehicle fuels.

7.2.2. IDENTIFIED OPPORTUNITIES

Support schemes for energy from renewable sources

Electricity generated from renewable energy sources is supported through a sliding feed-in premium determined in auctions for installed generation capacity according to “Erneuerbare Energie Gesetz” EEG (§22 EEG 2023). Installations with a capacity less than 1MW (wind and solar) or 150 kW (biomass) are exempted from the tender process (§22 EEG 2021).

Incentive for PV close to the highways

§48 Art. 1 Nr. 3c) aa) EEG 2021: PV plants receive guaranteed feed-in tariff per kWh if they are built within 200m of a highway. 15m min. distance for plants is required. § 9 Abs. 1 Nr. 1 Bundesfernstraßen-gesetz increases this distance to 40m if the local development plan does not state otherwise. Therefore, the minimum distance might vary locally depending on each region development plan.

Power Purchase Agreements (PPA)

Issues affecting renewable Power Purchase Agreements (PPA) were resolved in 2021 and are expected to continue to make PPAs an increasingly attractive option for renewable energy producers and consumers. There is an opportunity of doing a PPA scheme in between the NRA’s and the business in the rest areas.

Renewable Energy Communities

Even if in Germany there is a historical context of Energy Communities, Renewable Energy Communities have not been fully defined according to the European regulatory framework. The future definition might suppose an opportunity for increasing shared energy generation.

Other provisions on renewable energy in the transport sector

Greenhouse gas emission trading in Germany shall enable operators of electric charging infrastructure to capture additional income. Revenues are estimated to be 20 to 60 cent per kWh of charged electricity. This would significantly boost charging infrastructure and could positively influence the project.

Installation of PV on noise barriers

A special scheme was designed under §48 Art. 2 EEG 2023. PV plants on or at noise barriers received guaranteed feed-in tariff dependent on the installed capacity:

1. up to and including an installed capacity of 10 kilowatts 8.6 cents per kilowatt-hour,
2. up to and including an installed capacity of 40 kilowatts 7.5 cents per kilowatt hour, and
3. up to and including an installed capacity of 1 megawatt 6.2 cents per kilowatt-hour.

Installation of PV on parking places and resting areas

A tender pilot project took place in 2022 for integrated PV on parking sites. If conditions are prone, NRA could use the resting/parking areas along the roads for installing PV including close to the business along the road.

Integration Of Electromobility into The Electricity Network

The conditions under which operators of charging stations are well defined. Operators of charging stations in Germany need to notify the grid operator before connecting them to the grid. The rules for the connection have been published by Association of Electrical Engineers.

7.2.3. IDENTIFIED BARRIERS

Incentive for PV close to the highways

§48 Art. 1 Nr. 3c) aa) EEG 2021: PV plants receive guaranteed feed-in tariff per kWh if they are built within 200m of a highway. 15m min. distance for plants is required. § 9 Abs. 1 Nr. 1 Bundesfernstraßen-gesetz increases this distance to 40m if local development plan does not state otherwise. The minimum distance might vary locally depending on each region development plan. Minimum distance might be a barrier for the NRA's. Securing land close to the highways might be more difficult as more competition is expected because of the incentive tariff.

Simple-notification procedure for grid connections

Projects with a capacity of more than 10.8 kW go through standard connection approval process. This could potentially present a barrier as RE projects by the NRAs could exceed 10.8 kW (The upper capacity limit shall be confirmed against the latest legislation).

7.2.4. RECOMMENDATIONS

Incentive for PV close to the highways

Follow-up with local administrations on the possibility for the NRAs to install PV on the edges of the highways and the conditions under which this could be done.

Renewable Energy Communities

Renewable Energy Communities have not been fully defined according to the European regulatory framework. The future definition might suppose an opportunity for increasing shared energy generation.

8. E-LEARNING

As part of the dissemination and communication strategy (WP6), an E-Learning module has been created to communicate the results of the project in an interactive and visual way (Figure 90). By setting out and summarising the work done the main outcomes of the project have been identified.

The E- Learning addresses the following topics:

- Analysis of Renewable Energy Technologies: Potential of the different topologies and relevant energy generation technologies, including technical aspects to be considered.
- Legislative & Regulatory Framework: Present regulatory aspects to be aware of and suggestions on how governance and organization could be planned.
- Analysis of Business Models & Governance: Proposal of business models with applicable energy generation opportunities in the European markets

The various sections of the E-learning module not only present summarized information, but also some interactive questions to self-check the knowledge. A new menu "E-Learning" was created in the ENROAD tool that is linked to the index website of the module.

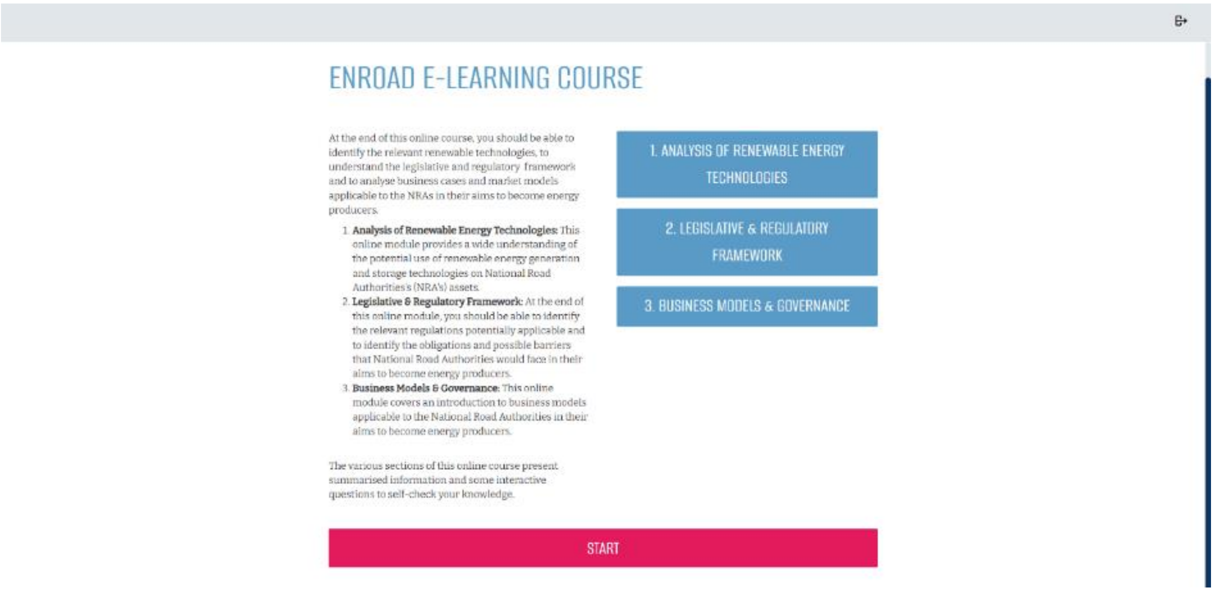

Figure 90.- Screenshot of the index of the E-Learning

Likewise, an online version of the User Guide presented in *Deliverable 5.2* has been published and linked to a new menu “User Guide” created in the ENROAD Tool (Figure 91).

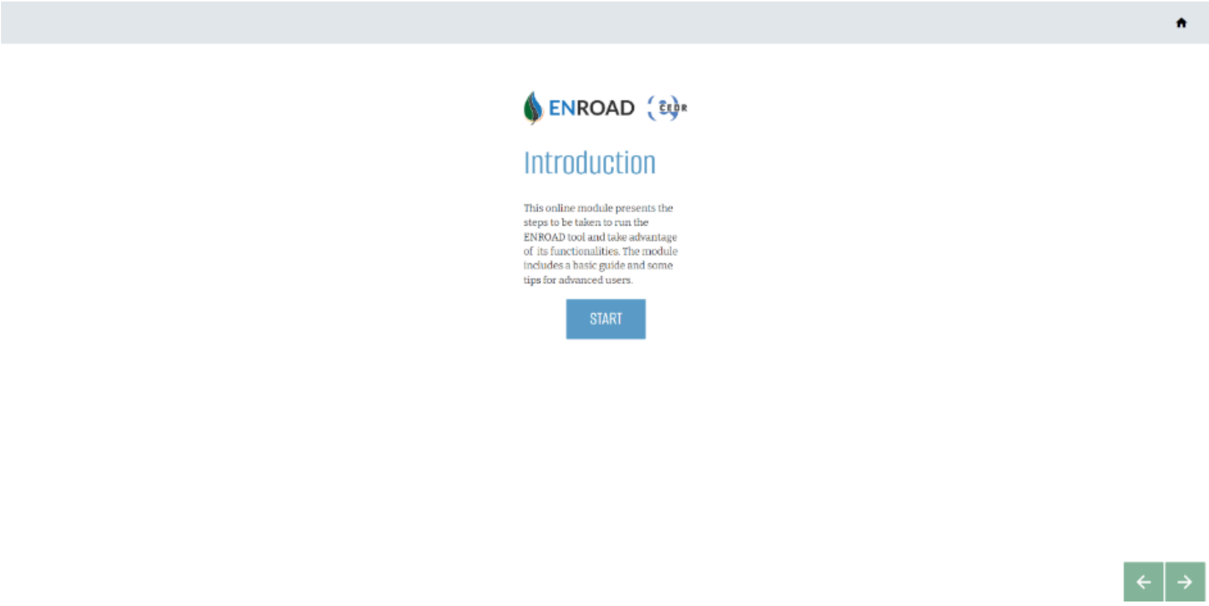

Figure 91.- Screenshot of the index of the web-based User Guide

9. OUTCOMES OF THE FINAL CONFERENCE

As part of the discussion during the ENROAD Project Final Conference in Madrid on October 24, 2023 at Arup headquarters, Spain, a number of comments and questions arose that are addressed below.

Q.- Interest was shown in specific studies on the disturbance to drivers by reflections from PV panels, the reason for the distance not being fixed in the ENROAD tool and on any reference found.

Answer: This was considered during the development of the project. Detailed technical information was search so that it could be implemented into the tool but nothing was found beyond different on-site studies of roads for which an indicator (low risk, moderate impact, etc.) is given only based on a distance (1.0-1.5-3.0 km) and/or the driver field of view (i.e., the location in which glare should not be considered a concern is between 30 and 50 degrees outside of the road users direction of travel). These studies say that a certain distance (that can be considered by means of the road buffer of the tool) has to be considered to avoid glare or otherwise carry out some mitigation actions like placing barriers, vegetable barriers, etc. Other research papers deal with the Potential Observation Hours (POH), which represent the aggregated value of the maximum number of hours in a mean day in which an object may be viewed by each possible observer. This helps to visually identify the places in the zone with the highest or lowest observability, but it doesn't give an indication of an impact on road users safety. Finally, other references mention the lack of impacts of glare from PV modules. So, in summary, no systematic methodologies that could be used for the purpose of the ENROAD tool has been found.

Following some of the references found:

- Hirsch, H.H. (2014). Impacts and Mitigation Strategies from Solar Array Systems within Colorado Department of Transportation’s Highway Right of Way Areas. ICSI 2014: Creating Infrastructure for a Sustainable World.
- Sutton, M. (2022). Solar Photovoltaic Glint and Glare Study. Pelham Solar Farm. PAGERPOWER - Urban & Renewables.
- Do I need to worry about about glare from solar panels? SaveMoneyCutCarbon (2024). https://www.savemoneycutcarbon.com/learn-save/do-i-need-to-worry-about-glare-from-solar-panels/
- Williams, A. (2021). Solar Photovoltaic Glint and Glare Study (Technical Appendix 15.2). Earraghail. PAGERPOWER - Urban & Renewables.
- Day, M. and Mow, B. (2018). Research and analysis demonstrate the lack of impacts of glare from photovoltaics modules. National Renewable Energy Laboratory (NREL). https://www.nrel.gov/state-local-tribal/blog/posts/research-and-analysis-demonstrate-the-lack-of-impacts-of-glare-from-photovoltaic-modules.html
- Qureshi, W. (2021). Solar photovoltaic glint and glare study. Gunthorpe Road Solar Farm and battery storage facility. Enso Energy.
- Scrivener, D. (2018). Solar Photovoltaic Glint and Glare Study. Bookaar Solar Farm. Pagerpower.
- Clean Energy Results (2015). Questions and answers: ground mounted solar photovoltaic systems. Massachusetts Clean Energy Center (MassCEC).

https://www.masscec.com/resources/clean-energy-results-questions-and-answers-ground-mounted-solar-photovoltaic-systems

- Whitepaper (2021). Evaluating the Field of View: Quantifying How the Location of a Solar Reflection Impacts a Road User. PAGERPOWER - Urban & Renewables.
- Thomson, Saddington and McGhee (2022). Glint and Glare Assessment. Sunny Oaks Renewable Energy Park. Neo Environmental.
- Fernandez-Jimenez A., Mendoza-Villena, M., Zorzano-Santamaria, P. Garcia-Garrido, E., Lara-Santillan, P. Zorzano-Alba, E. and Falces, A. (2015) Site selection for new PV power plants based on their observability. Renewable Energy 78 (2015) 7-15.

Q.- What is intended by "Buffer Area" in the ENROAD tool? Is there a value that can be used as a standard?

Answer: The slider of the buffer area function is activated when a new area is created. This function allows the user to define a percentage of the area in which wind turbines and solar panels will not be placed as the area is assigned to accommodate other equipment such energy storage facilities; or is intended to be passageways for maintenance purposes; or is thought to be used in the future, etc. No standard value for the buffer area has been found, which is due to the fact that every solar and wind park is different and has different technical requirements.

Q.- Is the inclusion of a new RETs foreseen? What about minihydro and micro-biomass.

Answer: Mini-hydro is definitely a very good option in case the tool is further developed. An initial attempt was made with the definition of potential water storages (volumes) for energy generation purposes, but further development was discarded due to time constraints. As for the micro-biomass, its implementation in the tool does not make sense as plants are designed by certain manufacturers based on specific power and energy demands. In case there was a relation between plant size and power /energy provided, a kind of functionality might be coded for the user to define an area in the tool and this gives the power/energy that a plant that size would provide (e.g.: a 100 m2 area is defined, and the tool place a 50 kW plant). Still, it doesn't seem to be very useful.

Q.- Can the azimuth and tilt angles be changed by the user? Can the types of panels defined in the tool by default also be modified?

Answer: Optimum angles provided by the tool can be easily changed with the help of sliders. Panels can also be swapped (or parameters be modified) as long as the user has a certain knowledge (advanced user). In fact, this functionality has been updated to increase the accuracy of the results (i.e., the error of the solar panel performance simulation is smaller and, therefore, the effect of the swap can be noticed more accurately). The parameters that have to be changed to swap solar panels and wind turbines, as well as some sources of information can be found in the ENROAD Tool User Guide.

Note: the ENROAD is not a design tool so the definition of some elements is out of the scope of this tool and therefore, the accuracy of results is limited to a pre-feasibility analysis for potential implementation of these technologies.

Q.- Could the range of azimuth and tilt angles be increased in order to support values that you would not normally consider for an analysis based on performance, but that it could be when the analysis if focused on the use of these renewable energy technologies along or next to the road asset (i.e., looking for safety in roads, road orientations, etc.)?

Answer: The range of Tilt and Azimuth angles has been increased to 5 ÷ 90 and -45 ÷ +45, respectively. Such high values do not make sense in terms of performance due to the low energy generation provided and the huge shadow effect generated, but we are open to increase the ranges in case it is requested.

Q.- The fact that users have to modify some date prior to update the template and make the calculations has to be highlighted. And the same with the different types of data and their corresponding colours.

Answer: All this has been referred in the step-by-step ENROAD Tool User Guide.

Q.- Could be the energy calculations (kWh) made and displayed in the GIS part of the tool (not in the Excel template)? That would make the tool more straightforward.

Answer: Yes, this is possible, but it would take a lot of work. Too much for the time frame of this project. This would be the next step in case new opportunities are found and the tool can be further developed.

Q.- How is the tool to be maintained?

Answer: From the point of view of the precise operation of the tool, an advanced user can update most of the technical, economic, financial and environmental data so that the results are always accurate (in the context of the aim of this tool). Solar and wind databases used for the calculations are expected to be periodically updated. New versions of the tool might be released in case that new opportunities for further development of the tool are found. As for technical maintenance (hosting, bugs, etc.), the software was scheduled to be hosted on the current server until the end of 2024, but the contract will be extended until 2025 as requested by PEB so the tool can be properly tested and bugs eventually fixed.

Q.- Have the Life Cycle Assessments been carried out by the ENROAD team (i.e., are results proprietary)?

Answer: Yes. The different LCAs have been performed with SIMAPRO.

Q.- Is maintenance included within the LCA?

Answer: No, maintenance has not been included due to data and time constraints. However, it should be noted that the extraction, manufacturing and construction (installation) phases together account for the vast majority of the energy consumption and emissions (see section 6.2 above for references).

Q.- Could the User Guide be included as part of the E-Learning module?

Answer: An online version of the User Guide has been published and linked to a new menu "User Guide" created in the ENROAD Tool.

Q.- Sweden is missing among the countries included the E-Learning module.

Answer: The error has been fixed and Sweden has been included in the online module.

Q.- How easy is to incorporate the E-learning module within another CEDR servers?

Answer: It is very easy to implement in another server and not much space is required.

Q.- Regarding the excel template: How is the file managed in local? What is it in the hidden sheets or cells? Can new sheets be added to the template? How costs are adjusted by country as based on average labour costs?

Answer: The users update the template in local, and then it is uploaded into the GIS-based tool so that the information is read and collected by the tool before the calculations are made. Once finished with the calculations, the results can be written into the template and downloaded by the users, but a copy of the template remains in the server. This means that users can manipulate and change the local version of the template because the server version can be downloaded again if it is necessary. Every time an operation is done with the GIS-based tool, the template is edited and modified (i.e., users will need to upload a new version of the template is the one in the server is not useful for them anymore). Hidden sheets and cells contain internal operations that must not be calculated by the user to avoid the corruption of the tool. Costs by country can be adjusted in the sheet **EU_Labor_Cost** in the template, just by selecting the country in the context of which the calculations are made.

LIST OF REFERENCES

Afton (2020). Afton Solar Array. Video. Minnesota Department of Transportation (MnDOT). https://www.youtube.com/watch?v=GWdcYbnDU4k

Arup. (2019). Five Minute Guide Electricity Storage Technologies. Retrieved from: https://www.arup.com/perspectives/publications/research/section/five-minute-guide-to-electricity-storage

Alternative ROW (2012). Alternative Uses of Highway Right-of-Way. Accommodating Renewable Energy Technologies and Alternative Fuel Facilities. FHWA. US Department of Transportation. https://rosap.ntl.bts.gov/view/dot/9607

Autobrennero (2009). Sustainability. Photovoltaic. Autostrada del Brennero SpA. https://www.autobrennero.it/en/sustainability/photovoltaic/

Badger, N. D. (2021). Global Wind Atlas. Retrieved 02 2022, from https://globalwindatlas.info/

BAM1 (2018).Wattway: solar panels on road surfaces. BAM. https://www.bam.com/en/csr/smart-city/a-sustainable-city/wattway-solar-panels-on-road-surfaces

Bierer, A., & Götze, U. (2012). Energy cost accounting: conventional and flow-oriented approaches. Journal of Competitiveness, 4(2).

BloombergNEF. BloombergNEF. Retrieved from https://www.bnef.com/insights/31023/view

BloombergNEF.. Energy Storage Assets. Retrieved from BloombergNEF: https://www.bnef.com/storage-assets

BloombergNEF.. GIGA Buffalo Solar Wind Energy Storage Project. Retrieved from https://www.bnef.com/storage-assets/15987

BloombergNEF. (n.d.). Battery Price Sensitivity & Builder. Retrieved from https://www.bnef.com/interactive-datasets/2d5d59acd900002d?tab=Battery%20price%20sensitivity

Blue Sky (2021). Blue Sky Project Website. Utah Department of Transportation. https://www.udot.utah.gov/connect/about-us/blue-sky-project/

Borunda, M. &.-E. (2020). Long-Term Estimation of Wind Power by Probabilistic Forecast Using Genetic Programming. Energies, 13(8), 1-24. doi:10.3390/en13081885

Bowden, C. A. (2019). Photovoltaics Education Website. Retrieved May 2022, from https://www.pveducation.org/

Burton, D. S. (2001). Wind Energy Handbook. John Wiley and Sons Ltd.

CENER (2019). Retrieved 01 15, 2022, from https://www.mapaeolicoiberico.com/

Cooper, P. I. (1969). The absorption of radiation in solar stills. Solar Energy, 333-346.

Cubes, G. (2022). Why Lithium is Taking Over Stationary Storage. Retrieved from https://greencubes.com/in-the-news/why-lithium-is-taking-over-stationary-energy-storage/#:~:text=Figure%202%3A%20The%20main%20two,density%20matters%20nothing%20beats%20NMC.

Dezso Sera, R. T. (2007). PV panel model based on datasheet values. 2007 IEEE International Symposium on Industrial Electronics (pp. 2392-2396). Vigo, Spain: IEEE. doi:10.1109/ISIE.2007.4374981.

Djohra Saheb, M. K. (2014). Technical and economical study of a Stand-alone Wind Energy System for Remote Rural Area Electrification in Algeria. Renewable Energy and Power Quality Journal (RE&PQJ), 638-643.

Elbarbary, Z. a. (2021). Review of maximum power point tracking algorithms of PV system. Frontiers in Engineering and Built Environment, 68-80. doi:https://doi.org/10.1108/FEBE-03-2021-0019.

EnergiGune. (2021). Gigafactorías: una gran apuesta de europa para su recuperación a través del desarrollo de fábricas de baterías. Retrieved from:
https://cicenergigune.com/es/blog/gigafactorias-apuesta-europa-recuperacion-fabrica-baterias

European Commission - EU Science Hub. (2020, March). PVGIS tool version 5.2. Retrieved May 2022, from https://re.jrc.ec.europa.eu/pvg_tools/en/

Goebel, Greg (2014). PSE Wild Horse Wind Complex WA. CC BY-SA 2.0 DEED Attribution-ShareAlike 2.0 Generic. https://www.flickr.com/photos/37467370@N08/20631702115/in/photostream/

Grottke, M., Suker, T., Eyras, R., Goberna, J., Perpinan, O., Voigt, A. et al. PV soundless – world record "along the highway"– a PV sound barrier with 500 kWp and ceramic based PV modules. 19th European Photovoltaic Solar Energy Conference, France (2003).

Guardian, The (2016). World's first solar panel road opens in Normandy village. Kim Willsher. The Guardian. https://www.theguardian.com/environment/2016/dec/22/solar-panel-road-tourouvre-au-perche-normandy

Hodges, T. and Plovnick, A. (2019). Renewable Roadsides. Public Roads. FHWA. US DOT. https://www.fhwa.dot.gov/publications/publicroads/19winter/04.cfm

Holmes, J. (2015). Wind Loading of Structures. Boca Raton, Florida: CRC Press.

Hou et al. Life cycle assessment of grid-connected photovoltaic power generation from crystalline silicon solar modules in China. Applied Energy 164 (2016) 882–890.

IEA (2022). International Energy Agency. Belgium.

Infrabel (2015). Sustainable development report. Infrabel Right On Track.

Innovative (2021). Project Profiles. Center for Innovative Finance Support. FHWA. US DOT.
https://www.fhwa.dot.gov/ipd/project_profiles/
https://www.fhwa.dot.gov/ipd/project_profiles/or_baldock_solar_station.aspx

Insulators, N. (2023). About NAS Batteries. Retrieved from: https://www.ngk-insulators.com/en/product/nas-about.html#:~:text=NAS%20battery%20has%20a%20calendar,long%20life%20can%20be%20expected.

Jiang, W., Yuan, D., Xu, S., Hu, H., Xiao, J., Sha, A. and Huang, Y. (2017). Energy harvesting from asphalt pavement using thermoelectric technology. Applied Energy 205, pp. 941–950.

Jochems, P.M. (2013). The potential of PV panels near road infrastructure in the Netherlands. Master Thesis. Eindhoven University of Technology. The Netherlands.

Justus, C. G., Hargraves, W. R., Mikail, A., & Graber, D. (1978). Methods for estimating wind speed frequency distributions. Journal of Applied Meteorology, 350-353.

Khoie et al. The Carbon Emissions of Wind Power; A Study of Emissions of Windmill in the Panhandle of Texas. International Solar Energy Society. ASES Solar 2020 Proceedings.

Kotzen and English (2009). Environmental Noise Barriers: A Guide To Their Acoustic and Visual Design. CRC Press, second Edition.

Lazard (2018). Levelised Cost of Energy and Levelized Cost of Storage 2018. Retrieved from: https://www.lazard.com/research-insights/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

Law Reviews (2022). The Energy Regulation and Markets Review: Belgium, The Law Reviews.

Leach, G. (2023, April). BloombergNEF Company Profiles: European Battery Manufacturers. Retrieved from: https://www.bnef.com/insights/30981/view

Ma et al. Distance Calculation Between Photovoltaic Arrays Fixed on Sloping Ground. Journal of Computational Methods in Sciences and Engineering 15 (2015) 107–116. DOI: 10.3233/JCM-150525.

Manwell, J. G. (2009). Wind energy explained: Theory, Design and Application. Amherst, USA: John Wiley & Sons.

Milne, R. M. (1921). Note on the Equation of Time. The mathematical Gazette, 372-375.

MnDOT (2020). Solar Energy at MnDOT. Sustainability and Public Health. Minnesota DOT. http://www.dot.state.mn.us/sustainability/docs/solar-overview-june-2020.pdf

Mowen, M. M., Hansen, D. R. & Heitger, D.L. (2014). Cornerstones of cost management. Cengage Learning.

National Renewable Energy Laboratory. (2021, Dec). National Solar Radiation Database (NSRDB) Ver 3.2.1. Retrieved May 2022, from https://nsrdb.nrel.gov/

NCHRP, 2013. Renewable Energy Guide for Highway Maintenance Facilities. National Cooperative Highway Research Program. Transport Research Board (TRB). ISBN 978-0-309-25911-8.

Nsitem. (2023, April). BloombergNEF, 2022 European Energy Storage Market Overview . Retrieved from: https://www.bnef.com/insights/28999/view

Nordmann, T. and Clavadetscher, L. (2004). PV on noise barriers. Progress in Photovoltaics: Research and Applications, Volume 12, Issue 6, Pages 485 – 495.

NREL (2021). National Renewable Energy Laboratory Reported timeline of research solar cells energy conversion efficiencies since 1976 to 2020. National Renewable Energy Laboratory (NREL).

NREL - EnergyPlus. (2021). EnergyPlus weather data. Retrieved from: https://www.google.com/maps/d/viewer?msa=0&dg=feature&mid=1BhMLmWuS8BVuqdkGCYsAsilqFy4&ll=42.30004341517257%2C25.28416418536264&z=4

ODOT (2016). Solar Highway Program: From Concept to Reality. A Guidebook for DOTs to Develop Solar Photovoltaic Systems in the Highway Right-Of-Way. Oregon Department of Transportation.

Patel, S. New solar roads unveiled. Power. Volume 161, Issue 2, 1 February 2017. https://www.powermag.com/new-solar-roads-unveiled/

Poe, C., Plovnik, A., Hodges, T., Hastings, A, Dresley, S. (2017). Highway Renewable Energy: Photovoltaic Noise Barriers. FHWA-HEP-17-088. Federal Highway Administration. U.S. Department of Transportation.

Power. (2020). Flow Batteries: Energy Storage Option for a Variety of Uses. Retrieved from: https://www.powermag.com/flow-batteries-energy-storage-option-for-a-variety-of-uses/#:~:text=With%20life%20spans%20reaching%20up,storage%20technologies%20on%20the%20market.

Pultarova, T. (2017). Welcome to the world's first solar road. Engineering & Technology 12(1), page 10. DOI: 10.1049/et.2017.0114. Print ISSN 1750-9637, Online ISSN 1750-9645.

Ray (2016). Solar-paved highway. The Ray Today. The Ray.

https://theray.org/technology/the-ray-today/ & https://theray.org/tech/solar-paved-highway/

Ray (2018). Nation's 1st Pollinator-Friendly Right-of-Way Solar Project Comes to Georgia. The Ray.

https://www.raycandersonfoundation.org/articles/nation%E2%80%99s-1st-pollinator-friendly-right-of-way-solar-project-comes-to-georgia

Ray (2019-1). The U.S. Solar Road Gets a Technical Upgrade, more Energy Production Expected: Data from two years of public testing led to advancements in solar road technology on The Ray, a section of Interstate 85 in West Georgia Press Releases. The Ray. https://theray.org/2019/12/19/the-u-s-solar-road-gets-a-technical-upgrade-more-energy-production-expected-data-from-two-years-of-public-testing-led-to-advancements-in-solar-road-technology-on-the-ray-a-section-of-interstate-85/

Ray (2019-2). Right-Of-Way Solar. The Ray Today. The Ray.
https://theray.org/technology/the-ray-today/
https://theray.org/tech/right-of-way-solar/

Renewables Now (2010). Enfinity, Infrabel to build USD-20m solar facility on Belgian rail tunnel.
https://renewablesnow.com/news/enfinity-infrabel-to-build-usd-20m-solar-facility-on-belgian-rail-tunnel-106470/

Renewables Now (2017). Belgium's Greensky wind farm adds 9 turbines. Renewables Now.
https://renewablesnow.com/news/belgiums-greensky-wind-farm-adds-9-turbines-571102/

Reuters (2011). Solar power for trains dawns in rainy Belgium. Green Business News. Reuters.
https://www.reuters.com/article/us-belgium-solar-trains-idUSTRE77B2KD20110812

Rijkswaterstaat (2021). Wattway. https://rwsinnoveert.nl/afgeronde-innovaties/@208740/wattway/

Rolling Solar (2021). Rolling Solar official website. https://rollingsolar.eu/home

Rolling Solar2 (2021). Rolling Solar official website. News.
https://rollingsolar.eu/news/i269/rolling-solar-test-phase-pv-noise-barriers-in-genk-and-rosmalen-has-begun

ROW (2017). FHWA Renewable Energy in Highway Rights of Way Peer Exchange. FHWA. US DOT.
https://www.fhwa.dot.gov/environment/sustainability/energy/workshops_and_peer_exchanges/highway_row/index.cfm

Rutgers (2019). Generating power every time you hit the road. News. Centre for Advanced Infrastructures and Transportation. https://cait.rutgers.edu/generating-power-every-time-you-hit-the-road/

Sánchez-Carbajal, S. & Rodrigo, P.M. Optimum Array Spacing in Grid-Connected Photovoltaic Systems considering Technical and Economic Factors. International Journal of Photoenergy. Volume 2019, Article ID 1486749, 14 pages. https://doi.org/10.1155/2019/1486749.

ScienceDirect. (2021). Sodium Nickel Chloride. Retrieved from
https://www.sciencedirect.com/topics/engineering/sodium-nickel-chloride#:~:text=The%20roundtrip%20efficiency%2C%20energy%20density,%2C%20and%2015%20years%2C%20respectively.

SEAC (2015). Solar Highways Benchmark Study. An overview and evaluation of existing photovoltaic noise barriers. Authored by: Minne de Jong. Organisation: SEAC. Life+ Project: LIFE13 ENV/NL/000971.

Sedagha, A., Gaith, M., Khanafer, K., & Bani-Hani, E. (2016). Rated Wind Speed Reality or Myth for Optimization in Design of Wind Turbines. Eleventh International Conference on Ecological Vehicles and Renewable Energies (EVER) (pp. 1-4). IEEE.

SolaRoad (2021). Pilot Projects. SolaRoad BV. https://www.solaroad.nl/portfolio/

Schultz and Carvalho. Design, Greenhouse Emissions, and Environmental Payback of a Photovoltaic Solar Energy System. Energies 2022, 15, 6098.

Solar Highways (2021). Solar Highways official website. https://solarhighways.eu/en

Thompson and Garrison (2015). Life Cycle Costs and Carbon Emissions of Onshore Wind Power. ClimateXChange.

TNO (2019). Solaroad's new phase: a motorway that also generates electricity. TNO Insights. https://www.tno.nl/en/tno-insights/articles/solaroad-s-new-phase-a-motorway-that-also-generates-electricity/

Twin (2020). Afton solar garden on MnDOT-owned land now online. TwinCities.com https://www.twincities.com/2020/10/06/afton-solar-garden-on-mndot-owned-land-now-online/

UDOT (2018). Renewable Energy Implementation at State DOTs Peer Exchange. FHWA. US DOT. https://www.fhwa.dot.gov/environment/sustainability/energy/workshops_and_peer_exchanges/utah/index.cfm

US DOE (2022). https://www.energy.gov/eere/wind/articles/how-wind-energy-can-help-us-breathe-easier

Van der Borg, N.J.C.M. and Jansen, M.J. (2001). Photovoltaic noise barrier at the A9-highway in The Netherlands. Results of the monitoring programme. ECN-C--01-021. ECN project number: 7.4457.

Volpe (2012). Alternative Uses of Highway ROW. Accommodating Renewable Energy Technologies and Alternative Fuel Facilities. Federal Highway Administration. Office of Planning, Environment, and Realty. U.S. Department of Transportation.

Wang, C., Song, Z., Gao, Z., Yu, G. and Wang, S. (2019). Preparation and performance research of stacked piezoelectric energy-harvesting units for pavements. Energy & Buildings 183: 581-591.

Wass, R. (2018, 09). Design of Wind Turbine Tower Height and Blade Length: an Optimization Approach. Mechanical Engineering Undergraduate Honors Theses. Fayetteville: University of Arkansas.

Wikimedia (2011). PV Soundless Freising. Creative Commons Attribution 3.0 Unported license. https://commons.wikimedia.org/wiki/File:PV_Soundless_Freising.jpg

Wikipedia (2021). Retrieved 02 01, 2022, from https://en.wikipedia.org/wiki/Log_wind_profile

World Bank Group (2021). Global Solar Atlas (GSA 2.6). Retrieved May 2022, from https://globalsolaratlas.info/map

Zabihi, N. and Saafi, M. (2020). Recent Developments in the Energy Harvesting Systems from Road Infrastructures. Sustainability 2020, 12(17), 6738. DOI: https://doi.org/10.3390/su12176738.

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Conference of European Directors of Roads (CEDR)
Ave d'Auderghem 22-28
1040 Brussels, Belgium

Tel: +32 2771 2478
Email: information@cedr.eu
Website: http://www.cedr.eu

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