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Supporting the implementation of renewable energy technologies in the road infrastructure (ENROAD)

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Abstract

Achieving 2030 targets of reduction of emissions and increase of energy generation from renewable sources require of the participation of the sectors with a greater impact on the environment, those highly contributing to the climate change. Transportation plays a key role for the economic and social transformation of the society, but it is also responsible for a large part of EU emissions. As main stakeholders, the commitment of National Road Administrations (NRAs) is necessary to meet the challenge. To this end, installating renewable energy systems in the lands and assets they own might be a great step towards the mitigation of the environmental impact of roads. The ENROAD Project is aimed at helping in the decision-making, not only from the perspective of the technical and financial implications, but also considering the regulatory barriers that might limit their implementation.

Keywords: decision-making; renewable energy; road administration; business models; regulatory framework; GIS.

1. Introduction and objectives

In 2020, renewables overtook fossil fuels as the EU's main power source (EC, 2021), with 38% of the electricity generated from renewable sources versus 37% coming from fossil fuels (and the remaining 25% from nuclear power plants). Although these figures are very stimulating, there is still much work to do in order to reduce not only the huge environmental impact associated to the extraction, refining and combustion of fossil fuels, but also the EU net energy import dependency, which reached 61% in 2020. In fact, the EU is constantly taking action to promote energy efficiency policies, the replacement of fossil fuels and the growing use of renewable energies. The adoption of the European Climate Law (OJEU, 2021) with the 2030 target of at least 55% GHG reductions, and the proposal to raise the EU 2030 target for renewables from the current at least 32 % to at least 40 % of the gross final consumption of

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energy as part of the package Delivering on the European Green Deal (EC, 2021), are very good examples of the EU bet on the decarbonisation and the use of clean energies.

However, new energy goals and more restrictive environmental policies require from the support of all the institutions, including the NRAs, all of them having internal or external targets to reduce their own energy use and GHG emissions. It is a very well-known fact that the transport sector accounts for around 30% of EU's final energy consumption (Eurostat, 2021) and a quarter of the EU's greenhouse gas emissions (Energy, 2020). To face these challenges, NRAs' lands and assets can be used for placing or allowing the placement of renewable energy systems from very different sources: wind turbines, solar power, or even small-scale hydro plants. Considering that NRAs manage a large infrastructure including a significant amount of land alongside their road infrastructure, it can be assumed that there is a huge potential for the generation of clean energies.

So far, several different renewable energy systems have been installed worldwide within the land or assets of the NRAs that can be classified into four main groups based on technology and location. Although impossible to include all the different installations, the following are very representative examples:

1. PV panels integrated into the road pavement such as those of the Wattway (2021) technology implemented in several places in The Netherlands (Fig. 1), France or USA (Georgia); or the SolaRoad (2021) systems installed in different cities in The Netherlands. A new project, participated by partners from Germany, The Netherlands and Belgium is now running in Europe (Rolling Solar, 2021).
2. PV panels integrated into noise barriers (PVNBs), a good number of which have been installed in Europe in the last 30 years. The world's first highway PVNB came into use in 1989 in Domat/Ems, Switzerland, along the A13 road. More recently, the barrier along the A50 road (Fig. 1) near Uden (The Netherlands), remains as the largest bifacial solar noise barrier in the world (Solar Highways, 2021; SH Final, 2020).
3. PV systems or large turbines in big areas aside or out of the road, most of which have been implemented in USA in the context of the many lands that US DOTs manage and that are close to electrical loads. The Baldock Solar Station at a rest area property of the Oregon DOT (Baldock, 2021), with power capacity of 1.75 MW, or the sites completed in 2019 by the Massachusetts DOT amounting a total power capacity of 4.3 MW (Hodges and Plovnick, 2019), are good examples.
4. PV systems or wind turbines in rooftops or road structures, such as the 32 kW and 50 kW small turbines at Ohio and Texas DOT's facilities (NCHRP, 2013); the 2.8 MW solar array on top of a long noise-barrier tunnel on the A3 highway near Aschaffenburg, Germany (Fig. 1); or the high speed rail tunnel (not a NRA land) in Belgium covered by panels with total power capacity of 4 MWp (Reuters, 2011; Tsanova, 2010).

In this context, the ENROAD project was born in 2020 as funded by different European NRAs (Austria, Belgium-Flanders, Germany, Ireland, Netherlands, Norway, Sweden and United Kingdom) in the framework of the CEDR (Conference of European Directors of Roads) Research Call 2019.

The aim of this project is to help those roads administrations with the decision making on the implementation of renewable energy technologies, not only from the technical and environmental point of view (which technologies), but especially considering the placement and logistics (where and how to integrate them), the regulatory framework (what structures are possible from the regulatory point of view) and the financial perspective. Thus, the lack of technical knowledge about certain aspects of the energy generation and distribution, although not the biggest issue for the NRAs, is covered by means of the development of a thorough review of potential applications. However, the lack of experience with the strict regulation applicable to the energy sector and in particular to the electricity market, as well as the fact that, in some countries, NRAs are not allowed to produce and sell energy on the electricity market is indeed an issue, as a difficult-to-handle multi-stakeholder approach is required that can lead to missing big project opportunities or to faulty decision-making.

Fig. 1. Solar road in Hengelo, NL; Solar Highways PVNB in Uden, NL; Baldock Solar Station in Oregon, USA; solar tunnel in Aschaffenburg, Germany (top to bottom and left to right).

Still under development, expected results are to fill the existing gaps regarding the **technical performance of the renewable solutions alongside the road asset, provide a practical explanation of the governance and legislative framework across the evaluated countries regarding the generation and distribution of RE, and define effective business models for economic and financial assessment** that are based on the technology and facility individually considered. In addition, the development of a GIS-based easy-to-use tool is expected that enable a preliminary assessment of the potential of NRAs assets for renewable power generation.

In this paper, the methodology followed for the development of the project as well as the main outcomes and conclusions obtained so far are introduced. It should be highlighted that to date the project is still almost one year to go, which somehow limits the scope of the contents included.

Nomenclature

BM	Business Model
CEDR	Conference of European Directors of Roads
DOT	Department of Transportation (US)
GHG	Greenhouse Gasses
GIS	Geographical Information System
GO	Guarantee of Origin
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
PPA	Power Purchase Agreement
PV	Photovoltaic
PVNB	Photovoltaic Noise Barrier
RE	Renewable Energy
RET	Renewable Energy Technology

2. Methodology

Initially for the development of the project, a literature review was carried out in order to provide an overview of the different RE technologies for power generation suitable for their placement within/along the road asset. This search also helped to identify the most typical topologies for the installation of those RE systems. At the same time, a survey was designed and sent to several 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) Gather their opinion on the criteria used for the selection of technologies, topologies and locations; 4) Collect more precise information about previous experiences on the topic.

For the design of the survey, the minimum possible number of questions were defined in order to collect as many answers as possible. The survey was split into two main parts: a first one with broader general questions and a second section with questions oriented to get knowledge on the current experiences of the surveyed NRAs. The professional software Limesurvey was used for the implementation so that the survey could be easily filled out and the answers sent from a computer or even the mobile phone. Some of the most interesting general questions are listed below:

1. *Does your organization have internal targets to reduce energy use and/or GHG emissions?*
2. *Does your organization currently generate Renewable Energy along the road asset?*
3. *In your opinion, what is the main barrier stopping the NRAs from investing on RE technologies?*
4. *Which of the following RETs would you consider for implementation? Check all that apply.*
5. *For which of the following energy consumers would be the RE used? Check all that apply.*
6. *Which of the following road topologies would you consider for the RETs? Check all that apply.*
7. *Which of the following criteria would you use for the selection of RETs? Check all that apply.*
8. *Which of the following criteria would you use for the location of RETs? Check all that apply.*

The link to the survey, along with a very short introduction to the ENROAD project, was sent to representatives of 28 European NRAs. To date, representatives (more than one in some cases) of 16 countries provided a full answer.

As for the analysis of legal risk/barriers existing in the countries involved in the ENROAD project, a research and due diligence report has been carried out that aims to identify the National and EU regulations, potentially applicable to NRA's in the area of energy production. The identification and summarising of the applicable regulations can help NRA's to identify opportunities and obligations in this area and any potential risks, pitfall and barriers. The categories examined were: 1) National & EU regulation applying to production, aggregation, grid injection and storage of RE (limited to small to mid scale renewable energy applicable to NRAs lands); and 2) National & EU regulation regarding energy supply for government entities.

The methodology followed consisted of carrying out a thorough analysis at an EU level and then at a national level of existing and foreseen regulation that conditions the generation and commercialization of electricity, both for self consumption and distributed generation. For this, national and EU legislation potentially applicable to NRA's in the area of energy production was previously identified in order to find the opportunities, obligations and possible barriers that NRAs would face relative to decarbonization and implementation of renewable energy projects within their assets.

The analysis intends to identify if, how and where the countries have defined and regulated figures that could be used in business models of interest for the NRAs such as: demand aggregators, closed distribution networks, renewable energy communities, charging infrastructure, PPAs and others. For this purpose, the analysis has been structured based on the requirements made to the countries by the following EU legislation, which set clear obligations for member countries to align with and achieve EU energy and climate objectives through their National Energy and Climate Plans and national legislation regulating the electricity sector: 1) Governance of the Energy Union and Climate Action (EU) 2018/1999; 2) Promotion of the use of Energy from Renewable Sources (Directive 2018/2001); and 3) Common Rules for Internal Electricity Market (Directive 2019/944).

In addition to the analysis of the technologies for the renewable energy generation within the road asset and other properties of the NRAs (e.g. buildings), and the study of the legal issues affecting the implementation of those RETs, the ENROAD project is aimed at providing the NRAs with an easy to use GIS-based Multi-Criteria Decision-Making tool for the selection and location of RE technologies based on technical, economical and environmental criteria. For this purpose, the tool will allow the end user to select the best possible location for a RE project within a certain area, quickly assess the available resource and potential energy generation, approach the environmental impact of the RET adopted and determine the cost-efficiency of the final implementation.

Along with approaching the energy performance of the renewable technology to be installed in a certain spot, the tool supports the economic and financial dimension of the selection by means of the ENROAD business model (BM).

In essence, a business model is a conceptual model of business that identifies the consumer utility and the appropriate market segments, confirms the possibility of getting a revenue stream, designs the mechanism to achieve it and finally turns the value provided by the organization into liquid funds (cash) and profits. The BM is considered to favour the energy transition to the renewable energies (Bryant et al. 2018; Karami and Madlener 2021) and their policies (Huijben and Verbong 2013; Gauthier and Gilomen 2016). As part of its design, a state of the art of the RE facilities simulation software including cost estimation was carried out that revealed a wide variety of such software: some are PV specific, others are oriented to wind farms design, and there are those for general optimization and economic assessment such as HOMER (2022) and RetScreen (2022).

The ENROAD tool also incorporates a methodology to evaluate the potential environmental impact of the different renewable energy technologies selected. A literature review was conducted to attain overview on the availability of information on the environmental impact of RETs from a LCA perspective. LCA evaluates the environmental impact of the whole life-cycle, from raw material extraction, through processing, production, transport, use and end-of-life (EoL) processing. The life-cycle stages included are based on the European standard EN 15804 (European Committee for Standardization, 2013) and focus on A1-A5 (production and installation), and B1 (use, energy production) without excluding the possibility to include maintenance (B2), End-of-life (C1-C4) and reuse (D) if information is avialable. Thus, the result of the literature review and available data in Ecoinvent is intended to be used to evaluate the potential environmental impact of the RETs with the goal of create a site-specific dynamic environmental impact calculator.

Finally, when planning the location of energy hubs, other factors should be taken into account such as: the location and capacity of power substations in order to properly quantify the power generation in the potential RET location; or the the need for a good coordination between generation and load to reduce the impact of transportation electrification, both in terms of energy losses in distribution grids, power congestion, power flow reverse, etc. In line with this, a new methodology has been proposed based on data aggregation from different open-source datasets that takes into account aspects like the traffic density patterns, EV charging patterns or the distance of the energy hubs from the closest power substation. The integration of this methodology into the ENROAD tool is still under consideration.

3. Outcomes and conclusions

Out of the 28 European NRAs surveyed, at least one representative of 16 countries sent a full answer to the survey: Spain, Italy, Belgium (Flanders and Wallonia), Ireland, Sweden, Netherlands, Norway, Germany, Austria, UK, Latvia, Portugal, Hungary, Denmark, Switzerland and Luxembourg. This means that almost 60% of the organizations kindly sent a proper answer to the questionnaire whereas the rest of them did not finished the survey or just refused doing it. It should be highlighted that these are not necessarily official responses from the NRAs but merely a contribution to a research project by people involved to a certain extent in the management of the road infrastructure (i.e. managers, strategic advisors, heads of technology, etc.).

The answers to the questionnaire revealed very different and interesting results. Thus, the answers to questions Q1 and Q2 regarding internal targets and renewable power generation along the road asset showed that while 75% of the countries surveyed have internal targets to reduce energy use or GHG emissions, only half of them currently generate electricity from renewable sources within the NRAs lands/assets. 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. Cost of investment, long authorization and administrative procedures, no feed-in tariffs for public bodies or not being primary purpose for NRAs are some of the specific answers obtained.

Questions Q4 and Q5 refer to the RETs that NRAs would consider for implementation, and the energy consumers for which the RE would be used. To these questions, answers are clearly in line with the implementation of small scale RETs, more specifically small PV systems. Small turbines and large PV also seem to be within the preferences of the NRAs. On the other hand, small hydro and less conventional technologies are far from being an option (Fig. 2). As for the energy consumers, road and tunnel lighting are the most preferred options for using the RE generated, with more than 70% of the surveyed NRAs voting for it.

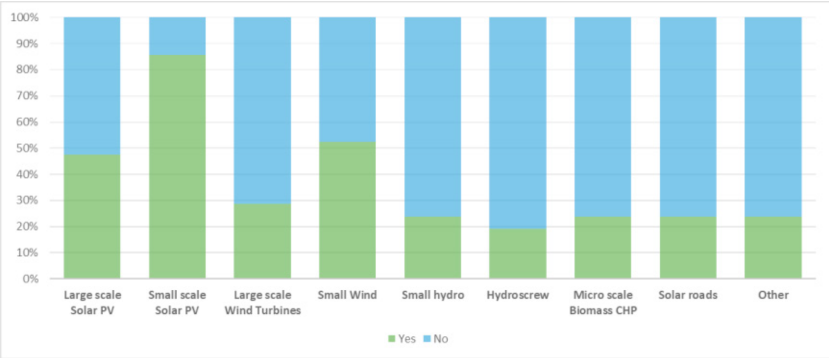

Fig. 2. Answers to question Q4 of the survey sent to the NRAs.

Some relevant answers were also obtained for questions Q6 to Q8. Thus, rest areas, parking canopies, signals and panels were defined by voters as the most convenient topologies for the RE systems installation. Slopes and noise barriers were also selected as suitable topologies. This is consistent with the answers given to question Q4. Likewise, lakes, rivers and channels were the less voted options (also consistent with Q4). For the selection of the RE technology, cost of installation, cost of maintenance, life cycle cost and environmental impact are the criteria that most of NRAs would use, with over 70% voting for them (Fig. 3). Results to the question Q8 states that avoiding traffic disruption, impact on road safety and distance to the road are 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 the traffic is a major concern for them.

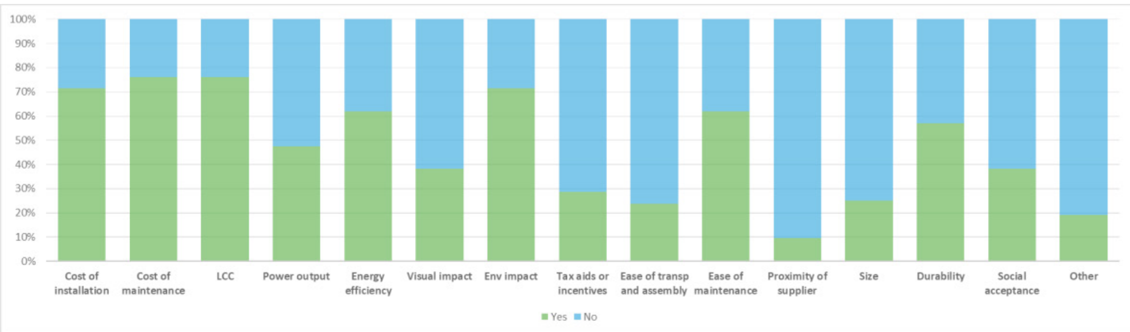

Fig. 3. Answers to question Q7 of the survey sent to the NRAs.

The analysis of legal barriers existing in the countries involved in the ENROAD is also key for the project. With respect to the status of requirements and targets made to countries by the three directives previously introduced, the following summary table (Table 1) provides a first approach to the current situation at a EU level. Colours in the table represents the risk level: green if no risk has been identified; yellow if there is a moderate risk for implementation; and red if there is an unmanageable barrier for implementation that would make a strategy/business model unfeasible.

In addition, **general considerations** can be made (those being a very short summary of the red flag report executive summary) regarding the topics in the table:

- On average, all the countries under study have set targets for around 50% reduction of GHG emissions by 2030 and zero net emissions by 2050. These goals are a positive driver for implementation of RE projects in the road infrastructure.
- Most of the countries under study focus on implementing renewable energy and energy storage strategies, as well as green mobility. In fact, almost every country is strongly promoting electromobility.

- Most of the countries have support schemes that prove they are committed to achieving the targets set, prioritizing RE projects and promoting decarbonization strategies. Potential barriers to the access to this support schemes have been detected in certain countries, though.
- Little potential risk can be attached to the guarantee of origin for energy from RE since all the countries under study are already familiar with GOs- and they all have legislation for this purpose.
- While some countries promote and support RE communities through specific legislation, some other have developed no specific frameworks. If RE communities are not allowed or defined, some potential business models based on these structures would not be viable.
- The increase and mainstreaming of RE in the transport sector can be a significant driver and enabler of RE projects by the NRAs. However, slow uptake in and slow rollout of associated charging infrastructure is a potential issue. In other countries there is not even dedicated legislation to date.
- Most of the countries under study allow customers to sell and purchase of electricity under the aggregation figure. Likewise, most of the countries support active customers through different instruments.
- No regulatory frameworks concerning closed distribution systems were identified. These systems could provide an interesting business cases for NRAs for projects in larger scale supplying several consumers adjacent to the NRAs assets.
- Almost every country involved in the study have legislation explaining all the necessary procedures when connecting new generation installations.

Table 1. Summary red flag report on EU regulation carried out by Arup within the context of the ENROAD project.

Legislation	Topic	Risk
Governance of the Energy Union and Climate Action (EU) 2018/1999	National long-term strategies	
	National energy and climate plans	
	2030 Framework for energy and climate for the Union targets	
Promotion of the use of Energy from Renewable Sources Directive 2018/2001	Binding overall Union target for 2030	
	Support schemes for Renewable Energy	
	Opening of support schemes for RE from neighboring countries	
	Procedures, regulations and codes for integration and deployment of RE	
	Simple procedure for grid connections	
	Guarantees of origin for energy from renewable sources.	
	Renewables self-consumers	
	Renewable energy communities	
	Mainstreaming Renewable Energy in the transport sector	
	Minimum shares of Renewable Energy in the transport sector	
	Other provisions on Renewable Energy in the transport sector	
Common Rules for Internal Electricity Market Directive 2019/944	Aggregation contract	
	Active customers	
	Citizen Energy Communities	
	Demand Response through aggregation	
	Integration Of Electromobility into The electricity network	
	Closed distribution systems	
	Connection of new generating installations storage facilities	

A country specific Red Flag analysis has been conducted with conclusions for each of the countries. Additionally, a Matrix Analysis was carried out where, once identified the potential risks and barriers for each country under study, more suitable countries are identified as well.

As said before, the ENROAD business model design's main aim is to support the economic and financial dimension of the multi-criteria decision methodology for the selection of the most appropriate renewable energy technology and the spot for installation at the NRA's land or road asset. Once estimated the energy performance of the RET (energy generated and nominal power) and the configuration of the installation (e.g. network-connected or not), the model will estimate the per kWh cost of production (levelized cost of energy, LCOE) as based on the cost of investment (power sources, structures, inverters, transformers, grid connection, batteries, etc.) or capital expenditures (CAPEX) allocated along the life of the installation, and the annual operational expenditures (OPEX). Additionally to those CAPEX costs, a more exhaustive analysis following the RETScreen (2022) costing model suggests the incorporation to the feasibility study of other important costs such as those related to the site investigation, permits and approvals, accounting and legal issues, environmental assessment or project management, among others. Engineering expenditures related to the civil, mechanical and electrical design, tenders, contracting and construction supervision might be also considered. As with the CAPEX, these costs are annually considered and therefore, depreciated during the project life time.

The model is expected to apply a cost-benefit analysis based on the country's energy prices (PPA) to estimate the annual profit losses and/or savings. Lastly, the cash flows would be forecasted for the life cycle of the installation to calculate the Net Present Value, the Accounting Rate of Return, the Internal Rate of Return and the Payback Period.

Finally, as target users of the environmental calculator are mainly members of the European NRAs, a European electricity mix is used by default for estimating the emissions. The reasons behind are the largely linked electricity market in Europe and the agreement for using Guarantees of Origin (GO) for the electricity from renewable sources (AIB, 2021). Due to the potential uncertainty of some of the input data, the results presented by the calculator would not be absolute figures but an indicator of the magnitude of the environmental impact, only for comparison purposes. On the other hand, the users of the ENROAD tool will be allowed to incorporate their own datasets, which should result in more precise estimations.

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