Report 2.1.2.

Representation of Connection Distances of Previously Unused RES Potentials

Europäischer Fonds für regionale Entwicklung (EFRE)
Der Oberrhein wächst zusammen mit jedem Projekt

This second deliverable of RES-TMO for work package 2 aims to represent the connection distances of previously unused RES potentials to the existing distribution or transmission grid or the grid connection points.

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Introduction

Report 2.1.1 was centered on providing an estimate on the renewable energy generation potentials of the Upper Rhine Region. In order to complement it and understand the structure of the grid, the background information of this report will focus on grid-related topics. The structure of this section is as follows: the general regulatory conditions related to grid connection and the grid connection procedure in Germany, France and Switzerland, an expert opinion about the reality of the grid connection process, and the general structure of the electricity grid.

Background Information

The Grid: Regulations & Procedure

It is important to mention and discuss the general regulatory conditions that are related to and affect the renewable energy and the grid connection process on a national level, provide a list of major regulatory provisions, and outline the procedure of connecting to the grid in each of the three countries.

Germany

General Structure

In Germany, RWE, LEAG, Uniper, Vattenfall and EnBW are the largest entities involved in electricity generation but they are facing increased competition from decentralised energy generation from RES. There are four transmission system operators (TSO) responsible for the transmission network in Germany. They are: 50 Hertz, Amprion, Tennet, & TransnetBW. As for the distribution network, there are currently around 900 DSOs in Germany, a large number of which are operating a network with less than 100,000 consumers.

Electricity Generation and Renewable Energy

Electricity generation in Germany has the following composition. The source "renewables" includes wind and solar and accounts for 31.20 % of the electricity mix, the largest contribution out of all the sources. Renewables are followed by coal with a 25.46% share.

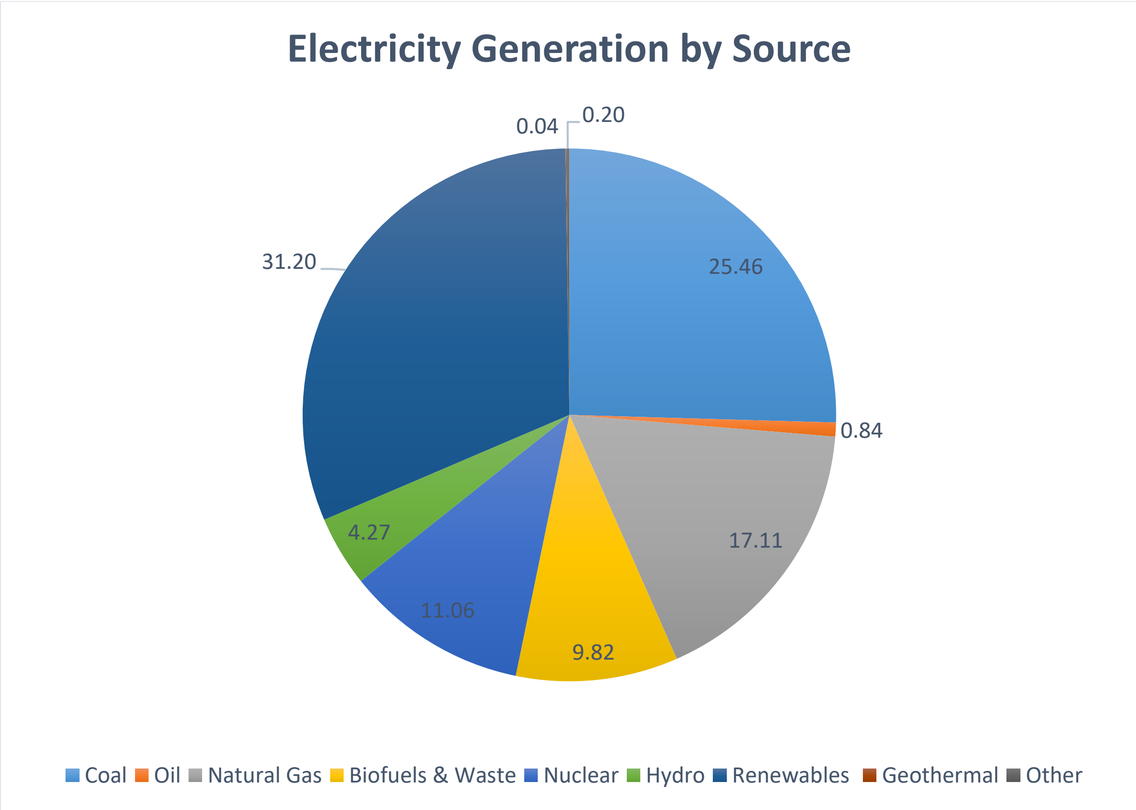


Figure 1: Pie chart depicting the electricity generation by source in % for Germany in 2020 (IEA, n.d.)

Regulatory Conditions

The Renewable Energy Sources Act, EEG (Erneuerbare-Energien-Gesetz) has controlled the priority feed-in of renewable energy sources in the grid since it was first introduced in April 2000. The EEG has been revised many times over the years and the latest version found is EEG 2021 as per the Federal Ministry for Justice and Consumer Protection's website. The purpose of the EEG is to synchronize the development of renewable energy technologies with the expansion of the grid and to improve the market integration of RES. (50 Hertz, 2020a)

Section 1 (§ 1) of the EEG 2021 states that the purposes and aims of this regulation are to: increase the share of electricity generated by renewable energy to 65% (the gross electricity consumption[1]) by 2030. The law also aims by the year 2050 to convert all sources of electricity generated or consumed in the federal republic of Germany and the federal territories into greenhouse gas neutral sources. (EEG, 2021a)

Other regulatory provisions related to renewable energy or grid development include:

1) EnWG (Energiewirtschaftsgesetz, *English translation: Energy Industry Act*);
   The purpose of the EnWG is to procure a secure, inexpensive, consumer-friendly, efficient, and environmentally friendly supply of electricity, gas and hydrogen for the general public that is based on renewable energy. (Section 1 of the EnWG (§ 1))
2) KraftNAV (Kraftwerks Netzanschlussverordnung, *English translation: Ordinance for Power plant network connection*);
   This ordinance regulates the conditions for the grid connection of systems generating electrical energy with an output of 100 MW or more to electricity supply networks with a minimum voltage of 110 kV (Section 1 of the KraftNAV (§ 1))
3) BBPlG (Bundesbedarfsplangesetz, *English translation: Federal Requirements Plan Law*);
   This law provides a list of projects and establishes their necessity for the energy industry in order to ensure safe and reliable network operation and for the general public in order to ensure public safety.
4) NABEG (Netzausbaubeschleunigungsgesetz Übertragungsnetz, *English translation: Grid Development Acceleration Law*);
   This law establishes the basis for a legally secure, transparent, efficient, and environmentally friendly expansion and upgrade of the transmission network (Section 1 of the NABEG (§ 1)).

The Grid Connection Procedure

There are different sections of the EEG that are dedicated to the grid connection procedure and the rules that regulate the exchange between plant operators and grid operators.

Some notable sections include:

1) Section 12 of the EEG (§ 12);

The grid operator is obligated to immediately optimize, boost, and expand the grid in keeping with the most advanced available technology when requested by a renewable energy plant operator interested in feeding in electricity to the grid such that the purchase, transmission, and distribution of electricity from renewable sources is guaranteed. This obligation extends to the grid operators that the plant is directly connected to and upstream grids with higher voltages (110 kV) on the condition that the needed grid upgrade is necessary to guarantee the purchase, transmission and distribution of electricity. The plant operators are entitled to the expansion on the condition that it is economically reasonable. (EEG, 2021b)

[1] Gross (national) electricity consumption includes the total gross national electricity generation from all fuels (including auto-production), plus electricity imports, minus exports. Auto-production is defined as a natural or legal person generating electricity essentially for his/her own use. Gross electricity generation is measured at the outlet of the main transformers, i.e. it includes consumption in the plant auxiliaries and in transformers" (EEA: https://www.eea.europa.eu/data-and-maps/indicators/renewable-electricity-consumption-1/assessment-2).

2) Section 8 of the EEG (§ 8);

Section 8 elaborates more on the responsibilities of the network operator in terms of the grid connection procedure.

Network operators must promptly connect systems that generate electricity from RES and "Grubengas" to their network at a connection point suitable for the voltage level and at the shortest distance possible to the system's location unless another network has a more technically and economically feasible connection point. Moreover, system operators may choose a different connection point if it is suitable in regards to voltage level only when the resulting additional costs for the network operator are not significant. The grid connection obligation persists if the grid needs to be optimized, reinforced, or expanded for it to be possible to purchase electricity. In regards to the grid connection procedure, network operators must provide system operators that are requesting a grid connection with an exact time schedule for the processing of a network connection request instantly after the receipt of the request. The schedule must include: (EEG, 2021b)

1) The steps needed for the processing of the grid connection request (EEG, 2021b)
2) The information to be provided by the system operator to the network operator in order to determine the grid connection point (EEG, 2021b)

Network operators have a maximum period of 8 weeks in order to gather and send the following information to the system operators:

1) A schedule for immediately establishing a grid connection with all necessary steps (EEG, 2021b)
2) All information needed by the system operator in order to check the suitability of the grid connection point and if requested the information necessary to perform a network compatibility test (EEG, 2021b)
3) An extensive and detailed estimate of the costs that will be incurred by the system operators because of the grid connection (EEG, 2021b)

In addition, KraftNAV or the Ordinance for Power plant network connection also elaborates on the connection procedure of power plants that are to be connected to the high voltage grid.

1) Section 3 of KraftNAV (§ 3)

The network operator must publish the following information on its website:

1) The minimum information required for submitting a network connection request and an overview of the line capacities available for connection use
2) Standard conditions for establishing a grid connection contract
3) A constantly updated, clear network diagram including identifying actual or expected bottlenecks

In case the system operator sends a network connection request to the network operator, the network operator within a maximum period of two weeks must provide the following:

- An explanation to the system operator about the necessary tests required to evaluate a network connection request, an overview of the line capacities available for connection use, and the ensuing costs of the tests.

- If additional information is required, the network operator is obligated to request this information in full from the system operator within a period of one week.

Once the system operator has provided an advance payment of 25% of the expected costs determined by the network operator, the network operator is obliged to carry out the tests necessary for establishing a grid connection and for forecasting the line capacities in regard to the connection point, connection lines, load flows and other effects on the network. If other electricity supply networks are affected by this connection then their operators must also participate in the inspection. The system operator can also request that the network operator carry out tests based on the system operator's assumptions. The system operator must be informed promptly about the progress and results of the tests. The network operator has a period of three months from the date of the advance payment (unless there are extraordinary circumstances or extra tests are requested or needed) to inform the network operator of the test results. Moreover, the system operator pays the costs of the tests. (KraftNAV, Section 3)

France

General Structure

In terms of electricity generation, EDF (Electricité de France) has the largest share and was responsible for 79.8 % of electricity production in the year 2019. Its prominent position can be attributed to the fact that it previously monopolized electricity generation and that it owns and operates all nuclear power plants in France. The transmission grid is operated exclusively by RTE, Réseau de Transport d'Electricité, the only TSO in France. It used to be part of EDF but was certified in 2012 by the Energy Regulatory Commission as an independent transmission operator. As per the French Energy Code, the majority of RTE's capital must be owned by the French state or other public entities. As for distribution, the DSO Enedis is responsible for the operation of 95% of the distribution grid. (Guénaire at al., 2020)

Electricity Generation and Renewable Energy

Electricity generation in France has the following composition. The source "renewables" includes wind and solar and contributes to 10.20 % of the electricity mix. As can be observed from the figure below, the biggest contributor to electricity generation is nuclear energy (66.46 %) followed by hydro and tide (12.62 %).

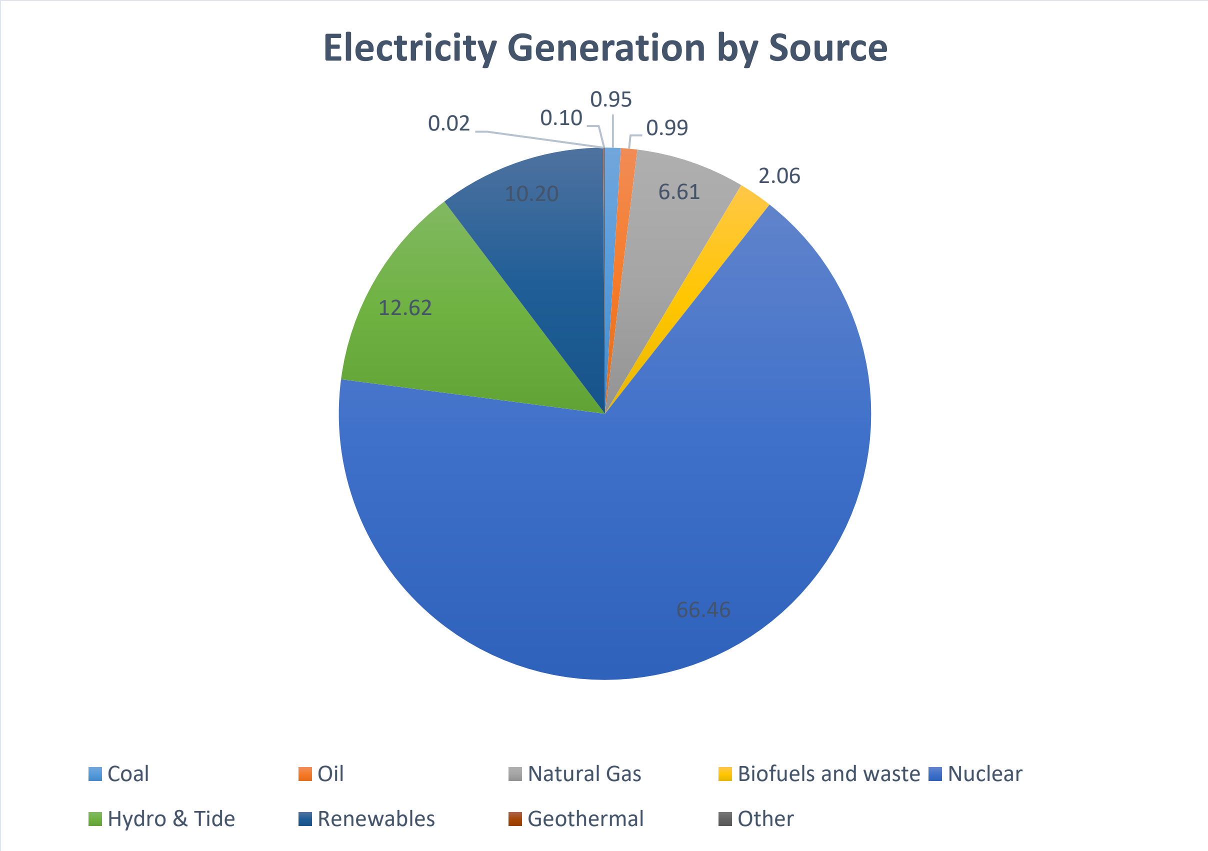


Figure 2: Pie chart depicting the electricity generation by source in % for France in 2020 (IEA, n.d.)

Regulatory Conditions

The French president signed Law No. 2019-1147 of 8 November 2019 regarding Energy and Climate (Loi n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat). The law transposed part of the EU "Clean Energy for all Europeans" legislative package which is composed of four directives and four regulations published in the period between June 2018 and June 2019. (Guénaire at al., 2020)

The law is supported by several ordinances. The reasons behind this law are to honor the commitments, which France made to the Paris Agreement in 2015. The commitments in question include coping with climate change and reducing carbon emissions. This law rectifies the French Energy Code to incorporate the aim of attaining carbon neutrality by the year 2050 through reducing the greenhouse gas emissions by more than six fold. In order to achieve this objective, the law sets the target of reducing the consumption of fossil fuels in France by 60% of 2012 levels by the year 2030. Moreover, the law contains concrete measures to help cut greenhouse gas emissions such as improved efficiency in buildings or reducing the emissions related to electricity generation. The measures related to electricity generation include: (Boring, 2019)

1) Limiting the operating times of the most highly polluting power plants;
2) Stopping the operation of coal power plants by 2022;
3) Postponing the goal of reducing reliance on nuclear power plants to 50% from 2025 to 2035 in order to ease the transition;
4) Increasing the use of renewable energy in the energy mix by increasing the construction of off-shore wind turbines and requiring new warehouses, supermarkets, and parking lots through shading structures to have at least 30% of their surface covered by solar panels (Boring, 2019).

There are many incentives by the French state and the EU to promote the development of renewable energy. Incentives include market premiums paid by EDF to producers of electricity to compensate for the difference in market price and target price. Moreover, by means of a feed-in-tariff, all electricity injected into the grid is bought by a purchaser (most of the time EDF) as part of a public service obligation, at a price over the market price. Furthermore, transmission and distribution operators are obligated to provide transparent and non-discriminatory access to the grid. (Guénaire at al., 2020)

Other notable regulatory provisions related to renewable energy or grid expansion include:

1) The Energy Code (Code de L'énergie);
   The Energy Code was created by Ordinance No. 2011-504 dated 9 May 2011 and finalized the transposition of the EU electricity directive into French law (Guénaire at al., 2020);
2) The PPE (Programmation pluriannuelle de l'énergie, *English translation: The multi-year program for energy*);
   The PPE is published for a five-year period (for example: 2019-2023 & 2024-2028 both published on January 25, 2019) and sets the government's goals for energy policy. Both programs were adopted by Decree No. 2020-456 dated 21 April 2020 and ensure the effectiveness of the COP21 Paris Agreement (Guénaire at al., 2020);
3) Ordinance No. 2020-866 dated 15 July 2020;
   It is one of the several ordinances added to the Law Nb. 2019-1147 of 8 November 2019 Regarding Energy and Climate. It helped "finalize the transposition of provisions on the energy performance of buildings and promotion of renewable energy sources". (Guénaire at al., 2020)
4) Law nº 2000-108 (Law related to the modernization and development of the public electric public service);
   This law transposed Directive 96/92/EC from the EU regulatory framework and gave industrials the right to choose and change the electricity supplier, changed the grid operator from EDF (Electricité de France) to the entity responsible for electricity transmission network, RTE (Réseau de Transport d'Électricité), and created an independent regulator. (Guénaire at al., 2020)
5) Law nº 2009-967 (Law related to the implementation of the targets set at the "Grenelle de l'Environnement" Summit)
   As the name suggests, this law defines the goals and targets to be reached in different domains such as transport, energy, buildings, etc.
6) Environmental Code
   The Environmental Code was created in 2000 and unifies all environmental laws and decrees and includes some provisions that regulate energy-related activities. (Guénaire at al., 2020)
7) Ordinance No. 2016-1060 of August 3, 2016 (Ordonnance n° 2016-1060 du 3 août 2016)
   This Ordinance introduced procedural reforms that ensure that the public receive information and participate in certain decisions that can impact the environment.

The Grid Connection Procedure

The connection procedure may vary and depends on the plant's capacity and whether the plant has to be connected to the high or low voltage grid. If the project to be connected has a capacity greater than or equal to 12 MW, then the connection request would be submitted to the French TSO RTE (RTE, n.d.). French DSOs can also process grid connection requests for projects depending on their capacity. Essentially, the general procedural guidelines follow a similar structure. (Enedis, n.d.)

There are different steps, some mandatory and some optional, to establishing a grid connection according to the French TSO, RTE.

An optional step is:

1) Requesting an exploratory study (6 weeks)
   It is possible for a plant operator (the applicant) to request an optional first feasibility study whose results include a timeline for the connection and a cost estimation. To request a preliminary study, the application, called D1 is submitted to RTE and specifically to RTE's System Access and Services Department. This step is non-binding to all the parties involved. (RTE, n.d.)

A queuing mechanism developed by RTE and DSOs puts in place a capacity reservation system that classifies connection requests on a "first come, first serve" basis. In order to put the project in the queue, applicants can submit two requests (one optional, one mandatory): (RTE, n.d.)

1) *Optional:* Requesting a Queue Entry Proposal (Proposition d'Entrée en File d'Attente or PEFA)
   By requesting a PEFA, applicants that have not finalized the details of their projects yet can discuss with RTE the technical and financial details of their prospective projects. A request is submitted to RTE's System Access and Services Department. The processing of the request can take up to 3 months from the receipt of the complete documents and the request. However, in case of more complex requests, this step could take longer. (RTE, n.d.)
2) *Mandatory:* Requesting a Technical and Financial Proposal (Proposition Technique et Financière, PTF)
   This is the first mandatory step in the connection procedure. The aim of this step is to develop a connection offer which is customized according to the data provided by the applicant. The processing of the request can take up to 3 months from the receipt of the complete documents and the request. However, in case requests are more complex, this step could take longer. A PTF request, called D2, is submitted to RTE's System Access and Services Department. The plant operator will be informed regularly about the progress of the application and request. (RTE, n.d.)
3) Signing the PTF
   Once the plant operator has signed the PTF, the different detailed studies and administrative procedures can commence. The plant operator will receive:
   a) the plant's constructive capacity specifications 3 months after signing the PTF at the latest
   b) the specifications of protection, tele-control, and metering by 6 months at the latest
4) The connection agreement is proposed by RTE (La Convention de Raccordement)
   The connection agreement takes into account the outcomes of the studies and the administrative procedures performed in the previous steps. The connection agreement determines the legal, technical, and financial terms for the connection and the conditions that the plant or project must meet in order to be connected to the grid. (RTE, n.d.)
5) Works Phase

RTE carries out the necessary works, metering and tele-control and keeps the plant operator updated about the progress. The duration of this step depends on the project at hand. (RTE, n.d.)

6) Testing Phase

   Before connecting a plant to the grid, the plant goes through a testing phase in order to evaluate its performance. The duration of this step also depends on the project at hand. At this phase, two contracts are signed with RTE: (RTE, n.d.)

   a) The Transmission System Access Contract (Le Contrat d'Accès au Réseau, CART) which sets out the metering, subscribed power and planned service interruptions commitments as well as the terms of liability, pricing and billing. (RTE, n.d.)
   b) The Operating and Conduct Agreement for Testing (La convention d'exploitation et de conduite pour essais) which specifies the respective responsibilities of each party in order to guarantee proper access to the grid and the operation and conduct rules that must be followed to keep both the property and people safe. (RTE, n.d.)

7) Network Access

   Finally, the plant obtains network access. (RTE, n.d.)

In case a plant operator wants to check beforehand the capacities available for installation at any point in the HV or LV grid, the capacities are published online on the website Caparésau. (https://www.capareseau.fr/).

Switzerland

General Structure

In Switzerland, around 80 companies contribute to the generation of electricity. Most of these companies are fully or partially state owned at the cantonal and municipal level. The power grid is divided into seven network levels. The first level (at 220/380 kV) is fully owned and operated by Swissgrid Ltd which is the national grid company and TSO. There are around 700 DSOs that supply electricity to end users. Some cantons have only one DSO, while others may have more than one option. (Scholl, 2020)

Electricity generation and Renewable Energy

Electricity generation in Switzerland has the following composition. The source "renewables" includes wind and solar and contributes to 3.72% of the electricity mix. As can be observed from the figure below, the biggest contributor to electricity generation is hydropower (57.34%) followed by nuclear energy (33.58%).

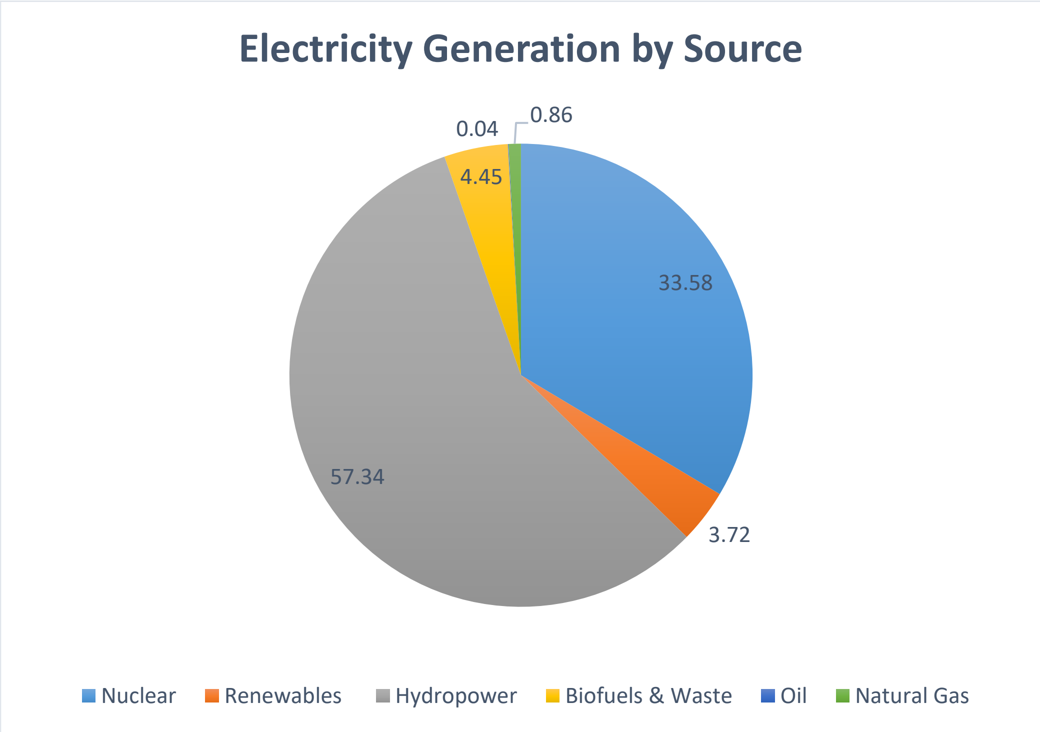


Figure 3: Pie chart depicting the electricity generation by source in % for Switzerland in 2020 (IEA, n.d.)

Regulatory Conditions

According to Swissgrid, the Swiss Transmission System Operator (TSO), the Swiss Transmission Code (TC2019 is the latest version that came into effect in May 2020) is a regulatory mechanism that establishes the technical and organizational governing principles of the Swiss transmission system. Moreover, there are provisions in the Transmission Code that define the relationship between Swissgrid and the different parties concerned, provide a task description for each of the parties, and control the interfaces between Swissgrid and the different parties. The different parties include:

- Distribution system operators or owners
- Generating units
- End consumers
- Other market players

In addition, the Transmission Code lists the minimum requirement needed for the operation, use, and connection to the Swiss transmission system.

Other regulatory provisions include:

1) Energy Act (Energiegesetzt, EnG)
   A complete revision of the Energy Act was voted for and passed by the Swiss electorate in May 2017 through a referendum. The Parliament deemed the revision necessary in order to introduce support measures that help to implement the Energy Strategy 2050 in phases. The Energy Strategy 2050 aims to reduce energy consumption, increase energy efficiency and promote renewables. Moreover, support is also given to help hydropower plants cover their production costs. Other amended legislation also helps introduce measures in support of the strategy.
2) Energy Ordinance (Energieverordnung, EnV)

This ordinance regulates among other things the spatial planning in connection with renewable energies, compensation for renovation measures for hydropower plants, the support measures in the energy sector, international cooperation within the scope of the EnG.

The Swiss government has put many incentives in place to encourage the propagation of renewable energy. The main incentive is the feed-in tariff which is available for hydropower, wind, solar PV, geothermal, biomass and biological waste. An incentive dedicated to solar energy is a one-time grant that solar plant operators whose plants produce up to 10 kWh can receive instead of the Feed-in-Tariff. The biggest hurdle for renewable energy development in Switzerland is the lack of societal acceptance and concerns over nature and landscape protection. (Scholl, 2020)

The Grid Connection Procedure

Swissgrid, the national grid company, must guarantee non-discriminatory network access to third parties. The technical agreement and conditions are set out in contract form between Swissgrid and the electricity producer. (Scholl & Bär & Karrer Ltd, 2020)

In order to connect a project to the grid, the plant operator must sign a Grid Connection Contract (NAV, Netzanschlussvertrag) whose general conditions are stated in the Appendix 2 (Anhang 2). The "General Conditions for Network Connection to the Swiss Transmission Network" (ABNA) state the framework conditions for system connections to the Swiss transmission network. The systems can be of different types such as generators, storage installations, distribution networks or end users. That the general conditions be met is an important and integral prerequisite to signing a Grid Connection Contract. (Swiss grid, 2017)

The general procedure to connect to the grid follows the following structure:

1) The grid connection applicant requests the creation of a new connection point at Swissgrid provided that the application meets the requirements defined by Swissgrid. This includes all the information related to planning, creating, and operating the grid connection. A decision is made upon the submission of the complete network connection application within a reasonable amount of time. (Swissgrid, 2017)
2) Swissgrid performs a check for every new application submitted whether the network conditions are suitable for the connection of a new system. Swissgrid also takes into account how different stakeholders can be affected by the new connection. (Swissgrid, 2017)
3) In case the network conditions do not support the capacity that is to be injected by the new plant, Swissgrid and the plant operators coordinate over the necessary grid expansion measures that can be executed. (Swissgrid, 2017)
4) Swissgrid offers the connection applicant a grid connection contract within a reasonable amount of time. If all the connection obstacles are solved, then the connection contract is finalized and should include, if applicable, the necessary grid expansion measures to be adapted as well as the relevant deadlines. (Swissgrid, 2017)

Expert Opinion

Mr. Christian Meyer is a management consultant in the energy field whose company, Energy Consulting, is based in Umkirch in Baden-Württemberg, Germany. Mr. Meyer's company takes on renewable energy plant operators as customers and supports them in the context of project development and the implementation of an economically feasible grid connection. He has provided his professional insight and experience about the actual conditions that surround the grid connection procedure of prospective renewable energy projects in Germany.

In practice, the locations of prospective renewable energy projects (at least in Germany) are often situated at large distances away from the public power grid. In addition, network operators often assign network connection points that are not economically feasible. Therefore, according to Mr. Meyer, an independent expert is often commissioned, the costs of which are borne entirely by the plant operator, in order to determine the appropriate network connection point while taking into account the regulatory conditions of the EEG and understanding the network operator's calculations. Using a detailed map as well as network data and information about the regional network disclosed by the network operator, the expert performs extensive calculations and simulations in order to determine the optimal network connection point. This investigation procedure requires the analysis of the existing cables and their cross-sections as well as the regional infrastructure and energy flows.

Once the extensive study is finished, the expert offers the plant operator recommendations on how to reach the optimal connection point and performs negotiations with the network operator. A possible recommendation of the expert would be that it is necessary for the network to be upgraded or expanded within a reasonable scope. However, if the network operator refuses to implement the network expansion, the generating capacity of the plant would have to be reduced in order for the project to proceed. As a result, many renewable energy projects are forced to reduce their capacity to be connected to the grid. At this point, the plant operator has two choices. One is for the renewable energy plant to be built with the reduced capacity and connected to the grid. The second, on the other hand, is not implementing the project because, in some cases, reducing the capacity of a renewable energy project can lessen its economic viability, which in turn renders it unattractive for the plant operator. In the long term, these conditions lead to a lower overall total installed capacity of renewable energy projects in the network.

The Electricity Grid

The Grid Components

The different grid components (substations, transformers, and transmission structures) used in this study and their definitions are found below:

1) Substations

   Substations are "the points in the power network where transmission lines and distribution feeders are connected together through circuit breakers or switches via bus-bars and transformers. This allows for the control of power flows in the network and general switching operations for maintenance purposes." (Bayliss & Hardy, 2012, Publisher Summary)

   "In the distribution system, transformers typically take medium, or "primary," voltages measured in the thousands of volts and convert them to secondary voltages—such as 120, 240, or 480 volts—that can be safely delivered to homes and businesses all over the world." (Bhattacharya, 2017)

2) Transformers

   A transformer is a device that transfers electric energy, by either stepping up or down the voltage, between two AC circuits by using electromagnetic induction. (Britannica, 2021)

Moreover, there are different types of transformers that can be found in substations. “Transformers at substations can be classified in different (possibly disjoint) groups, with respect to their voltage levels (power levels), function in a power grid, insulation class, or construction, etc.” (Rafique, 2018, Section 3.1.5).

a) “Transmission substation: for connecting two or more than two transmission lines, via grid breakers. These transformers are inserted in the grid system to improve the power efficiency of the system by reducing the transmission line losses.
b) Distribution substation: to decimate the power level for the distribution level consumers, a distribution transformer is used.
c) Collector substation: usually step up transformers, generally are connected to increase the level of power from the generation level, for example, in wind fields for the high power level consumers.
d) Converter substation: these devices can change some important parameters like frequency of the applied signal.” (Rafique, 2018, Section 3.1.5)

3) <u>Transmission Structures (poles, towers)</u>

“Transmission structures support the phase conductors and shield wires of a transmission line. The structures commonly used on transmission lines are either lattice type or pole type. Lattice structures are usually composed of steel angle sections. Poles can be wood, steel, or concrete. Each structure type can also be self-supporting or guyed. Structures may have one of the three basic configurations: horizontal, vertical, or delta, depending on the arrangement of the phase conductors.” (Fang et al., 1999, Introduction and Application, p. 1)

The Grid Structure

According to the German transmission system operator (TSO), 50 Hertz, the electricity grid is divided into four levels. (50 Hertz, 2020b)

1) The Extra High Voltage Grid (220 kV to 380 kV)
2) The High Voltage Grid (110 kV)
3) The Medium Voltage Distribution Grid (3kV to 30 kV)
4) The Low Voltage Distribution Grid (230 V or 400 V)

Moreover, renewable energy projects can be connected to all of the above levels depending on how large their capacity is. For example, large renewable energy projects like off-shore and on-shore wind energy projects as well as large hydroelectric and pumped storage power stations are connected to the Extra High Voltage Grid. The High Voltage grid can accommodate medium renewable energy installations such as on-shore wind energy turbines and large scale photovoltaic installations in addition to medium sized hydroelectric and pumped storage power stations. Smaller renewable energy installations that can be in the form of on-shore wind energy turbines, photovoltaic arrays, rooftop installations, biomass plants, and small scale hydroelectric and pumped storage power stations can be connected to the Medium Voltage Grid. Finally, the Low Voltage Distribution Grid can also be fed electricity produced by small renewable energy installations such as on-shore wind turbines and household rooftop installations as well as small decentralized power stations such as CHP plants. (50 Hertz, 2020b)

Formulating the Research Question

General Conditions

As described above in the background information, the regulatory structure and the grid connection procedure are different in the three countries of interest. For one, it is clearly stated in German regulation that priority is given for renewable energy projects to feed into the grid and that grid operators are by law obliged to optimize and boost network capacity in order to accommodate the new renewable energy projects. In France and Switzerland, although grid operators are obliged to be non-discriminatory by law, there is no priority given to renewable energy projects over other types of projects. Moreover, even in Germany, where priority is given to renewables, in reality, as observed by our expert, renewable energy projects don't always succeed in entering the grid at maximum capacity. What can also be observed is that the grid connection in Germany is decentralized and the steps to be followed are clearly stated in the EEG while in Switzerland and France, the deciding authority is the TSO (Swissgrid and RTE respectively) and the process has a more centralized structure. In general, it can be noticed from the regulatory structure and expert advice, that in the three countries, a large part of the responsibility of connecting to the grid lies on the plant operator. The plant operator also has to cover the larger part of the costs of connecting to the grid as well as the planning of the project.

Assumptions

The following conditions led to the three assumptions described below:

1) The grid connection procedure can vary from project to project and from country to country because each project is evaluated on its own before entering the grid. The projects can also vary in terms of capacity and by referring to the structure of the grid, the prospective renewable energy projects can be connected to all four levels depending on their production capacity. In the case of the estimation for the URR, there isn't one specific project (with defined borders and a specific capacity) to be evaluated.
2) The study of entering the grid consists of an extensive analysis of the specific conditions and energy flows and is performed at a regional level generally and more specifically, at a project level meaning that the project's capacity and exact location has to be known.
3) The renewable energy potentials in the URR found in Report 2.1.1 are mapped according to their usable area. The usable area is spread out continuously over the whole URR region and not in the form of discrete clusters that constitute possible projects at specific locations.

   <u>Assumption #1</u>

   Because the potentials are depicted in the form of a continuous area and not in the form of project clusters (each with specific capacity and defined borders related to each) that can be matched to a certain grid level. Moreover, it is in this case not possible to perform a regional evaluation of the energy flows. Therefore, the study of the proximity of the RE potentials to the grid had to be done statistically.

4) There are no specifications in each of the three countries that determine the minimum or maximum distances that a prospective project should have from the grid in order to be executed.

   <u>Assumption #2</u>

The distances that are chosen in the methodology are based on assumptions that were picked logically but at random in order to evaluate the proximity of the potential to the grid

5) The data available for the structure of the regional grid is a mapping of the different point components of the grid (substations, transmission structures, and transformers) as described in the background information section.

   Assumption #3

   The grid was assumed to be a sum of its different point components as described in the methodology.

Research Question

The research question in this case is:

Given the above general conditions and assumptions, how can one evaluate the proximity to the grid of the unused RE potentials?

Methodology

In order to study the proximity to the electricity grid of the potentials calculated in Report 2.1.1, a statistical method was used to calculate the distances that separate the RES potentials from the grid. This method views the grid as a grouping of its different point components (poles, towers, substations) and the RE potential as land area that is spread out within the entire study area. Substations and transformers are considered together because most transformers are found in substations.

By computing the area of the previously found potentials that is located in the vicinity of these different point components, it is possible to draw certain observations about the proximity of the unused renewable energy potentials to the grid.

As a first step, a buffer was created around the different grid components (poles, towers, substations) at different distances (500m, 1 km, 2km) to create four proximity zones per grid component where:

1) Zone A: Usable areas situated in this zone are located within 500 m or less from the closest grid connection point
2) Zone B: Usable areas situated in this zone are located within 500 m to 1km from the closest grid connection point
3) Zone C: Usable areas situated in this zone are located within 1 km to 2 km from the closest grid connection point
4) Zone D: Usable areas situated in this zone are located more than 2km away from the closest grid connection point.

In figure 1, 2, and 3, the four proximity zones (A, B, C & D) are depicted around each grid component (poles, towers, & substations respectively) to indicate the significant areas in this study.

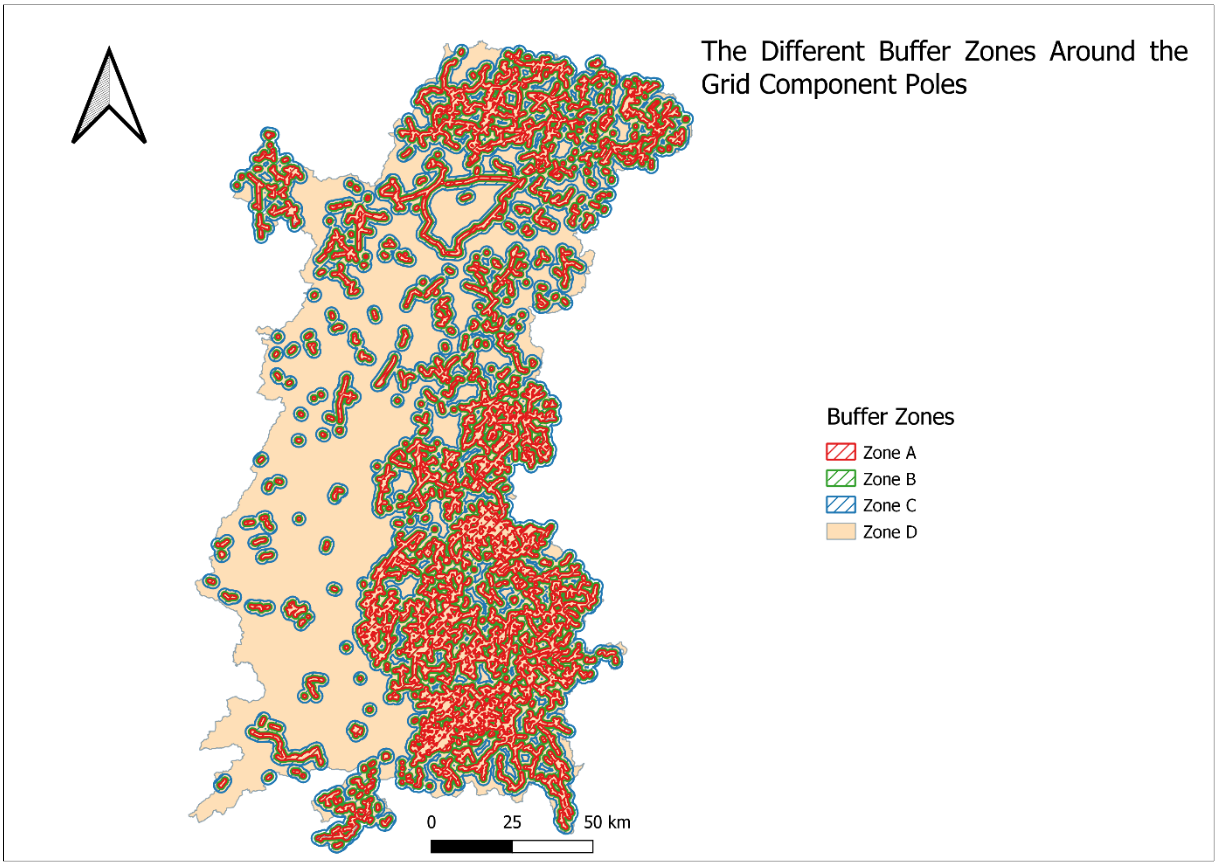


Figure 4: Buffer Zones around the Poles

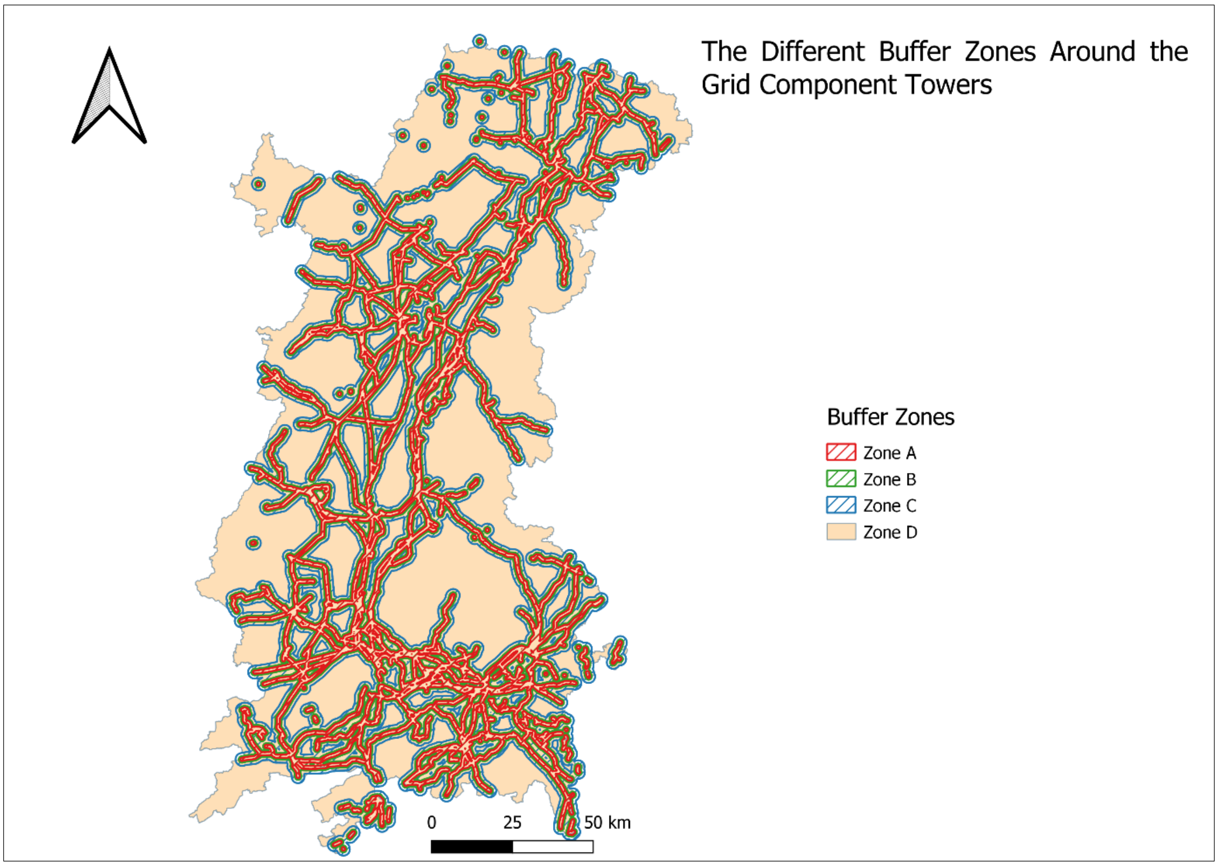


Figure 5: Buffer Zones around the Towers

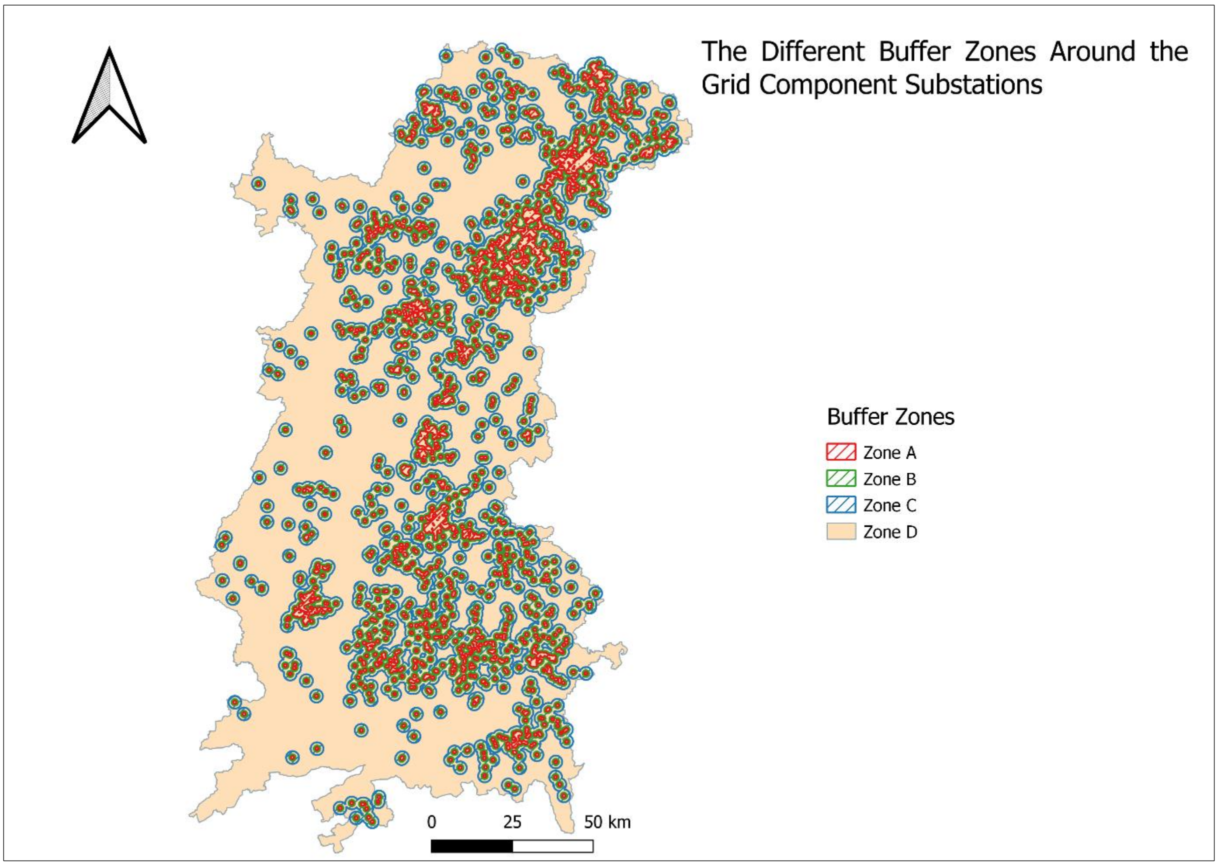


Figure 6: Buffer Zones around the Substations

At this point, the zones of the grid components are analyzed individually. Taking as an example the towers that are part of the electricity grid, the method is as follows:

a) The area of the four proximity zones (Zones A, B, C, & D) mapped around the towers is intersected with the usable areas of each RE source, wind, solar PV (Agro-PV, Ground-mounted PV, and Rooftop PV). The resulting intersection area constitutes the usable area situated in each zone. The figures below illustrate the example of the proximity zones around the grid component towers. The same method is repeated for the other two grid components. In figures 7, 8, 9, & 10, an example of the results of the grid component towers is portrayed. Figure 7 shows RE potential for each source (GM-PV, Agro-PV, Wind, & Rooftop PV) located in Zone A around the towers. Figure 8 shows the RE potential around Zone B. Figure 9 shows the RE potentials located in Zone C and Figure 10 the RE potentials of Zone D around the grid component towers.

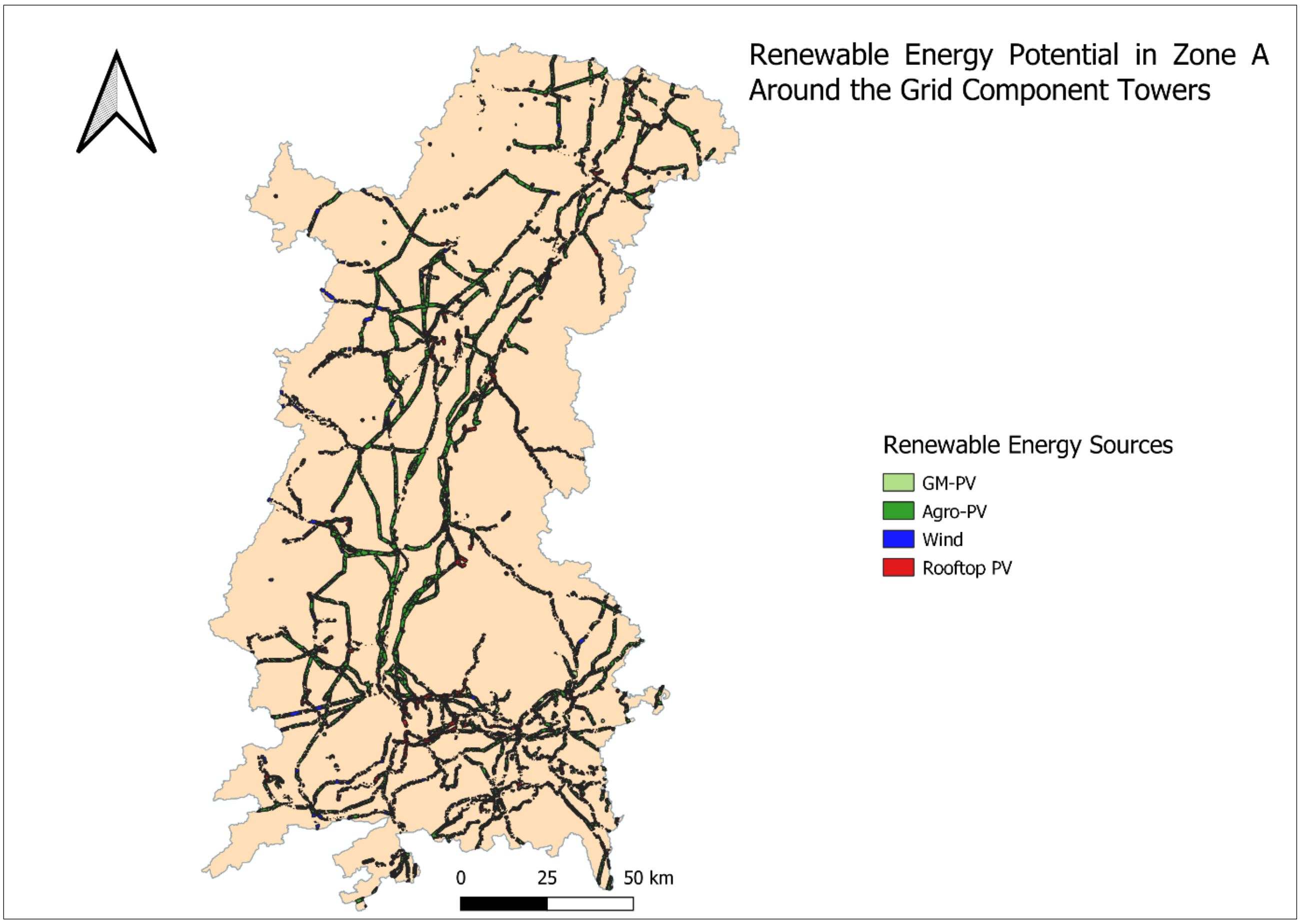


Figure 7: RE Potentials in Zone A around the Grid Component Towers

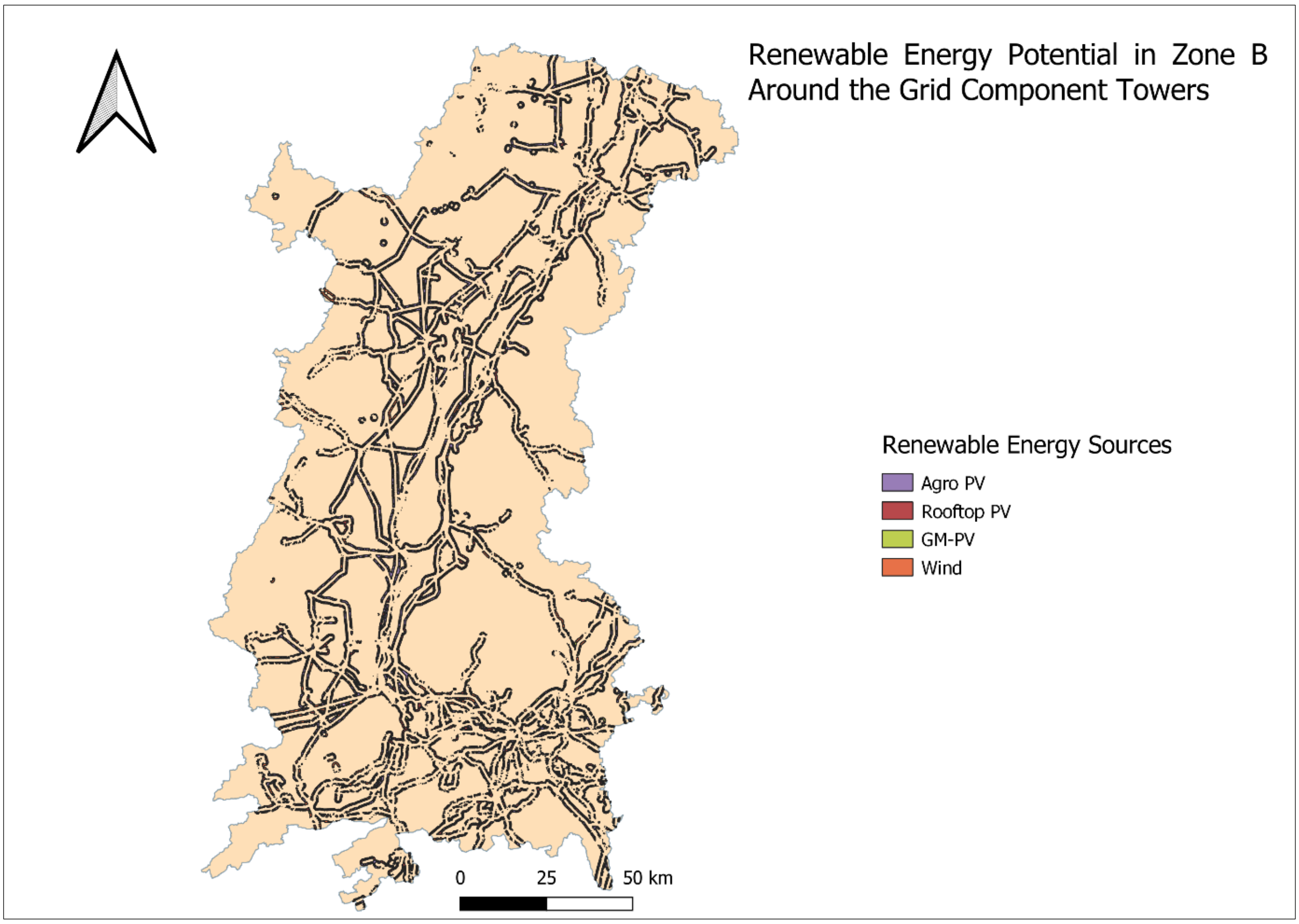


Figure 8: RE Potentials in Zone B around the Grid Component Towers

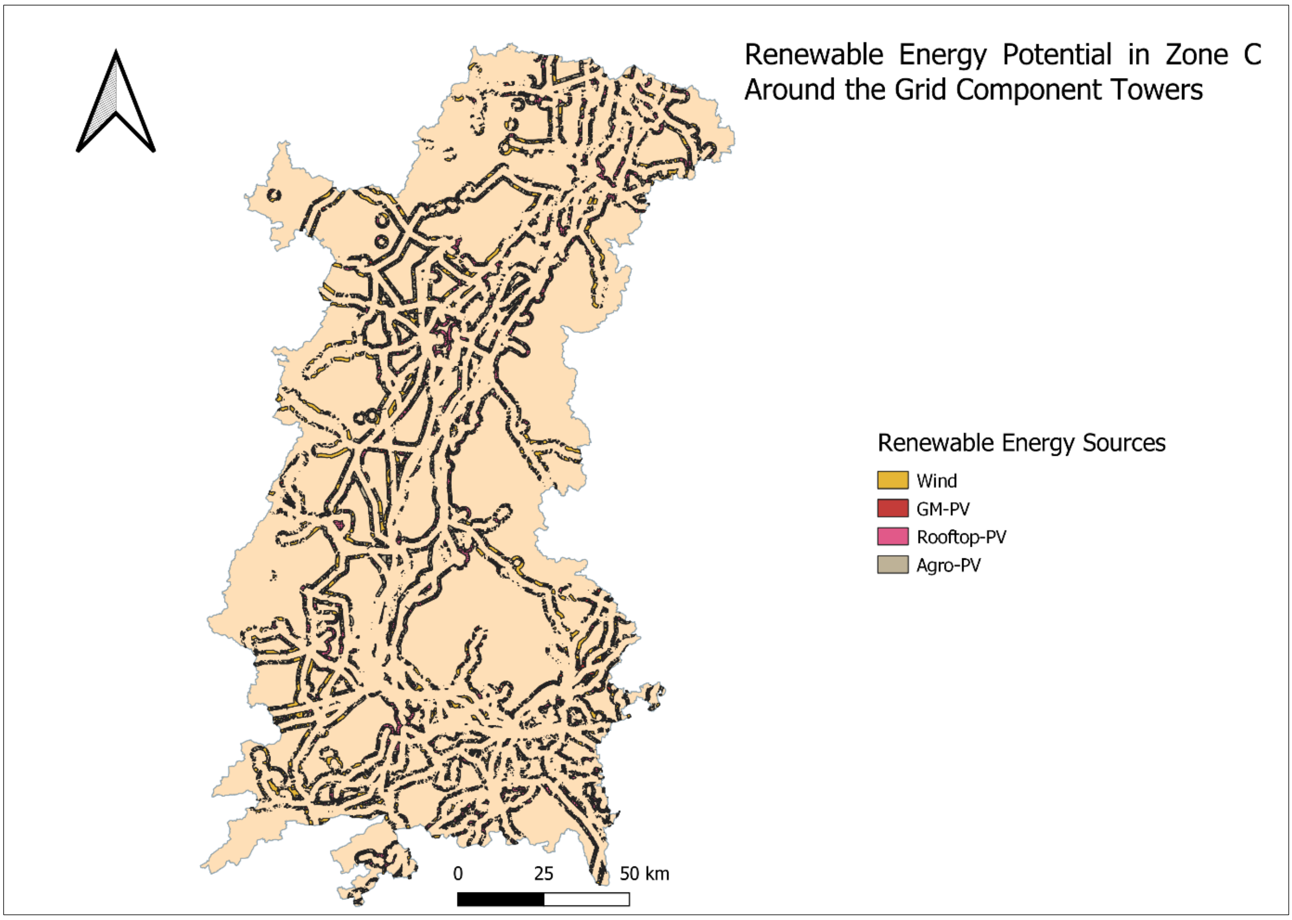


Figure 9: RE Potentials in Zone C around the Grid Component Towers

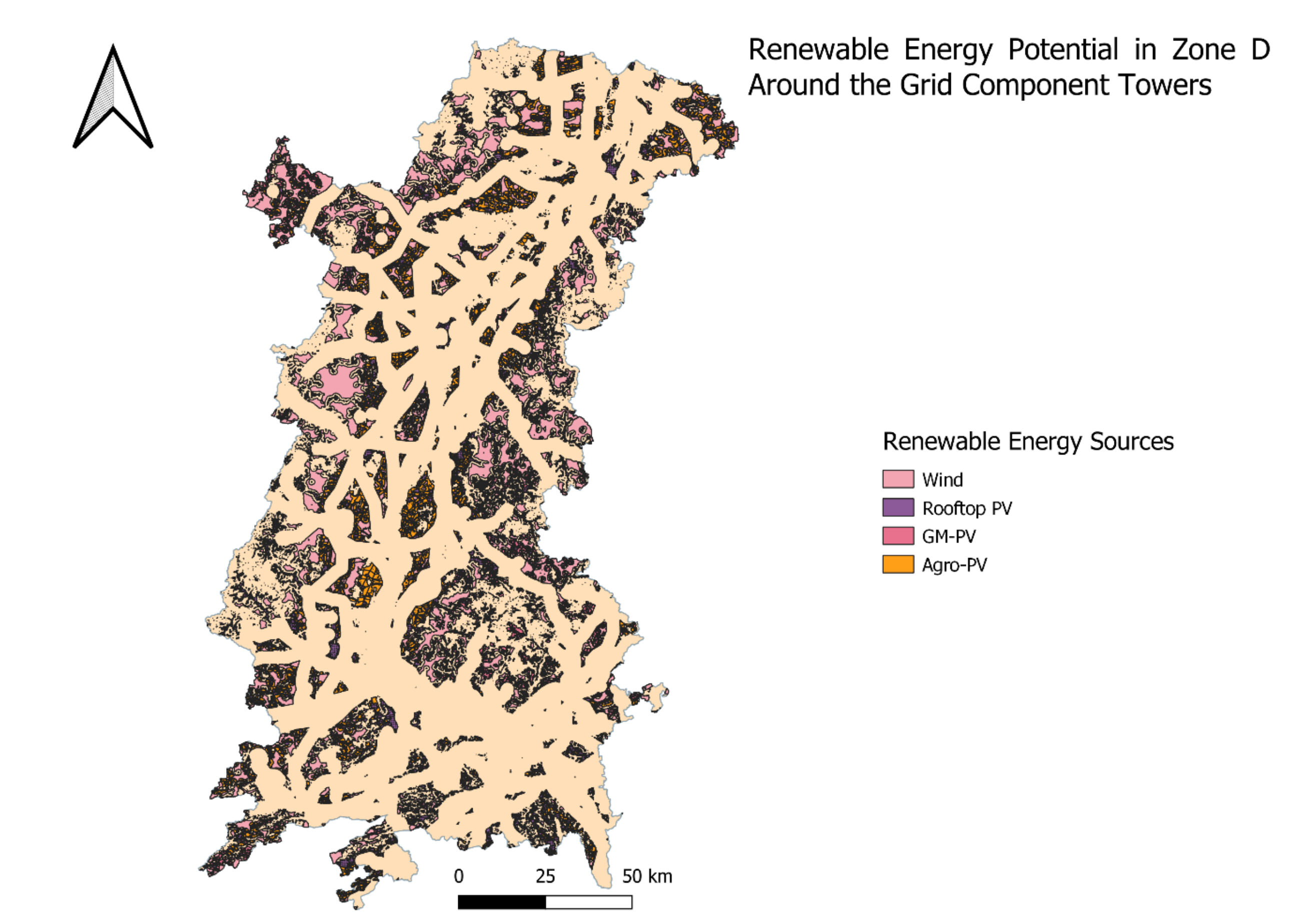
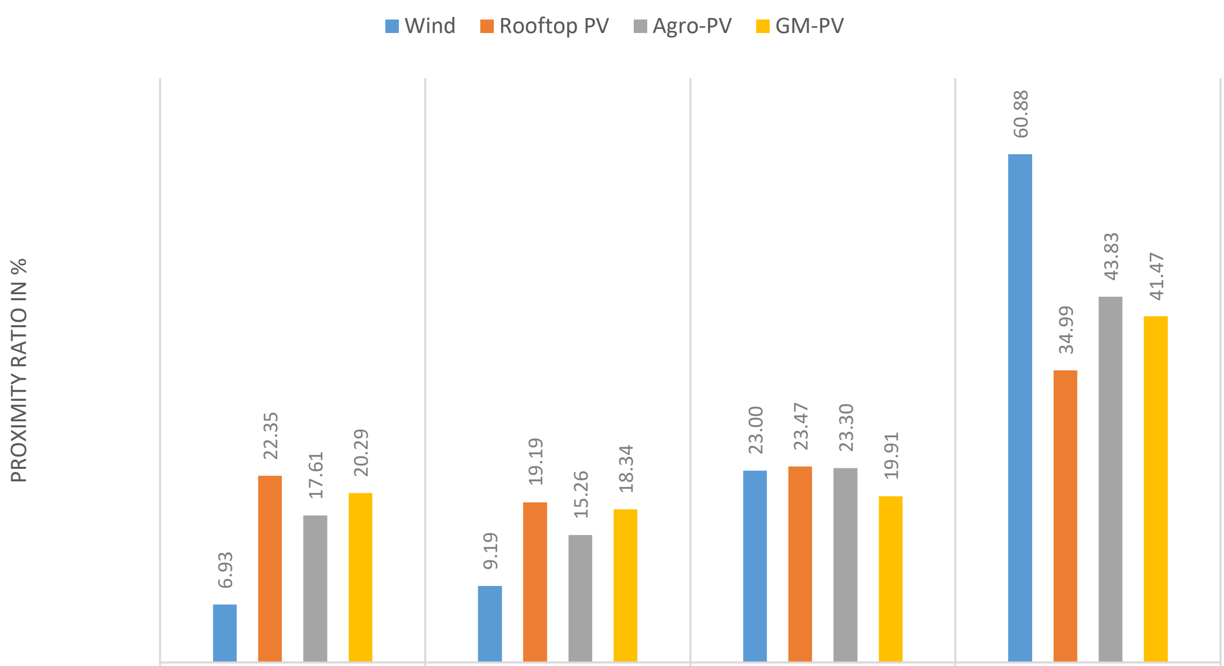


Figure 10: RE Potentials in Zone D around the Grid Component Towers

b) For each combination of zone (A, B, C, & D) and RE source (wind, solar PV (Agro-PV, Ground-mounted PV, and Rooftop PV)), the resulting area of the intersection is divided by the total usable area of the RE source and the obtained ratio (named the proximity ratio) is given in %. The proximity ratio is calculated with respect to the overall usable area of the renewable energy source. Therefore, it depicts the ratio of area found in the buffer zone with respect to the total area, per renewable energy source and grid component, in %. Larger values of the proximity ratios do not translate into a larger usable area in the proximity zones but rather it means that a larger portion of the total usable area of the RE source is found within the proximity zones.
c) After calculations are finished for each grid component, average values for the proximity ratios are calculated and the results are presented in terms of overall grid proximity to the different RE sources.

Results

Figure 11 depicts the results obtained using the methodology described above. In general, it can be observed that the largest areas of potential are located in Zone D. It is observed that the wind potential has the least percentage of area located in Zone A and Zone B while rooftop PV shows the largest percentages in Zone A and Zone B. Rooftop PV is followed by GM-PV that has the second highest percentages in the first two zones. Wind, rooftop PV, and agro PV exhibit comparable percentages in Zone C (approximately 23%). In general, solar PV potentials have more area located in the first three zones (meaning that their area is mostly located less than 2 km away from the grid) while the area available for wind is mostly (60%) located more than 2 km away from the grid. Of the three types of solar PV, Agro-PV has the highest percentage in zone D while rooftop PV and GM-PV are generally closer to the grid.



	Zone A	Zone B	Zone C	Zone D
Wind	6.93	9.19	23.00	60.88
Rooftop PV	22.35	19.19	23.47	34.99
Agro-PV	17.61	15.26	23.30	43.83
GM-PV	20.29	18.34	19.91	41.47

PROXIMITY ZONES

Figure 11: Table Comparing the Proximity Ratios of the Different Grid Components

Discussion

Limitations

The limitations to the method described above are:

a) The grid component transformers are mostly found in substations; however, the study shows that there are some free standing transformers. The method was also performed on the free-standing transformers alone, but they were then excluded because the results obtained were inconclusive mainly due to their low number.

b) There is no differentiation between the different substation types that are mentioned in the grid component definition part in the grid data used for the study.

c) For rooftop PV, the usable area mapped is a bit larger than the actual exploitable rooftop area due to the effect of the roof utilization factor mentioned in Report 2.1.1., which portrays the "share of the roof area may be used for PV installations, due to constructional constraints like chimneys, ventilation systems, antennas etc." (Mainzer et al, 2014, p. 719). For this study however for computational reasons, the usable area was used.

d) It can be observed that the French part of the URR (from Figure 1, 2, & 3) has fewer poles on its territory than Germany or Switzerland, which can be related to how the French grid is structured.
e) Because the grid components are taken individually, the method does not account for intersections in the buffered land around each component so the proximity ratio is calculated for each grid component and RE source and then average values are computed accordingly.

Conclusion

When it comes to the potentials, it can be concluded that solar PV has larger potentials located closer to the grid than wind energy does. Within solar PV, the closest to the grid is rooftop PV followed closely by GM-PV, while Agro-PV is the farthest solar PV type from the grid. The logic behind the results is that rooftop PV is concentrated in cities or buildings that are usually well connected to the grid (or in close proximity to the grid) while GM-PV and Agro-PV are found in arable areas that do not necessarily have to be in close proximity to the grid. The results also seem to indicate that the wind energy potential usable area is the farthest away from the grid.

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