RES-TMO

Report 2.1.1.

Representation of RES Potentials in the Upper Rhine Region

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

This first deliverable of RES-TMO for work package 2 describes the detailed methodology used to calculate the renewable energy potential in the Upper Rhine Region and displays the results obtained including a mapping of renewable energy potentials, separated into previously used and unused potentials.

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The following deliverable is made up of two parts:

1) Part 1 explains the methodology and results of the preliminary potential calculations
2) Part 2 validates and refines the technical potential estimation. It was completed at a later stage of the project

Part 1

Preliminary estimation of the technical potentials

Introduction

To put electricity into context: Electricity accounts for around 21% of the final energy consumption in the EU (European Commission, 2019a). The EU energy mix in 2019 was made up of petroleum products (36.3%), natural gas (22.3%), solid fossil fuels (12.7%), renewable energy (15.5%) and nuclear energy (13.1%) (European Commission, 2019b).

In 2017 the energy sector – fuel combustion and fugitive emissions from fuels (excluding transport) accounted for 54% of total greenhouse gas (GHG) emissions. The second largest sector was transport (including international aviation) which accounted for 25% and increased considerably from 15% in 1990. (Eurostat, 2017)

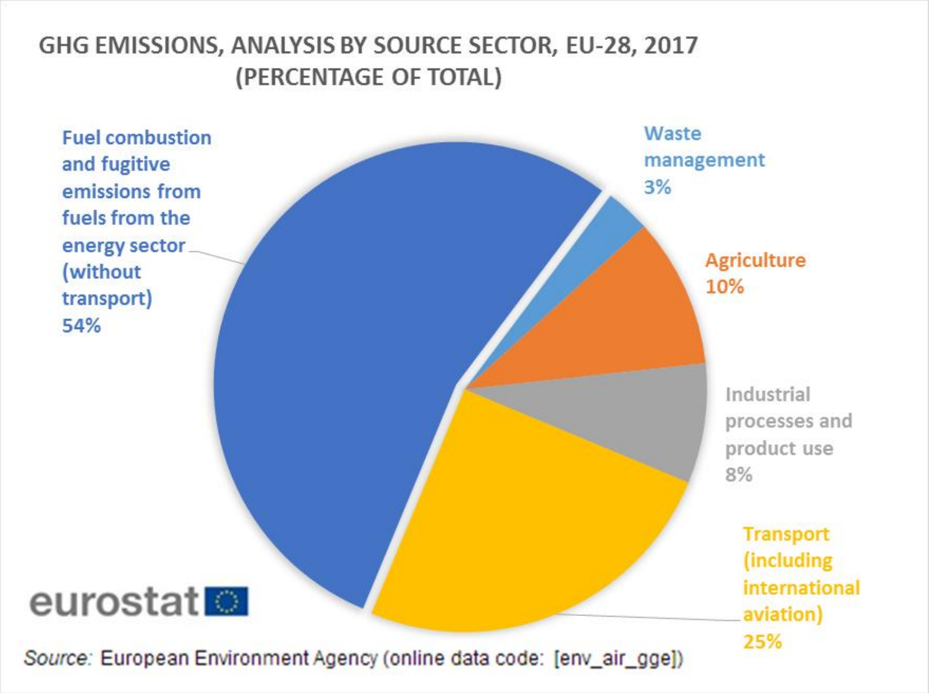

Figure 1: EU-28 GHG Emissions by Source in 2017 (Eurostat, 2017)

Defining the Different Potentials

In order to understand the methodology used, it is important to define what is meant by the different types of potential. The following definition relies on Jäger et al. (2016). The different types of potential are theoretical, geographic, technical and economic respectively. Moving from the theoretical to the economic potential, the complexity of calculating the potential output increases incrementally. Their precise definition is stated below:

The *theoretical potential* is the amount of energy that is theoretically supplied by the wind or the sun in a specific region at a certain time. For calculating the theoretical renewable energy potential, data about the atmospheric conditions, in particular wind speed and solar radiation, and its temporal and spatial resolution are of great importance. In this case, the Upper Rhine Region is characterized by the Rhine valley, enclosed by the mountainous regions of the Vosges in the east and the Black Forest in the west. On the southern edge are the foothills of the Jura in Switzerland. Consequently, the orography of the investigation area is complex which adds to the complexity of modeling the wind speed for example. The *geographic potential* describes the usable area for the generation of renewable energy. It takes into account competing land uses such as urban agglomerations or nature protection areas and legal restrictions depending on the regional law. In the Upper Rhine Region, merging all regional regulations is a challenging task due to its tri-nationality. Even within the same country (especially Germany and Switzerland), the regulations are varying due to the federal structure and legislation. Furthermore, the legal restrictions might differ depending on the energy source due to energy source-specific requirements (e.g. distance constraints to wind turbines).

The *technical potential* additionally takes into account technical constraints limiting the theoretical energy yield like conversion efficiencies of PV modules and wind turbines. Numerous parameters shape the technical potential. Consequently, the complexity of the applied model to estimate the technical potential heavily determines the accuracy of the resulting potential. The conversion efficiency of PV modules or wind turbines is determined by wind turbine-specific or PV module specific power curves (Huld, 2017 & Jung & Schindler, 2018). For wind energy, the air density is an additional parameter shaping the energy yield (Jung & Schindler, 2019). Moreover, wake effects, such as turbulence and reduced wind speed, determine the technical wind energy potential. The technical PV energy output is among others influenced by the reflectivity of the PV module itself, which is related to the solar angle of incidence, the PV module temperature that is depending on the surrounding temperature and the prevalent surface wind speed (Huld, 2017).

The *economic potential* is the technical potential that is economically feasible within a specific region and a certain time range. The final stage of the potential hierarchy is the *feasible potential*, additionally taking into account the organizational and social dimension. This includes for example the society's acceptance of wind turbines in specific areas related to noise pollution or aesthetic landscape aspects, elements addressed in WP4 of the project.

Expert Opinion

The Regulatory Environment

In order to overcome the tri-nationality hurdle, expert opinion was resorted to in order to understand not only the specific regulatory environment related to each country but also the reality of it.

Switzerland

Dr. Wieland Hintz, a renewable energy specialist working at the Swiss Federal Department of the Environment, Transport, Energy and Communication (UVEK) at the Federal Office for Energy (BFE) attested that when it comes to PV in Switzerland, because of the strict land protection rules, it is very hard to acquire a building permit for a GM (ground-mounted)-PV or an Agro-PV project. Moreover, there are currently no national regulations for feed-in tariffs which makes the most favorable implementation of PV on top of buildings and structures, for the operator's own use. To this day, all PV installations are rooftop installations. The strict land-use regulations also hinder the propagation of wind farms, and in fact there are less than 40 windfarms in the whole of Switzerland. In fact, it was noticed that in the Swiss part of the URR, there is not one GM-PV or Agro-PV installation and only three wind farms. (TRION-climate, best practice map). Also according to Dr. Hintz, the contents of a position paper about solar PV that was collaboratively published in 2012 by the Federal Office for Spatial Development (ARE), Federal Office for the Environment (BAFU), Federal Office for Energy (BFE), and Federal Office for Agriculture (BLW), are still valid today. The position paper comes to three conclusions: the first is that as long as enough expansion potential on buildings and facilities exists, this potential should receive priority. The second is that a GM-PV project shouldn't be established other than exceptionally because of certain reasons including land use conflicts. Finally, GM-PV should be regulated in utility plans (*Nutzungsplänen*) and if a project is to be exceptionally established, it should be addressed in the Cantonal structure plan. (ARE et al., 2012) Moreover, because rooftop PV is important for the Swiss, there is a governmentally developed website, Sonnendach, (www.sonnendach.ch) that can calculate the rooftop PV potential of any building in Switzerland by taking as input the building's address.

France

Dr. Melis Aras is a postdoctoral researcher and lecturer at the University of Strasbourg and contributor to the RES-TMO project. She explains in one of her lectures that when it comes to the establishment of renewable energy projects in France, the requirements are: as a first step acquiring a building permit where each project is examined on a case to case basis and each project should conform to the legal regulations specific to its location. The rules that apply in general are that the project should have minimal effect on the environment, the landscape, and protected sites and respect the public utility easements and other administrative easements as well. The project should also respect the regulations related to the urbanism, environment, and energy codes. The urbanism code requires the respect of general and particular urbanism rules and documents. The environment code regulations require the commissioning of an environmental evaluation report and a public enquiry. The energy code requires the connection to the transmission network and verification that the source of electricity is renewable. The project must respect and comply with the local urban document that is implemented which can be the PLU, the local plan for urbanism, communal map or in the case where the first two documents are not found then by default the RNU, the national regulation for urbanism. The PLU for example divides the land into different zonal categories and attests that the installations should not be implemented on an agricultural zone or a terrain used for agriculture. For the French part of the URR for example, the PLU of Colmar and Strasburg only was found as GIS data on a governmental website, Géoportail de l' Urbanisme. (https://www.geoportailurbanisme.gouv.fr) Article L.161-4 of the communal maps also states that the installation should not be in conflict with an activity that is related to agriculture, pastoral, or forest activities. The RNU states that the project should be situated in continuity or discontinuity with already existing urban structures and outside the areas that are of agricultural value or not well equipped, or exploited land where the installation could jeopardize agricultural or forestry activities.

Germany (Baden-Württemberg)

The German state of Baden Württemberg has clear criteria in the form of a published criteria catalog when it comes to solar and wind energy and the areas that are suitable for the establishment of a wind or solar farm. The criteria catalog clearly defines hard restriction areas, which are considered forbidden zones for the propagation of wind and solar projects, and conditionally or partially restricted zones that can be utilized in theory. For solar, they also mention favorable zones such as disadvantaged municipalities (in general where the soil is not suitable for agriculture) where it is encouraged to invest in a PV project. The "disadvantaged areas" according to German law are the acceptable areas for bidding on the development of a ground mounted PV project. The restrictions and other relevant information for renewable energy are included on the website Energieatlas Baden-Württemberg. (https://www.energieatlas-bw.de/)

Germany (Rhineland-Palatinate)

Rhineland-Palatinate also has certain conditions for wind and solar PV project dissemination that can be found on the Energieagentur Rheinland Pfalz's website (https://www.energieagentur.rlp.de/). In the case of wind, technical and regulatory information are published. Moreover, the location of less-favored or disadvantaged areas that are favored by regulation when it comes to free-range PV are specified as in the case of Baden-Württemberg. Other related documents such as nature protection guidelines from NABU (Naturschutzbund Deutschland) are also published, however, though the published information is relevant, Baden-Württemberg's Criteria Catalog constitutes in comparison a more structured guideline with well-defined restriction categories and buffer distances.

Assumptions

Unlike the theoretical and technical potentials, which transcend international boundaries, the tri-nationality of the study area translates into a tri-national regulatory environment, which affects by definition the geographical potential. The geographical potential by definition should take into consideration the areas that are by regulation classified as inadequate for the dissemination of renewable energy projects. Because the study area comprises three different countries with their own regulatory environment and structure, there is a large disparity in the quality and quantity of publicly available information.

The geographical potential entails the calculation of the usable area, which is source-dependent and calculated separately for the different sources of renewable energy: wind, rooftop PV, and free-range PV. In the case of wind energy and free-range PV potential, the usable area is the area that remains after subtracting the restricted areas for each source such as residential or protected areas and their distance buffers from the total area of the URR. The distance buffer simply takes into consideration the distance that must be respected between the possible renewable energy project sites and the different restricted areas such as cities and roads. In the case of rooftop PV, the usable area is the area of the rooftops in the URR. Moreover, because the geographical potential is closely related to competing land uses, taking it a step further, free-land PV can also be divided into two types of potential that require different land-use area types: conventional Ground-Mounted (GM)-PV and Agricultural (AGRO)-PV. The potential of GM-PV and Agro-PV is calculated by dividing the remaining usable area for free-range PV further and accounting for the type of land-use pattern.

As stated by the experts above, in Switzerland, there are stringent regulations and no clear guidelines when it comes to wind energy and ground-mounted (GM)-PV projects and in France, the evaluation of renewable energy projects happens on a case-to-case basis. On the other hand, the criteria published by the state of Baden-Württemberg establishes clear and concrete guidelines that can be used to determine the areas where wind or solar dissemination would not be favorable. Therefore, for solar PV and wind energy, the BW criteria catalogs were used in the mapping of the restricted areas and consequently the available usable area. In this way, the methodological framework is more homogeneous and comparable between the three countries.

The Study Area

According to Schumacher et al. (Eds.) (2017), the land use categories that can be observed in the URR show a particular spatial distribution which is modeled by the topographic structure of the region. Some of the URR's distinguished topological features that can be observed are:

1) Approximately 37% of the URR area is used by agriculture.
2) "Arable land is concentrated on the flat of the Rhine valley" (Schumacher et al. (Eds.), 2017).
3) "Permanent grassland is generally located in the mountainous regions and along the rivers" (Schumacher et al. (Eds.), 2017).
4) "Viticulture represents only 2% of the total surface, but remains an important economic sector for the URR. The main occurrences of viticulture are on the slopes of the Black Forest, the Vosges and the Kaiserstuhl" (Schumacher et al. (Eds.), 2017).
5) "Forests cover the highest percentage of the land, with about 43% of the total URR area. They are mainly located in mountainous areas such as Black Forest, Vosges and Jura. Broad-leaved forests are relatively rare in the Black Forest with 10% land cover, but more extensive in the Vosges with 19%. Conifer forests are inversely more important in the Black Forest (18%) than in the Vosges (9%)" (Schumacher et al. (Eds.), 2017).
6) "The main urban agglomerations are Karlsruhe, Strasbourg, Mulhouse, and Basel" (Schumacher et al. (Eds.), 2017).
7) "The URR has relatively favorable climate conditions. Warm and humid air masses from the Mediterranean coming through the Belfort Gap influence the local climate. In addition, thanks to its distance from the Atlantic, the Rhine Graben is situated in a transition zone between oceanic climate and continental. This is characterized by an

annual mean temperature around 10°C in most of the Rhine valley." (Schumacher et al. (Eds.), 2017).

Methodology

Wind

The mountainous terrain and orographic complexity of the study area requires a high-resolution grid and a high temporal resolution, in order to capture the small-scale features of the wind distribution, a process that needs enormous computational resources. Therefore, the wind energy potential is based on data from the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017). It is a statistical wind model that uses data from meteorological stations of the national weather services as input for its calculations. Using statistical methods, the long-term median wind speed is mapped on a high-resolution grid of approximately 250m x 250m. Using this information, conclusions about the geographical variations of the wind energy potential in the Upper Rhine Region can be drawn. The model provides reasonable results for long-term annual and monthly averages of wind speed. However, the methodology is limited in its reliability on long term time scales and doesn't take into account the more detailed inner daily variability.

In the calculations of wind potential, Grau et al. (2017) aptly and descriptively name the broadest potential category (the theoretical potential), the meteorological potential (MP), because it depicts the "available kinetic energy contained in the atmosphere over an area" which can be assessed by the wind power density (WPD in W/m^2). Therefore, the first step of calculating the MP requires the calculation of the WPD which is mathematically related to the wind speed. Therefore, the monthly measurements of wind speed taken from 64 meteorological stations are spread out over the period 1 January 1980 to 31 December 2018. The wind speed data sets often contain gaps in certain timeframes or illogical values and so, in order to assure the comparability of the measured data, we used data preparation methods such as gap filling, testing for homogeneity, and de-trending. The result is the yearly and monthly median wind speed value over the entire period. The median wind speeds were then extrapolated to the three chosen hub heights (120m, 140m, & 160m) by using the Hellmann power law. The WPD at the level of the three chosen turbines was calculated by using the resulting wind speed values. Furthermore, based on Manwell et al. (2009), potential wind turbine sites can be classified according to the available wind power density into three categories:

1) WPD < 100 W/m^2 is considered inappropriate
2) WPD ≈ 400 W/m^2 is considered as appropriate
3) WPD > 700W/m^2 defines regions of great wind power resources

By classifying the study area according to the three WPD categories described above, the meteorologically suitable areas are found.

The meteorological potential is limited by the geographic potential which takes into consideration the restrictions related to orography and competing land use which are specified by legislation. The geographic potential was estimated by defining the restricted areas in the total study area. After that, the restricted areas were subtracted from the total study area and the usable area for wind dissemination was left. The Baden-Württemberg criteria catalog was used as a reference for the calculations of the restricted area.

Finally, the technical potential is calculated. The technical potential minimizes the geographic potential by factoring in turbine efficiency in the conversion of the kinetic energy found in the usable area into electrical energy (kWh/year). (Grau et al., 2017) In the literature, Jung (2016) describes in detail the steps to calculate the Annual Energy Yield (AEY) estimation by using power curves.

The GIS raster files used for the calculations are taken from the raster files developed for the Master's thesis, Wind Energy Assessment in the Upper Rhine Region submitted in 2020 by Michael Chimeremeze Ezem. The author used the measurements of 64 weather stations, divided over the three countries, for surface wind speed to calculate the meteorological potential in the study area based on the wind speed wind shear model (WSWS) developed and described by Jung & Schindler (2017).

Solar PV

Rooftop Potential

The possibility of placing PV panels on building roofs (PV rooftop potential) offers a large potential for electricity production. Compared to the free-land PV energy potential, the rooftop potential does not evoke land use conflicts, resulting in a higher public acceptance (Mainzer et al., 2017).

For the theoretical energy potential, the software package PVMAPS was used to calculate the solar irradiation. The package uses a combination of observational satellite data for the solar radiation (Surface Solar Radiation Data Set – Heliosat [SARAH] – Edition 1) and the digital elevation model (Shuttle Radar Topography Mission, Farr et al., 2007) and reanalysis data of temperature and wind speed (ECMWF ERA-Interim). PVMAPS take into consideration factors that affect the power generation of solar modules such as: air temperature, wind speed data, and the content of water vapor and aerosol in the atmosphere. Moreover, the software also takes into account terrain elevation, a factor which is important in the determination of clear-sky radiation and the more accurate calculation of the air temperature. (Huld, 2017) The generated rasters depict average yearly global irradiation in Wh/m^2 received by the URR and can be calculated based on the inclination angle of the solar panels and their orientation. The choice of orientation and inclination angles were determined by assumptions related to the geographical potential and are discussed below.

The geographical potential consists of roof areas, so buildings in the URR were extracted from Open Street Maps (OSM), clustered, and mapped; consequently, an estimation of the ground area of buildings and number of buildings per municipality was obtained. It was important for buildings to be clustered together because taking individual buildings into account results in large files that often lead to problems and computational errors. It was assumed that the ground area of the buildings is equal to the roof area. Mainzer et al. (2014) developed a method for solar PV rooftop potential calculation and used it to perform a high resolution estimation of the residential rooftop PV potential in Germany. The method described below to calculate the geographical and technical potential is based on the one used by Mainzer et al. (2014).

Roofs can be of different shapes and types such as flat or slanted, which in turn can have many different orientations (north, south, east, west, north-east, north-west…) and inclinations (with respect to a flat surface). It was assumed that the roof orientation is evenly distributed, meaning that it is equally likely for a roof to be oriented in each considered direction. The orientation of the roof and consequently the PV panels starts at 0 degrees and is incremented by 15 degrees until 270 degrees (south) is reached. The inclination angles are considered to follow a Gaussian or normal distribution with a mean of 44 degrees and a standard deviation of 7 degrees as shown in the figure below. (Mainzer et al., 2014)

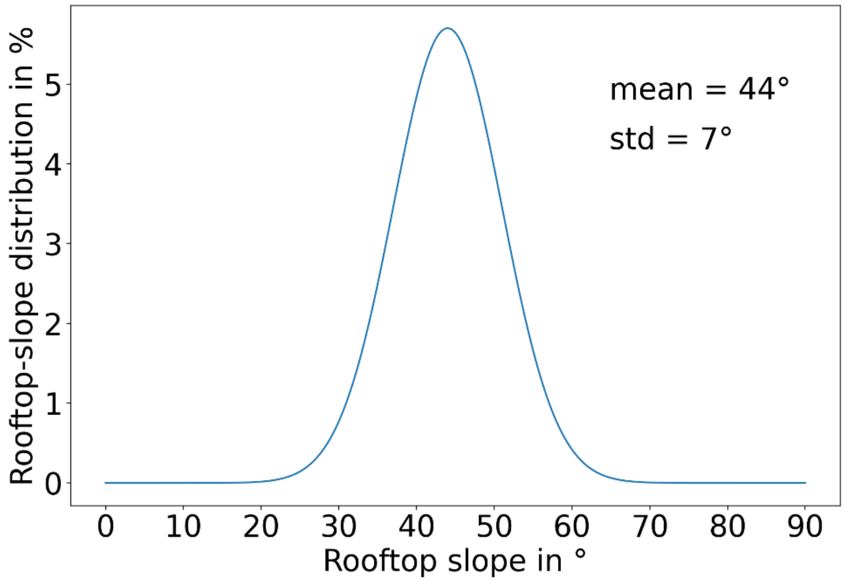

Figure 2: Gaussian distribution of inclination angles as per Mainzer et al. 2014

Unlike Mainzer et al. (2014), in this study, GIS data and not statistical data was relied on for obtaining the available roof surface area, so flat surfaces are not considered on their own in the calculations, but rather as a smaller part of the inclined surfaces because of a lack of data. Moreover, it was assumed that PV panels on a flat roof would be more likely to be optimally tilted in order to maximize the yield and could be a type of inclined roof.

The inclination angles start at 0 (flat surface) and are incremented by 10 degrees until 90 degrees (perpendicular to a flat surface) is reached. All possible combinations of orientation and inclination are considered together and are generated by using the PVMAPS package resulting in different maps depicting solar irradiation. Applying the generated solar irradiation maps to the available roof area (usable area in this case) results in the geographical potential of rooftop PV in the URR. The last step of the geographical potential is factoring in the roof utilization factor, which accounts for the "share of the roof area that may be used for PV installations, due to constructional constraints like chimneys, ventilation systems, antennas etc." (Mainzer et al, 2014, p. 719). The roof utilization factor has been estimated by many previous studies. Mainzer et al. (2014) proposes that this factor be considered 58 % for slanted roofs. In comparison to those from previously conducted studies, it is larger than average values because no orientation direction is excluded.

The final step is the calculation of the technical potential which can be achieved by factoring in the technical parameters of the polycrystalline silicon solar cell installations, the most used type so far, such as average module efficiency (14.5%) and the performance ratio (85%). The output of this stage is the energy produced (in Wh/year) by the rooftop PV panels. (Mainzer et al., 2014)

GM & Agro-PV Potential

GM-PV is considered one of the most competitive sources for energy production worldwide and the demand for it is continuously increasing regardless of the decreasing availability of land or its acceptability with respect to rooftop-PV. In order to avoid future economic, social, ecological and political conflicts, one of the proposed solutions to solve land use conflicts and competition evoked by GM-PV is to resort to Integrated Food-Energy Systems (IFES) which allow the simultaneous production of energy and food. One solution is the use of Agro-photovoltaics (APV). In Germany, there are so far eight Agro-PV power plants, three of which are used for research purposes. Meanwhile, France has already implemented APV dissemination policies and in Germany these policies are in discussion. Since 2015 in Germany, crop-land used for PV-GM is no longer considered eligible for the subsidies awarded by the Common Agricultural Policy of the European Union because it is considered as an expansion of built-up area. (Schindele et al., 2020) Schindele et al. (2020) proposes that in the general discussion of land-management, the land used for GM-PV dissemination should be considered as expansion of built-up area and therefore should not include arable land with certain agricultural practices which in turn should be explicitly related to APV as it may even improve the agricultural yield according to some studies and observations. In conclusion, APV and GM-PV target different types of terrain which should be taken into consideration. (Schindele et al., 2020) In the study for free-range solar PV potential, at the level of the geographical potential, there was a differentiation between the usable land of APV and GM-PV in order to keep up with future research and political trends.

Schindele et al. (2020) provide a definition for APV as an integrated food-energy system that maintains or improves agricultural yield. APV, unlike GM-PV, does not intrude on agricultural practices because the APV installations are designed in a way that allows agricultural activities to continue which allows policy-makers to categorize land underneath it as agricultural and not built-up. The authors limit APV to land areas used for agricultural production processes involving agricultural crops while the areas that are considered appropriate for GM-PV are defined as grasslands that are also used for animal husbandry, synergies that have already been found in GM-PV implementations in Germany and France. An APV guideline, Agro Photovoltaics: Opportunities for Agriculture and the Energy transition, published by Fraunhofer ISE also confirms that APV can protect plants and soil from negative environmental impacts and in this way may help combat climate change. The guideline also classifies agricultural land into three categories: cropland, grassland and greenhouses. Cropland can include annual, perennial and permanent crops and some notable examples can include: orchards, berries, grapevines, vegetables, and other types of arable farming, grassland is defined as permanent grassland and some examples are pastures and hayfields. While cropland can be further divided into more subcategories, for simplification purposes in the calculations, cropland was considered to be land used for APV and grassland was considered to be land used for GM-PV, in order to differentiate between them. (Fraunhofer ISE (Ed.), 2020)

Copernicus land monitoring service, in coordination with the European Environment Agency, produces CORINE land cover (CLC) datasets for Europe for different years, the latest of which is in 2018. This land-cover dataset includes around 44 layers representing different land-cover and land-use classes. A published guide, Updated CLC Illustrated Nomenclature Guidelines, also thoroughly describes the components of the different layers. In the calculations of the APV and GM-PV potential, at the geographical potential level, after the exclusion of the restricted areas, the usable land was further divided into two categories:

1) APV arable land which includes the following three land-cover classes:
    a) Non-irrigated arable land which is a broad category defined as: "Cultivated land parcels under rain fed agricultural use for annually harvested non-permanent crops, normally under a crop rotation system, including fallow lands within such crop rotation. Fields with sporadic sprinkler-irrigation with non-permanent devices to support dominant rain fed cultivation are included." This class

includes crops such as: regular annual crops, such as cereals, root crops, leguminous crops, oil crops; fodder crops, annual or multiannual grown as part of the crop rotation (alfalfa, sown grass for silage or hay production); vegetables and others (EEA et al., 2019)

   b) Vineyards which are areas planted with vines (where vineyard parcels cover more than 50% of the land) including vineyards for wine production, consumer grape and raisin production, permanently irrigated vineyards, recently abandoned or established vineyards, vine-growing nurseries (EEA et al., 2019)
   c) Fruit trees and berry plantations which include: "Cultivated parcels planted with fruit trees and shrubs, intended for fruit production, including nuts. The planting pattern can be by single or mixed fruit species, both in association with permanently grassy surfaces." The crops that are included are: berry shrubs (like black and/or red currants, raspberries, gooseberries, black-berry) , orchards (apples, pears, plums, apricots, peaches, cherries, quinces, other rosaceae and figs), citrus fruit trees (oranges, lemons, mandarins, tangerines, grape fruits, pomelos), nut crops (chestnut, walnut, almond, hazelnut, pistachio), tropical fruit trees (avocados, bananas, guavas, mango, kiwis, passion fruits, papayas, pineapples), permanent industrial plants (coffee, cacao, mulberry, tea), hop plantations, willow plantation, permanent florist plantation of roses, recently abandoned orchards (EEA et al., 2019)
2) GM-PV arable land which includes the following class:
   a) Pastures: "Permanent grassland characterized by agricultural use or strong human disturbance. Floral composition dominated by graminacea and influenced by human activity. Typically used for grazing - pastures, or mechanical harvesting of grass – meadows." Pastures are defined as extensively grazed permanent grasslands with presence of farm infrastructure like fences and machinery. Among the classes included in this area are: permanent grasslands under grazing by domestic animals, permanent grasslands used for harvesting grass by mowing, abandoned arable land after 3 years that starts to show herbaceous vegetation signs, permanent grasslands with large signs of human disturbance, humid meadows with dominating grass cover, pastures with scattered trees and shrubs, herbaceous vegetation cover of abandoned or reclaimed mineral extraction sites and dump sites, grass-covered ski areas used as grazing ground for most of the year, heavily grazed semi natural grassland, drained wetlands… Also part of the class which could be seen as limitation to the methodology (scattered woody vegetation, stonewalls acting as separators, drainage ditches, installation of farming infrastructure) (EEA et al., 2019)

CLC maps were also used to determine the restricted areas, in addition to the guidelines taken from the criteria catalog of Baden Württemberg because by studying the description, these lands were evaluated as inappropriate for PV dissemination. The following classes were part of the restrictions:

1) Complex cultivation patterns: "Mosaic of small cultivated land parcels with different cultivation types - annual crops, pasture and/or permanent crops -, eventually with scattered houses or gardens." This layer includes a mix of arable land, permanent crop-land and pasture but none of them occupying more than 75% of the area (EEA et al., 2019)

2) Land principally occupied by agriculture, with significant areas of natural vegetation: "Areas principally occupied by agriculture, interspersed with significant natural or semi-natural areas (including forests, shrubs, wetlands, water bodies, mineral outcrops) in a mosaic pattern." This layer includes a combination of agricultural land which could be arable, pasture, or permanent crops and scattered patches of natural land which occupies between 25 to 75 % of the area (EEA et al., 2019)
3) Natural Grasslands which are defined as "Grasslands under no or moderate human influence. Low productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes; frequently including rocky areas or patches of other (semi-natural vegetation." (EEA et al., 2019)
4) Transitional woodland shrub areas: "Transitional bushy and herbaceous vegetation with occasional scattered trees. Can represent woodland degradation, forest regeneration / recolonization or natural succession" (EEA et al., 2019)
5) Different forest types such as mixed forest, coniferous forest, broad-leaved forests, sparsely vegetated, inland marches, peat bogs, moors and heathland (EEA et al., 2019)
6) Green Urban Areas which are defined as "Areas with vegetation within or partly embraced by urban fabric. This class is assigned for urban greenery, which usually has recreational or ornamental character and is usually accessible for the public." (EEA et al., 2019)
7) Sports and leisure facilities, a class assigned for "is assigned for areas used for sports, leisure and recreation purposes. Camping grounds, sports grounds, leisure parks, golf courses, racecourses etc. belong to this class, as well as formal parks not surrounded by urban areas." (EEA et al., 2019)

The land-cover classes listed above were evaluated and by definition found not suitable or maybe partially suitable only for PV, so they were also considered as part of the restricted areas.

For calculating the GM-& AGRO-PV theoretical potential, PVMAPS package was also used; however, in this case, the orientation and inclination angle could be optimized because they are not constrained by the architecture of already existing structures like the rooftop potential is.

The geographical potential was then calculated in two steps: the first step was to include the restrictions found in the criteria catalog from Baden-Württemberg and the CLC land cover areas that are unsuitable. The second step was to separate the usable area depending on the type of land: agricultural or grassland.

Finally, the technical potential includes the conversion efficiency and the performance ratio of the PV panels. These two parameters were considered to be the same as rooftop PV for homogeneity.

Hydropower

The Rhine is considered one of the most important rivers in Europe. It connects the Swiss Alps, where it originates from, with the North Sea and its catchment area spreads over nine states. In addition to hydropower, its major functional uses include navigation, agriculture, and water supply among many others. Because of navigation, hydropower, and flood protection surfaces, there are on the Rhine numerous hydraulic structures that have been built to regulate the water level of the mainstream water body. These structures can be in the form of locks, impoundments, and dikes. The phenomenon called "hydropeaking", which happens during consumption peaks, when hydropower plants adjust the water supply to accommodate the power supply, directly impacts the flora and fauna. (ICPR, 2015)

Hydro-morphological alterations affect the overall ecosystem of the Rhine and its function in different ways such as:

1) The widespread alteration of the transfer of solid matter causes loss of river dynamics and biological diversity. (ICPR, 2015)
2) The many embankments, the shortening of the course of the river, and the removed floodplains lead to biodiversity losses and increased flow velocity. (ICPR, 2015)
3) The existing barrages limit the ecological continuity of the Rhine ecosystem by the restriction of upstream migrations for fish due to the lack of or insufficient capacity of upstream passages and by the damages caused by the absence of downstream migration passages. (ICPR, 2015)
4) The high mortality rates of downstream fish migrations brought about by serially operated turbines used for hydropower (ICPR, 2015)
5) All the negative effects of damming such as a slowed down flow velocity around the barrages, eutrophication, and a considerably changed and reduced species population. (ICPR, 2015)
6) Increased flow velocity downstream of the barrages, which can affect and change the species composition and favor alien species. (ICPR, 2015)

Moreover, TRION-climate conducted a study within the same study border area and evaluated the already used, built-up potential of renewable energy related installations and developed a best practice map. When it comes to hydropower, there are numerous installations of hydropower plants along the German-French and the German Swiss border. The German-French hydropower plants are: Kembs, Ottmarsheim, Fessenheim, Vogelgrün, Marckolsheim, Rhinau, Gerstheim, Strasbourg, Gambsheim, and Iffezheim. The latter two power plants are operated byGermany and France in cooperation. They have an overall installed capacity of 1450 MW. The Swiss-German hydropower plants are: Birsfelden, Reckingen, Albbruck-Dogern, Laufenburg, Säckingen, Ryburg-Schwörstadt, Rheinfelden, and Augst-Wyhlen. Two of the 8 hydro-power plants (Ryburg-Schwörstadt and Augst-Wyhlen) are operated by a German-Swiss energy company. They have a joint capacity of approximately 635 MW. (TRION-Climate e.V., 2019)

The Territorial Bank (Le Banque des Territoires) is an investment and finance institution that was created in France to follow and replace the Deposit Register (Caisse des Dépôts), an older financial institution used to finance infrastructure restoration projects after World War II. The need for the creation of a new institution arose because of transparency and development equality reasons as per the French government's website. (Gouvernement, 2018) The territorial bank published an article that discussed the subject. It stated that EDF and the regional council of Alsace (Le conseil régional d'Alsace) both agree on a sustainable energy policy. Moreover, the two entities are committed to combining economic imperatives with the two other pillars of sustainable development, social and environmental. In the Alsace region, hydropower is already extensively used with a lot of energy produced by installations on the Rhine. The director of the direction of Agriculture, Tourism and the Environment of the council (Dafte) stated that extra kilowatt hours shouldn't be built at the expense of biodiversity or stream life. Therefore, the regional council of Alsace along with ADEME have been financing studies to evaluate the repowering of old turbines even if their production capacity is not optimal. The published article also states that micro-hydropower installations could also contribute to the future energy system of the region if engineering costs could be adjusted by EDF in favor of micro-scale projects. (Banque des Territoires, 2010)

On the German side of the Rhine, EnBW is an electric utility company in Baden-Württemberg. According to its website, when it comes to Germany, the potential of hydropower is nearly exhausted as there are no possible new locations for large hydropower plants. In order to achieve an increase in production, the focus is on replacing, expanding, and modernizing the already existing power plants. (EnBW, n.d.)

Axpo is the largest energy company in Switzerland and according to its website, it is also the largest Swiss producer of renewable energy, a large portion of which is hydropower. According to an article published on their website, on the Rhine stretch between Schaffhausen and Basel, where the Rhine flows on the border between Germany and Switzerland, there are already 11 power plants (8 of which are located in the URR). Also according to Axpo, there is no more space on this route for additional power plants and the only possible solution would be to increase the efficiency of the already existing plants. (Axpo, 2018)

In conclusion, according to statements of experts and energy producers in the three countries, the same observation can be made, the hydropower potential is nearly exhausted in the study region specifically on the Rhine and the way forward is through improving the efficiency of the already existing facilities through modernization. Therefore, the damaging effects hydropower installations have on the ecosystem listed above coupled with the different regional energy experts stating that the regional hydropower potential is mostly exhausted led to the calculated potential relying on the already existing potential of hydro-power plants on the Rhine River, the region's largest flowing water body.

Bioenergy & Biomass

Biomass is used increasingly nowadays to substitute fossil fuels in the transport and the energy sectors. It has the advantage of regional availability in Europe in comparison to fossil fuels and its ability to be stored in comparison to the intermittent renewable energy sources like wind and solar. Its future demand is expected to rise because of the depleting fossil fuel reserves and their decreasing availability, political incentives, and changing consumption patterns. On the other hand, increasing biomass usage is accompanied by numerous social challenges such as public acceptance and sustainability challenges such as land use competition, resource overexploitation and mono-cropping, biodiversity losses, soil degradation, and air and water pollution. However, because the national goals of the three countries align in the need to increase the production of renewable energy, biomass will have to contribute as well. (Schumacher et al. (Eds.), 2017)

The project "Biomass OUI" studied the energy generation based on biomass potentials of the Upper Rhine Region, ran over the course of three years, and was completed in July 2015. The aim of the project was to "establish the tri-national Upper Rhine Region (URR) as one of the most innovative regions in Europe in the field of sustainable biomass utilization". The project was composed of six individual research areas systematically looped together and each of which relied on the expert contributions of a large number of scientists from different disciplines and backgrounds. The contributors included economists, engineers, forestry scientists, physicists, biologists, chemists, geographers, and sociologists from prime research institutions across the tri-national region. Moreover, as part of the project, this network of scientists interacted with a large number of stakeholders from industry, politics, NGOs and civil society in the region through various stakeholder workshops throughout the project in order to make the study more comprehensive, relevant, and realistic. An advisory board composed of experts was also formed for support. Given the broad range of expertise within the contributors and the stakeholders, a trans- and interdisciplinary research approach could be adopted. The main themes of the six research areas included studying the biomass resources and land use change, biomass value change and logistics, biomass conversion pathways, biomass scenario development and analysis, and biomass sustainability impact analysis. All these themes converged in order to establish a roadmap for sustainable biomass utilization in the URR. The output of the project was the publishing of a report called: "Innovations for sustainable biomass utilization in the Upper Rhine Region" which described the methodology used and the outputs of the different research area groups. (Schumacher et al. (Eds.), 2017)

It is attested that in order to develop a sustainable bio based economy (BBE) in Europe, it is important to look into strategies that identify low risk feedstocks in terms of land-use change impact. In fact, land use change can be divided into direct and indirect (designated by dLUC & iLUC respectively). The Intergovernmental Panel on Climate Change (IPCC) has defined dLUC as "a change in the use or management of land by humans, which may lead to a change in land cover" and iLUC as "shifts in land use induced by a change in the production level of an agricultural product somewhere else in the world" which in turn can be the result of a change in market mechanisms and political measures that result in an increasing demand for biomass or land. iLUCs are more complex and difficult to quantify than dLUCs. (Sumfleth et. al, 2020) Moreover, according to Rudi et al. (2017, Abstract), "Valorization of biomass as a source of energy is challenging due to the large variety of biomass feedstocks and conversion technologies." In other words, the calculation of the biomass potential is not as straightforward a task from a methodological perspective as calculating the potential of wind energy or solar PV because bioenergy can be attributed to different sources (woody biomass, manure, energy crops…) that can also be imported into the region and exported out of it. Moreover, these sources can be matched with a range of different technologies and conversion pathways (anaerobic digestion, combustion…) that produce different outputs (heat, biogas, bioethanol, biodiesel…). Also, the location of biomass plants does not necessarily have to be in the vicinity of the biomass sources. Therefore, because the "Biomass OUI" project is a heavily researched and comprehensive project with concrete outputs, it was used as a basis for the RES-TMO's mapping of the biomass potential of the URR.

The first research group (RA1) had the task of identifying local biomass resources and land use conflicts in the Upper Rhine Region. The researchers in this group completed their task by relying on "statistical data, maps, remote sensing, and Geographical Information System (GIS) modeling". The main aim was to establish "an inventory of the currently available biomass resources and land use in the URR" by determining for each of the three sub-regions, "the total agricultural land area and the proportions of the different cultivated crop plants and their respective yields". Additionally, the forest areas were geographically mapped and their wood yields were statistically determined. The amounts of secondary biomass such as "organic household waste, bulk waste, green waste, and vineyard residues" which make up a portion of organic waste were also calculated. The outputs determined by this group were an estimated technical biomass potential and these outputs were consequently later used as an input for some of the other research areas. (Schumacher et al. (Eds.), 2017) RA1 also published a report titled, "Synthesis Report on Current Resources of Land and Biomass to Produce Bioenergy in the

Upper Rhine Region (URR)" which explained the methodology and defined the terms used by the scientists to collect and map the information.

In the synthesis report, Weber et al. (2014), identified the different sources of biomass that are essentially divided over three sectors which are forestry biomass, agricultural cropping, and organic residues and waste. By giving a precise definition of these sources, accurate data acquisition and biomass potential calculations were rendered possible. The results were merged by RA1 with the corresponding land-cover types that were assembled in order to facilitate the calculation of the potential in relation to the sub-regions. The three sectors and the sources of biomass they include are listed below:

1) Agricultural Cropping:

This sector includes crops grown on agricultural land. Moreover, "energy crops" are crops that are grown for the purpose of biomass production and can be perennial (p) or annual (a) crops by nature. They can be divided into 5 groups as follows (Weber et al., 2014):

a) "Oil containing crops like sunflower (a), rape (a), soy (a) and oil palm (p),
b) Sugar crops like sugar cane (p) and sugar beet (a),
c) Starch crops like corn (a), wheat (a) and barley (a),
d) Woody crops deriving from short rotation coppice and (p),
e) Grassy crops (p)" (Weber et al., 2014)

Even though an inventory of possible energy crops was gathered for the region, the biomass potentials for RA1 relied on forestry biomass and organic waste categories mentioned below.

2) Forestry Biomass:

This sector is composed of wood that comes from "natural forests, short rotation plantations on forestlands and trees in settlement or infrastructural areas". The components can be stem wood or other forestry residues that are divided into three categories: primary residues (stumps, branches, twigs and leaves) and secondary residues (residues from processing wood like sawdust, bark, cutter chips and black liquor). Tertiary residues like used wooden materials from construction or households are considered in the category organic household waste. Moreover, the woody biomass residues from orchards and vineyards are also counted as agricultural residues in the organic residues and waste category below. (Weber et al., 2014)

3) Organic residues and waste:

It includes all biomass types that have gone through the first processing step, for example harvesting and processing. As mentioned before, agricultural residues (straw, other plant residues) belong in this category. Moreover, the secondary residues from plants used for food production and other processes such as husks, kernels, or peels are also part of this sector. Manure that comes from livestock is another category of agricultural waste. Organic waste is biodegradable waste and can be in the form of residues from industry, trade and households, municipal waste, wood from construction and old furniture, sewage sludge and landfill gas. (Weber et al., 2014)

RA1 also came up with important observations regarding the three important conversion methods of biomass in the URR:

1) The most important renewable source for heat production in the URR is wood (Schumacher et al. (Eds.), 2017)
2) Forest biomass for energy production is already extensively used in the URR (and only an additional 10% of added potential still exists). (Schumacher et al. (Eds.), 2017)
3) The largest fraction of wood harvested in the URR is stem wood that has material uses (among the other uses could be for energy or industry) (Schumacher et al. (Eds.), 2017)
4) The most common biomass to energy conversion pathways used in the URR up to date include: anaerobic digestion, wood combustion, and waste incineration. The region has considerable experience with the aforementioned technologies. (Schumacher et al. (Eds.), 2017)
5) Woody biomass contributed considerably to air pollution in the URR, especially on the French side. (Schumacher et al. (Eds.), 2017)
6) There is political support for bioenergy in all three regions, but the incentives offered vary. Moreover, environmental and social awareness has led to recent restrictive measures being taken as well. (Schumacher et al. (Eds.), 2017)
7) The agricultural land use in the URR varies between the three countries. For example, in France relies on corn maize production, Switzerland on permanent grassland and husbandry, and Germany has the highest share of permanent cultures (Schumacher et al. (Eds.), 2017)

The table below includes the outputs of RA1 that were calculated and used to map the bioenergy potential of the Upper Rhine Region. They are taken from Schumacher et al. (Eds.) (2017).

Table 1: Biomass potential by source in the URR in kWh/capita as adapted from Schumacher et al. (Eds.) (2017)

Biomass Potential Category	Yearly Value (in kWh/capita)	Country/Region
Energy Wood	520	Germany
Energy Wood	400	France
Energy Wood	570	Switzerland
Agricultural Residues	170	The URR
Manure	30	The URR
Organic household waste	36	The URR
Green waste	50	The URR
Sewage sludge	50	The URR

The unit of the calculated potentials is given per capita; therefore, the calculated potential and its geographical distribution does not depict the physical location of the biomass but rather the potential per URR citizen. In the case of agricultural residues, the report confirms that 170 kWh/ca. represents the energetic content of 50% of the agricultural residues in the URR and in fact at the moment, agricultural residues are not used for bioenergy production. In addition, the value of 30 kWh/ca. attributed to manure is the potential that arises from processing 50 % of the manure generated in the URR in biogas plants. When it comes to generated household and bulk waste, it is mainly incinerated and is considered to be only 50 % renewable.

Two of the scientists that worked on the Biomass Oui project were contacted. Ms. Nadège Blond, also a scientist working on part of the RES-TMO project, offered her insight about the above potentials. She clarified that the above potentials were reached by using the data collected from RA1 but that the calculated values took into consideration the recommendations and feedback of experts. In the case of woody biomass for example, the potential is already exhausted and could only be increased by 10% (which is already included in the numbers above). In France especially, the energy wood potential is already exhausted and can only be increased in the case of changing the appliances used into more efficient ones because wood is already extensively harvested in the region. It is important to mention that energy wood is not the only type of wood being collected, so in case the other two uses mentioned above have a lower demand in the future, energy wood potential could be increased. In the report, it was also asserted that while the potential for manure is 30 kWh/ca. in the URR, only a small percentage of that potential is currently being used.

Finally, according to the European Alternative Fuels Observatory (EAFO), there are 71 advanced biofuel production facilities around the world. More information is listed on the website (https://www.eafo.eu/). In addition, the technology that has developed the most rapidly is the hydro treatment of vegetable oils. (https://www.eafo.eu/alternative-fuels/advanced-biofuels/generic-information) It is important to mention that biofuels were not looked into for Biomass Oui or for this project and therefore the estimated potential could still increase as new and more advanced technologies emerge especially considering used vegetable oil as mentioned above.

Geothermal

Geothermal energy sources can be differentiated into technologies utilizing the shallow subsurface (10s to 100m depth) and methods exploiting the deep subsurface (1000s of meters depth) for energy extraction. Shallow geothermal energy is commonly used to supply heating or cooling energy, while deep geothermal energy can be employed for both electricity generation and space heating. In the following, the potential for both types of geothermal energy in the TMO region is briefly explained.

Shallow geothermal energy systems generally take advantage of the constant temperature of the shallow subsurface (~10°C) and, coupled with heat pumps, are predominantly used for heating and cooling family homes (Sarbu & Sebarchievici, 2014). Climate, with cold winters and hot summers being advantageous, and electricity prices and sources determine whether ground source heat pump (GSHP) systems are more cost-effective than conventional heating systems. The combination of GSHPs with electricity from other types of renewable energy (solar, wind) allows for a significant reduction of the carbon footprint of heating and cooling residential buildings. The Vosges Mountains and the Black Forest experience cold winter months with the average temperature dropping below 0°C for December to February, making borehole heat exchangers more efficient than air-water heat pumps. Contrarily, the lowlands of the Upper Rhine area have warm summers (around 20°C) and in recent years have commonly experienced heatwaves with tropical nights, highlighting the potential of shallow geothermal energy for cooling. There are already several 10.000s of GSHPs installed in the TMO region, predominantly in the German and Swiss sections. However, there are several 100.000s of single-family homes in the region which could be heated and cooled with GSHPs, in particular when combined with a future-proof low-energy renovation. Thus, increasing the share of GSHPs used in the TMO will enable a drastic reduction in carbon emissions related to space heating and cooling.

Deep geothermal technologies produce waters with temperatures in the range of 100 to 250°C for district heating and electricity generation (Barbier, 2002). The efficiency of deep geothermal wells is dependent on how deep hot fluids are encountered as well as the properties of the rocks the fluids are sourced from. Geologically, the TMO region is dominated by the major rift of the Upper Rhine Graben (URG) with the Vosges and Black Forest mountains forming the Graben shoulders to the West and the East of the North-South oriented Graben structure (Dèzes et al., 2004). As a result of the rifting and the associated crustal thinning, the URG has a high heat flow density which leads to high temperatures in the relatively shallow subsurface, and thus represents an ideal region for deep geothermal exploitation (Harlé et al., 2019). The first scientific geothermal wells in the URG were drilled in the late 1980s in Riehen (Switzerland) and the early 1990s at Soultz-sous-Forêts (France). At the latter location a pilot geothermal power plant was installed subsequently and started producing electricity in 2010 (Sanjuan et al., 2006). Currently, there are nine geothermal energy plants operating or in construction in the TMO region, producing 22 MWel and 101 MWth (TRION-Climate e.V. (2019)). The theoretically recoverable heat in the rocks that lie at a depth shallower than 7000m depth in the URG is in the order of $7.4*10^{12}$ GJ (GeORG-project team, 2013), which is equivalent to $2*10^{12}$ MWh. While only a fraction of this energy is technically recoverable, there is an enormous potential for both heating and electricity generation from deep geothermal power plants in the TMO region. One of the main issues related to exploration and production of deep geothermal energy in the URG is the complex geological situation and the need for reservoir stimulation in the tectonically strongly affected region.

Results

According to Mainzer et al. (2017, Introduction paragraph), "the assessment of the potential for power generation from PV is an important field of study and methods and tools that enable local decision makers to assess PV potentials in their respective communities are of vital importance". Therefore, the renewable energy potentials for solar PV and wind were established on a municipality level. However, for biomass, display on a municipality level was not possible because it was based as mentioned above on the data provided by the Biomass Oui project.

Wind

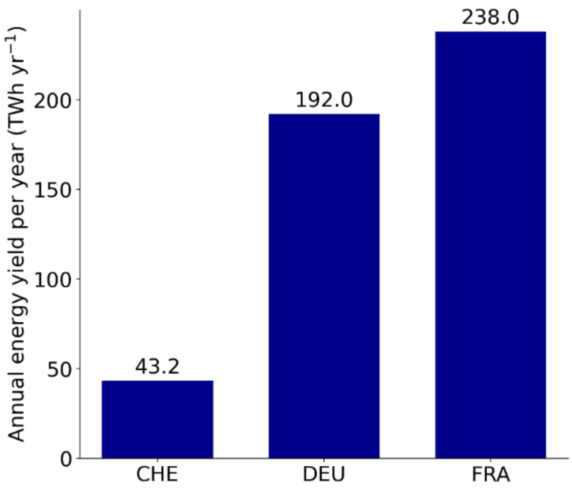

Figure 3: Annual Wind Energy Potential in the three countries of the URR

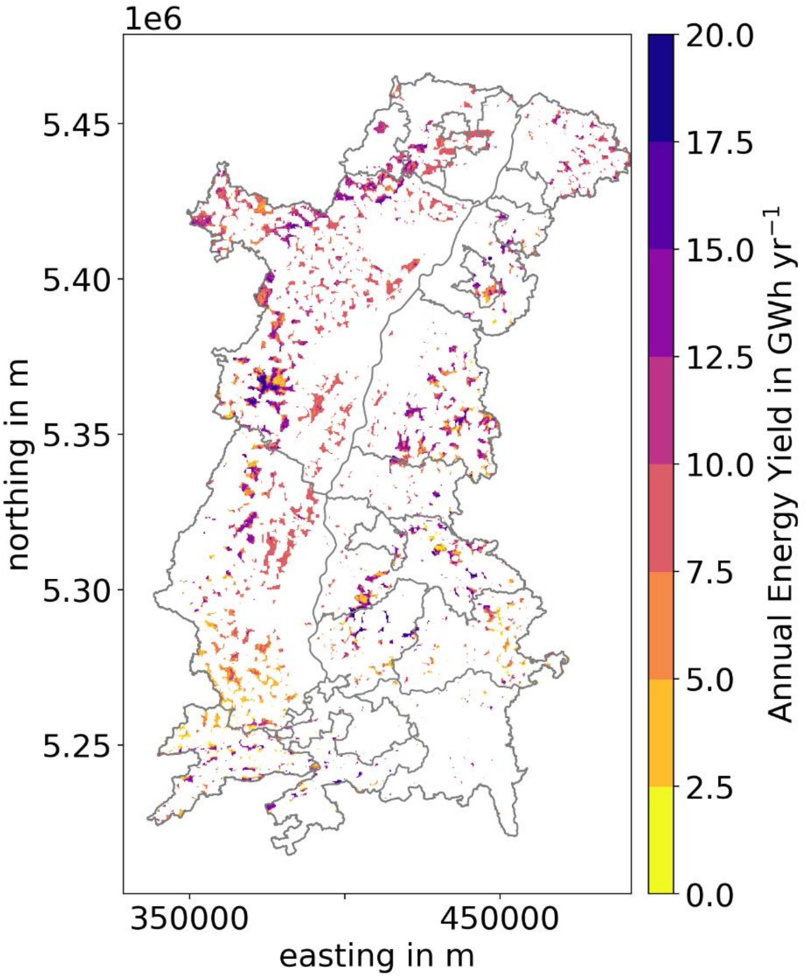

Figure 4: Spatial distribution of the annual wind energy potential in the URR

Solar PV

Rooftop PV

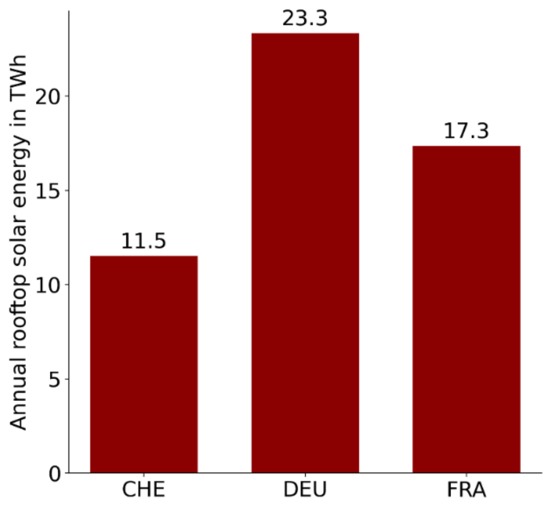

Figure 5: Yearly rooftop solar PV Potential in the three countries of the URR

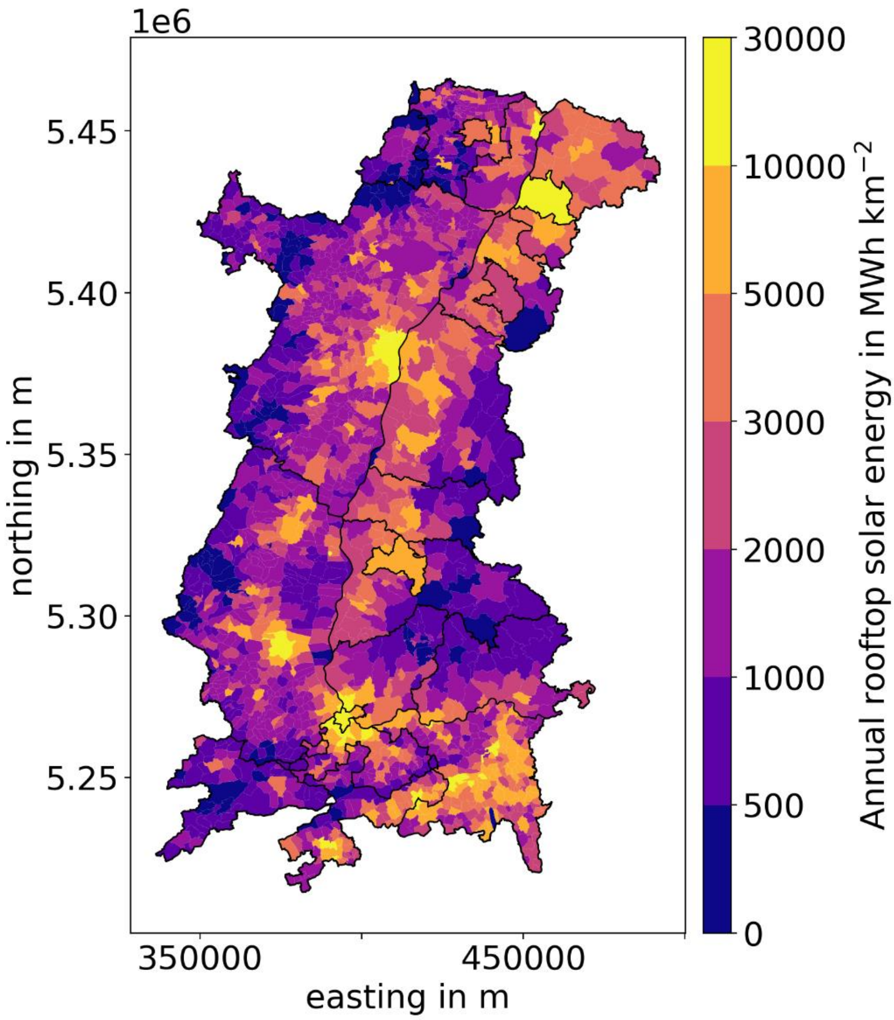

Figure 6: Spatial Distribution of the yearly rooftop PV potential in the URR

GM-PV

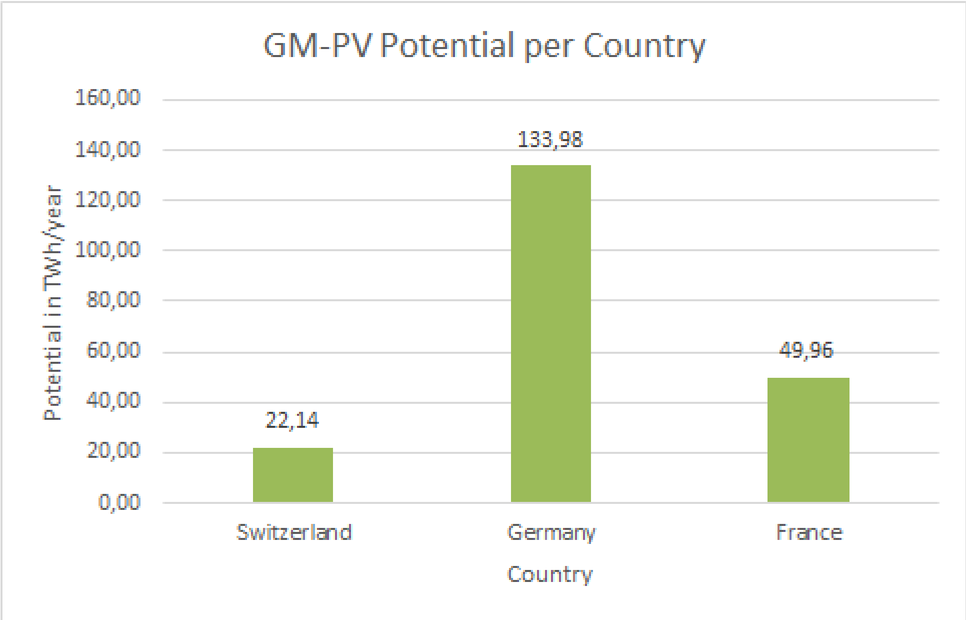

Figure 7: Yearly potential of GM-PV in each country of the URR

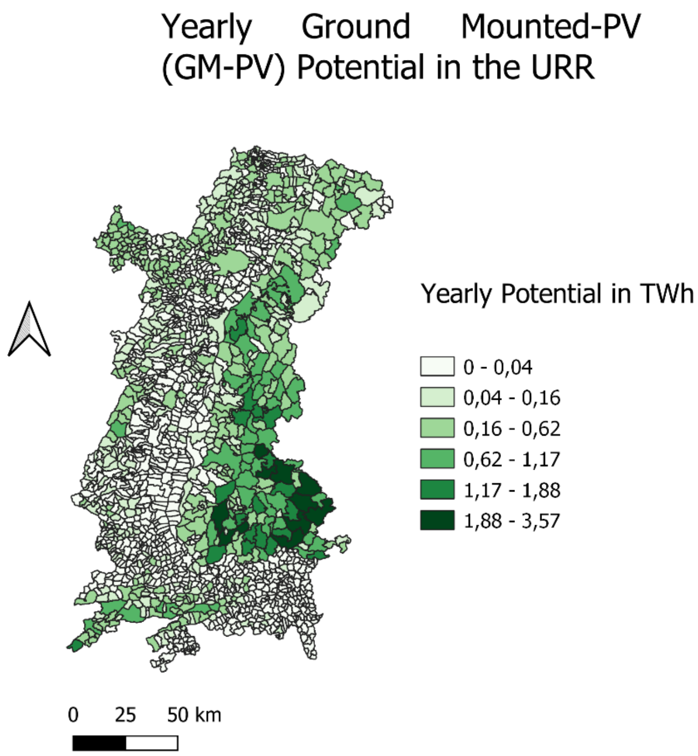

Figure 8: Spatial distribution of the yearly GM-PV Potential in the URR

Agro-PV

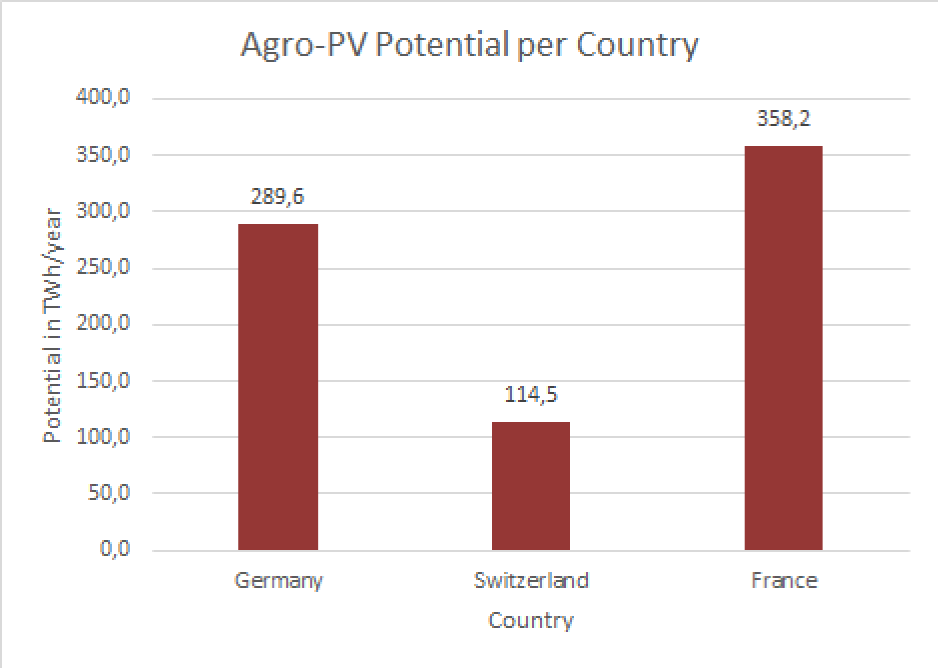

Figure 9: Yearly Agro-PV Potential in each of the three countries in the URR

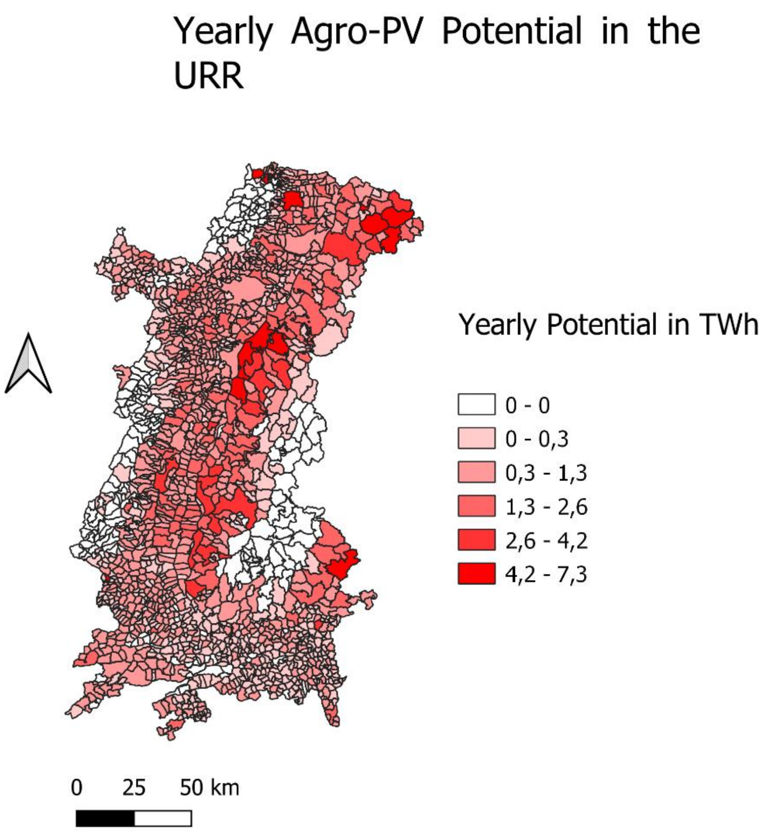

Figure 10: Spatial distribution of the yearly Agro-PV Potential in the URR

Hydropower

The Hydropower potential is the already existing potential as mentioned in the Methodology section. On the French side, according to EDF (n.d.), the 10 French-German turbines produce on average 10 TWh per year. On the German-Swiss side, according to Axpo (2018), there are 11 turbines delivering almost 5 TWh of electricity per year. Assuming that the energy produced can be equally divided over the 11 turbines, 8 turbines would have a combined output of 3.6 TWh.

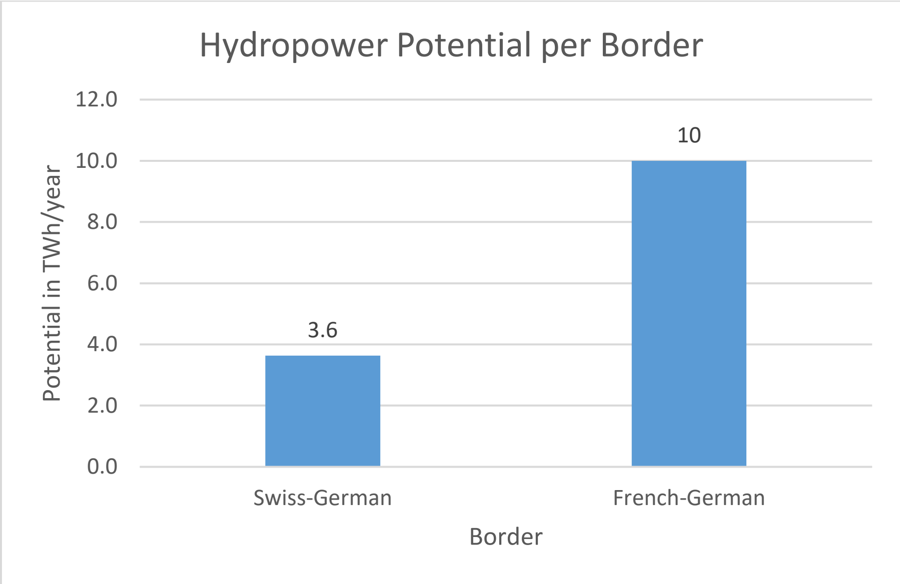

Figure 11: Yearly Hydropower Potential per country border in the URR

Biomass & Bioenergy

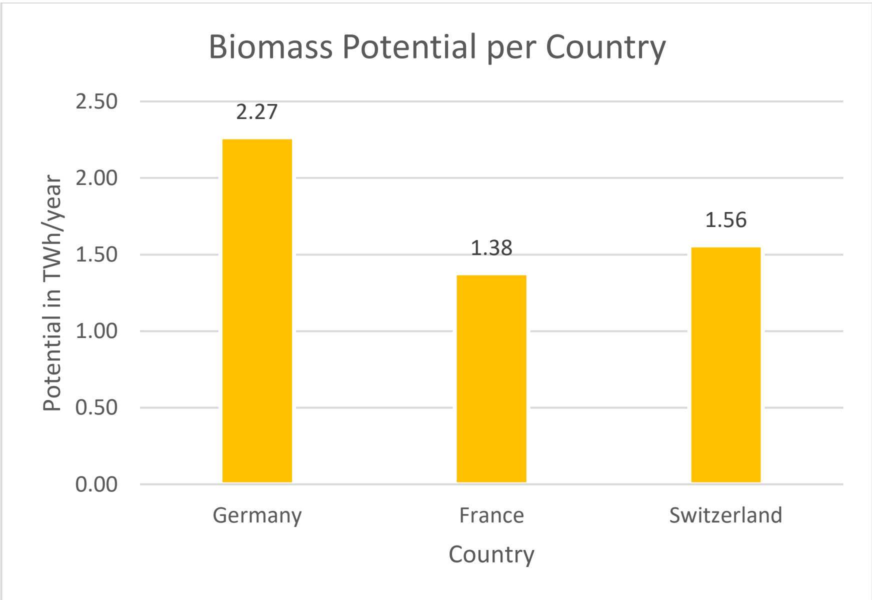

Figure 12: Yearly Biomass Potential per country in the URR

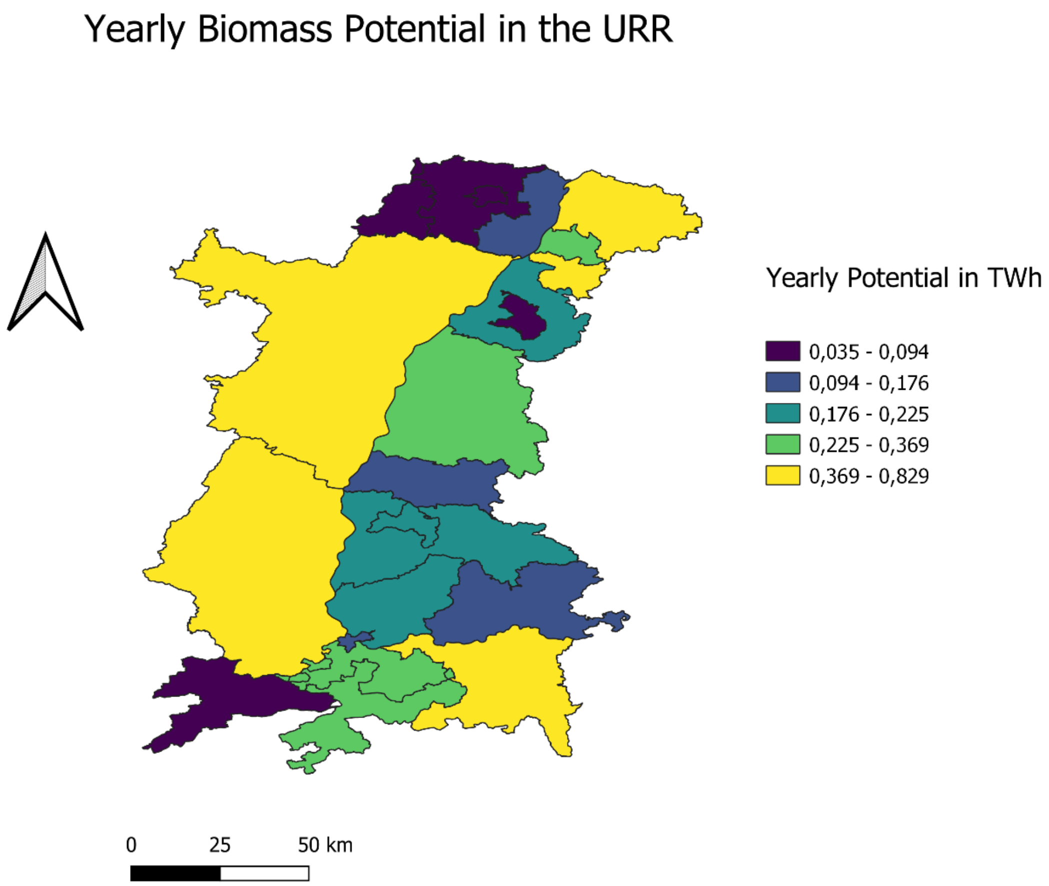

Figure 13: Yearly Biomass Potential in the URR

The Potentials

Table 2: Yearly URR Renewable Energy Potential by Source

RE Source	Annual Potential (in TWh)
Wind	473.2
Solar PV Rooftops	52.2
Solar PV Agro	762.3
Solar PV GM	206.1
Biomass	5.2
Hydropower	13.6

In general, it can be observed that the greatest potential is for (free-standing) solar PV. The joint potential of Agro- and GM-PV in the URR reaches about 968 TWh. Agro-PV alone constitutes the bulk of this potential with 762.3 TWh owing to the regions' high share of agricultural area as mentioned by Schumacher et al. (Eds.) (2017). In fact, the total usable area for Agro- and GM-PV makes up about 33% of the URR total area and of this area about three quarters is designated for Agro-PV. The second largest potential in the region is wind. For wind, the total usable area is about 15.5% of the total URR area. Solar rooftop potential is also significant in the URR. According to Fraunhofer ISE (Ed.) (2020), PV and wind power are considered pillars of the future energy supply. They constitute the bulk of the region's potential.

Limitations

When it comes to wind energy, limitations in the methodology include the focus on yearly timescales that don't take into consideration the monthly variations in wind energy potential that could vary significantly between the different months of the year. However, for the purpose of this task, yearly averages help in the estimation of the average yearly potential.

The main limitations, when it comes to calculating the solar and wind potential, stems from the tri-national nature of the region and specifically the difference in regulatory structure. For example, in the German state of Baden-Württemberg, a clear definition of the areas that are restricted for PV and wind dissemination are found in the form of a document titled "Kriterien Katalog" (a criteria catalog), on the website Energy Atlas Baden-Württemberg (https://www.energieatlas-bw.de) which lists the hard restriction areas that are considered a forbidden zone for the propagation of wind and solar farms and a conditionally or partially restricted zone which can be utilizable in theory. In France, as it was determined by our expert opinion, when it comes to renewable energy projects, the decision and study is made on a case to case basis and an extensive environmental impact assessment study should be completed. In Switzerland, GM-PV projects are in general not recommended and the focus of PV propagation is on rooftop installations. (EEA et al., 2019)

The calculated potential for GM-PV and Agro-PV takes into consideration the whole area that is available without accounting for installations and the difference in land use between GM-PV and Agro-PV, which needs to take into account significant spacing for equipment and activities related to agriculture.

Historical buildings were not factored out in the rooftop potential. As discussed in the methodology section, the rooftop potential usable area consists of clusters of buildings for technical purposes so it was not possible to subtract historical buildings and structures. However, this is not a critical criteria as for example in Switzerland, it is possible to install but better not to significantly interfere with historical buildings as per the website, Sonnendach (https://www.sonnendach.ch).

When it comes to biomass, the limitations are defined by the limitations of the data acquisition part of the Biomass Oui project and are mainly related to the heterogeneity of the available information from the three different countries due to different factors including confidentiality. Moreover, the smallest level of detail could not be achieved in France for example which meant that the results could not be portrayed at the lowest level of the arrondissement, Kantone, Landkreise. (Weber et al., 2014)

Built up Potential

The Interreg project TRION-climate, evaluated renewable energy sources in the same study area and came up with a map consisting of all the renewable energy installations in the region (best practice map). The map below is taken from TRION-CLIMATE Report for 2019. (https://trion-climate.net/energieanlagen).

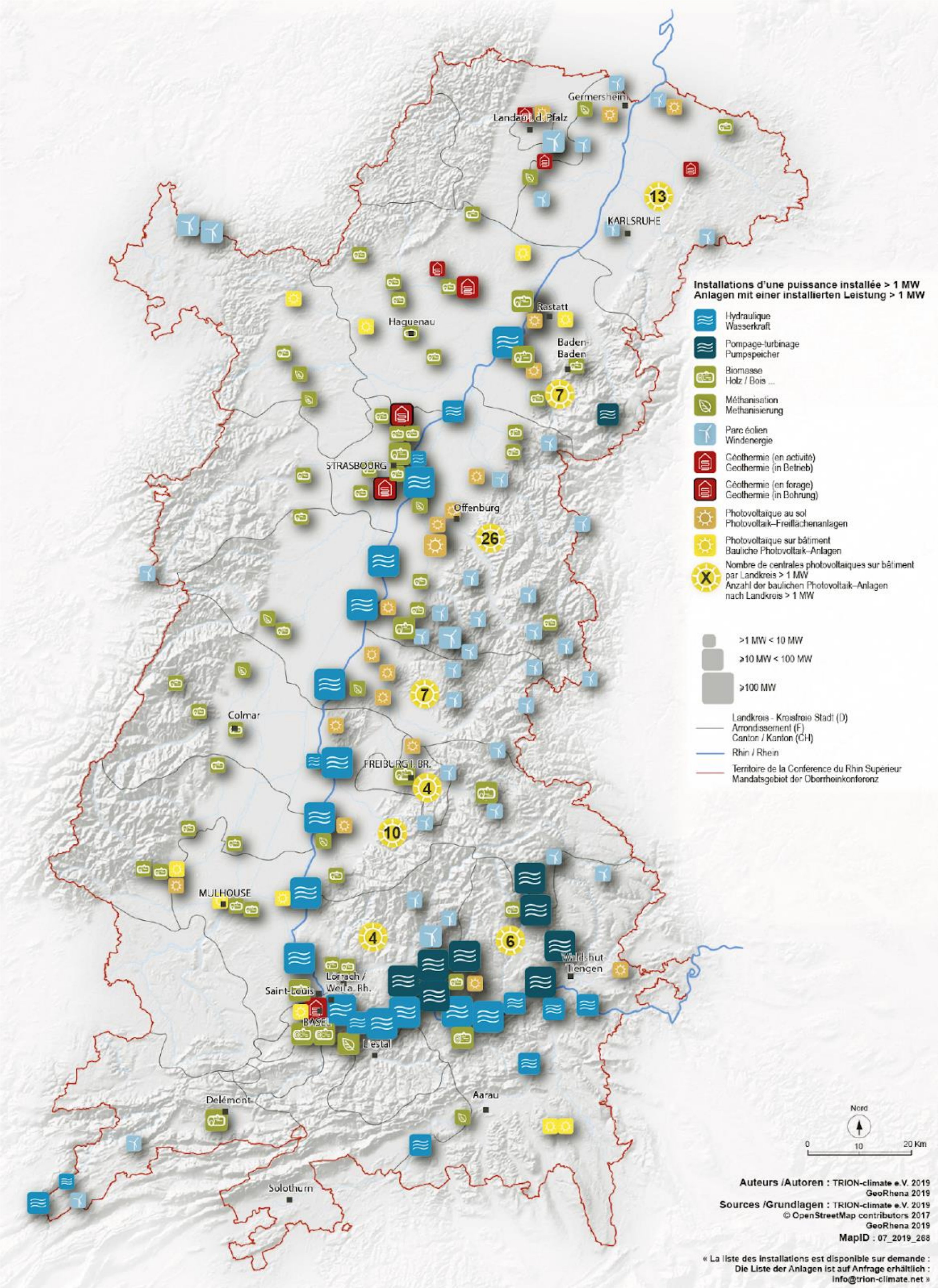

Figure 14: The used renewable energy potentials in the URR (TRION CLIMATE e.V., 2019)

Main Findings

The main findings are:

1) The highest potential of RES in the URR is estimated to be attributed to Solar PV and specifically Agro-PV. The potential and the area that can be used for Agro-PV propagation is also much larger than that of GM-PV.
2) France has the highest potential for Agro-PV while Germany has the highest potential for GM-PV.
3) Wind has the second highest potential in the region and Germany has the highest wind potential.
4) According to the findings of the Biomass Oui Project that were integrated into the research, the potential for woody biomass production in the region is exhausted.
5) The large hydro potential of the region is exhausted, however, mini-hydro installations could still be developed.

Background Information on Refining the Potentials

Throughout the RES-TMO project, WP2 and WP3 were in close contact and communicated the results to each other despite the different research goals set in the beginning of the project. WP2's research goals are more concentrated on the geographical potential and establishing an annual estimate for the renewable energy potential in the TMO region and WP3's research goals are more concentrated on modeling and energy scenario development for the TMO region. However, it was foreseen that WP3 would integrate the potential analysis from WP2 as a basis to expand their model. Because the long task of analyzing the RE potentials took place simultaneously with WP3's research and the fact that WP3's work depended on the potential analysis to begin with, WP3 had to perform their own estimation of the potentials.

By using a more basic methodology to estimate the area needed to supply the energy demand of the URR by the different renewable energy sources (mainly solar and wind), WP3 was able to obtain a maximum and minimum estimate of the potential per area of the region (in TWh/km2). Their starting point was the solar irradiation and wind speed and the end result was two scenarios for each renewable energy source, a best case and worst case in the form of an area range (from minimum to maximum) needed to supply 100% of the energy demand of the URR. The maximum area is the area needed to supply the demand when the worst conditions are accounted for (lowest value for solar irradiation or wind speed in the region) and the minimum area is the area needed to supply the demand when the best conditions are accounted for (highest value for solar irradiation or wind speed in the region). While there are differences in the methodology used by both packages, the area range calculated by WP3 provided a good scale of measurement for the accuracy of the results obtained by WP2 and led to more investigations into the RE potentials . Moreover, the range obtained for WP3's study provided a base for comparison and validation of WP2's results especially since there is no previous similar study performed on the region in question to compare with.

Solar PV Refining Method

When it comes to solar PV as described in Report 2.1.1., the software PVMaps does not account for the "partial shadowing" effect. This effect is dependent on the local conditions, specifically how the modules are installed on the ground. (European Commission, n.d) Therefore, the calculated Solar PV potential could be reduced by factoring in the spacing requirements. However, as mentioned previously, there will be a difference between the spacing requirements for Agro and GM-PV projects as Agro-PV projects include the dual usage of land for agricultural activities and energy production. The usable area found in the previous sections will not change but the placement requirements of the PV modules on the available surface and the spaces that should be left as provisions for other activities reduce the calculated technical potential.

GM-PV

According to Koerner (2015a), in the case of GM-PV, the row spacing of a solar PV park can be determined as a function of the inclination angle used.

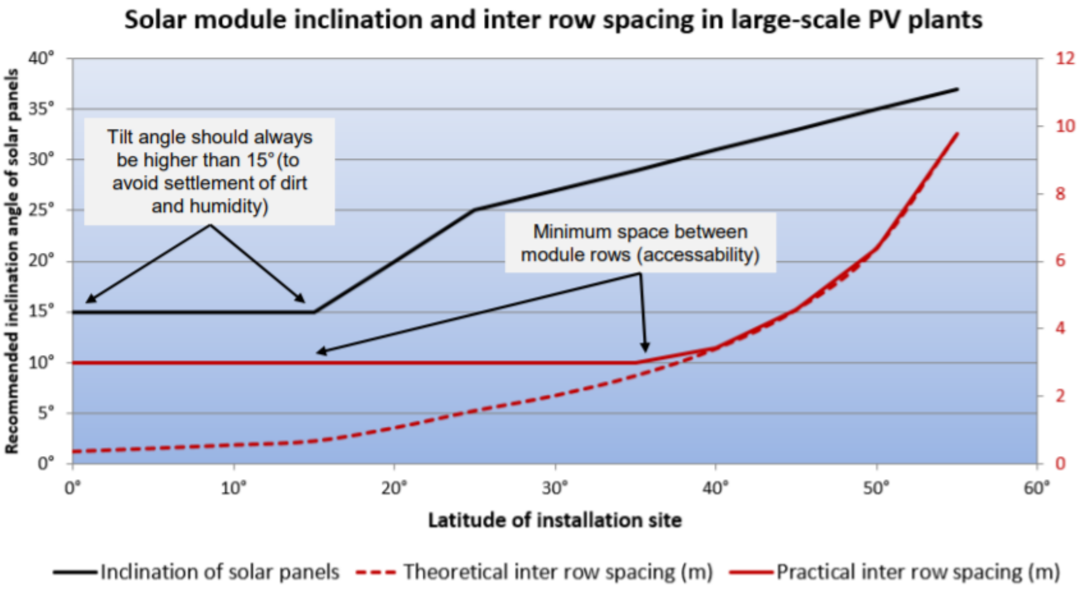

Figure 15: Solar module inclination and inter row spacing for large scale PV (Koerner, 2015a)

According to Jacobson & Jadhav (2018) who provided an estimate of the optimal tilt angles for fixed solar panels of different countries, the optimal angles for Southern and Western Germany are between 32-33 degrees, for France, between 30-33 degrees, and for Switzerland at around 32 degrees. (Jacobson & Jadhav, 2018) Moreover, according to Breyer & Schmidt (2010, Sept 6-10), in southern Germany, the optimal tilt angle is usually between 25 to 30 degrees. So, in the case of the URR, the inclination angle for free-range PV was taken optimally as 30 degrees and the orientation was optimized as southern facing.

Therefore, the inter-row spacing was found to be 3 meters by using the above figure.

Assuming that there is an area of 1 km^2 (a square of dimensions 1 km x 1 km) and utility scale 72" solar panels that cover the whole area of dimensions: $0{,}99\, m \times 1{,}96\, m$. For visualization purposes, the figure below represents the situation described.

Figure 16: Representation of a solar park (Koerner, 2015a)

If we apply the theoretical situation to the drawing above, we obtain the figure below:

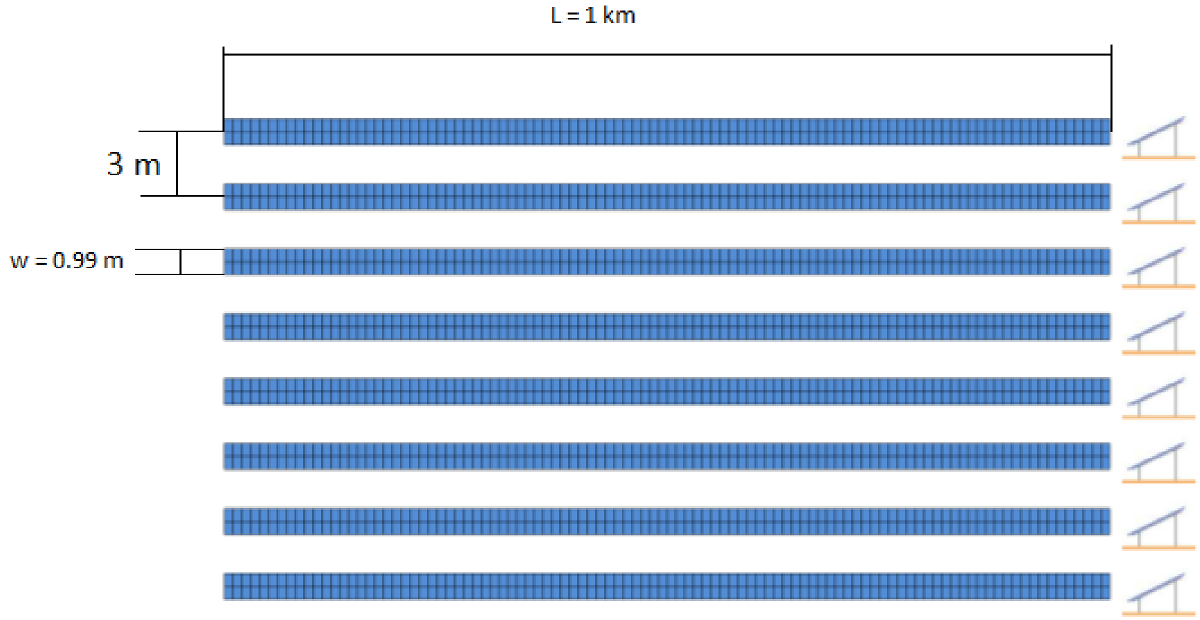

Figure 17: Representation of a solar park (Koerner, 2015a) with dimensions

Also assuming that the solar panels cover the whole width of the area:

The area occupied by 1 PV panel row is:

$$A_{row} = w \times l = 0{,}99\ m\ \times 1000\ m = \ 990\ m^2$$

The area occupied by the spacing between the panels:

$$A_{spacing} = w \times l = (3 - 0.99)\ m \times 1000\ m = 2010\ m^2$$

The combined area of the spacing and 1 PV panel:

$$A_{combined} = 990\ m^2 + 2010\ m^2$$

An area of 1 km^2 can fit a combination of:

$$\frac{1{,}000{,}000\ m^2}{3000\ m^2} = 333\ combinations\ of\ panels/spacing$$

The total area occupied by panels is:

$$A_{panels} = 333\ \times 990\ m^2 = 330{,}000\ m^2$$

The percentage of area that can be covered in panels considering an area of 1 km^2:

$$\frac{A_{panels}}{A_{total}} = \frac{330{,}000\ m^2}{1{,}000{,}000\ m^2} = 33\ \%$$

Because of the spacing requirements of PV panels, when calculating the potential per km^2, the technical potential will be reduced by a factor of 33%. This means that while the usable area calculated is in fact the area that can be used for PV panel placement, due to spacing requirements, the panels can only occupy 33% of the area and therefore the technical potential of GM-PV is reduced by 33%.

Agro PV

As stated previously in the report, in the case of Agro-PV, the spacing requirements are different than in the case of GM-PV because in the case of Agro-PV, agricultural activities take place simultaneously on the area in question. Agro-PV is still an emerging technology with different test projects distributed in Germany, in Fraunhofer ISE (Ed.) (2020), the authors give two examples of Agro-PV test projects in Germany with two different values for row spacing. The first example is an Agro-PV plant in Weihenstephan and can be found below. The row spacing is observed to be 7 m.

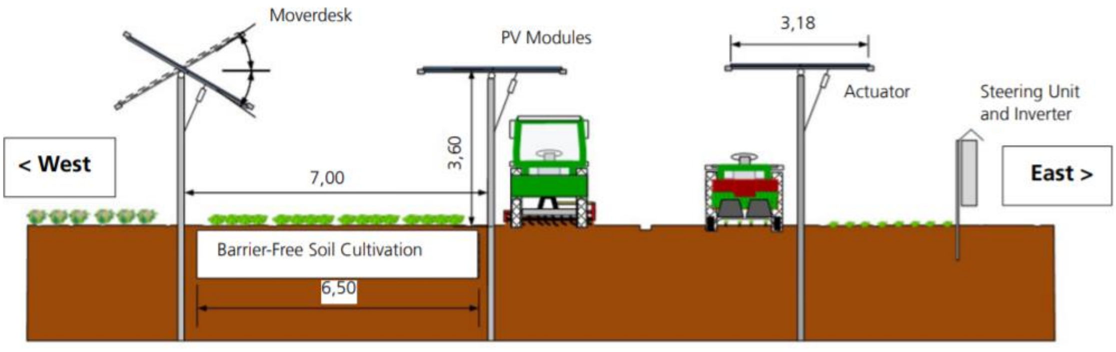

Figure 9: Cross-section of the agrivoltaic plant in Weihenstephan. © 2020 B. Ehrmaier, M. Beck, U. Bodmer

Figure 18: Agro-PV plant in Weihenstephan (Fraunhofer ISE (Ed.), 2020)

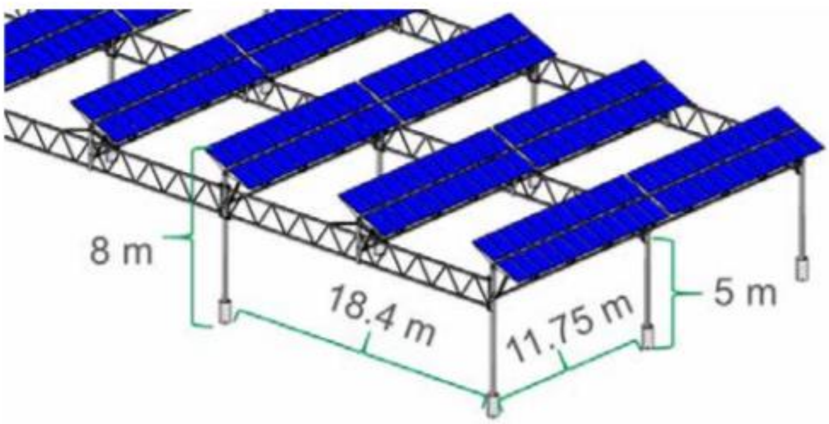

Figure 11: Sketch of the agrivoltaic reference plant in Heggelbach. © Hilber Solar

Figure 19: Sketch of the Heggelbach Agro-PV project (Fraunhofer ISE (Ed.), 2020)

The second example is the Heggelbach PV plant which can be found depicted in the above sketch. As can be observed, the row spacing equals (18.4/2) 9.2 m.

$$Row\ spacing = \frac{18.4}{2} = 9.2\ m$$

As an assumption, the row spacing was considered to be an average of the above values and taken to be:

$$Average\ row\ spacing = \frac{(9.2 + 7)}{2} \approx 8\,m$$

The above calculations are repeated for Agro-PV also considering an area of 1 km^2 and the same dimensions for the PV panels:

The area occupied by 1 PV panel is:

$$A_{panels} = w \times l = 0.99\,m \times 1000\,m = 990\,m^2$$

The area occupied by the spacing between the panels:

$$A_{spacing} = w \times l = (8 - 0.99)m \times 1000\,m = 7010\,m^2$$

The combined area of the spacing and 1 PV panel:

$$A_{combined} = 7010\,m^2 + 990\,m^2 = 8000\,m^2$$

1 km^2 can fit a combination of:

$$\frac{1{,}000{,}000\,m^2}{8000\,m^2} = 125\ combinations\ of\ panels/spacing$$

The total area occupied by panels is:

$$A_{panels} = 125 \times 990\,m^2 = 123{,}750\,m^2$$

The percentage of area that can be covered in panels considering a total area of 1 km^2 is:

$$\frac{A_{panels}}{A_{Total}} = \frac{123{,}750\,m^2}{1{,}000{,}000\,m^2} = 12\,\%$$

Because of the spacing requirements of PV panels, when calculating the potential per km^2, the technical potential will be reduced by a factor of 12 %. This means that while the usable area calculated is in fact the area that can be used for PV panel placement, due to spacing requirements, the panels can only occupy 12% of the area and therefore the technical potential of Agro-PV is reduced by 12%.

The table below describes the refined solar PV potentials in terms of the spatial reduction factors:

Table 3: The Refined PV Potentials

Solar PV Type	Potential (in TWh/yr)	Spatial Reduction Factor (in %)	Usable Area (in km^2)	Potential (in TWh/km^2)
Agro-PV	762,3	12	5.399,246	0,017
GM-PV	206,1	33	1.509,710	0,045
Rooftop PV	52,2	N/A	2.855,221	0,018

Wind Energy Refining Method

When it comes to wind energy, which was the first of the potentials to be calculated, as mentioned in Report 2.1.1., the raster files used in the data collection part were taken from a student at the University of Freiburg who generated the files as part of his Master's thesis. The results obtained by WP2 (in terms of potential per area (TWh/km^2) were much larger than the range obtained by WP3. An analysis of the results obtained resulted in a theory that the potential is overestimated because the spacing between the different turbines is underestimated in the GIS files. This theory was tested by performing basic calculations of the results. Knowing that an Enercon turbine with the following characteristics was used in the calculations:

Table 4: Parameters of the Enercon E-115 Wind Turbine*

Rotor diameter	115.7	m
h hub	149	m
Rated power	3	MW

*Taken from: https://www.enercon.de/produkte/ep-3/e-115-ep3/

Knowing that the rated power is the "maximum capacity, at which rate it (the turbine) will produce power when the wind is in the ideal range for that model." (National Wind Watch, n.d.) Assuming that grid cells in the distance of four times the rotor diameter are not considered:

Table 5: Area occupied by each turbine and the number of turbines in 1 km^2

Area occupied by 1 turbine	334,662	m^2/turbine
Area occupied by 1 turbine	0.33	km^2/turbine
Turbines found in 1 km^2	3*	turbines/km^2

*Approximation

The equation used to calculate the area occupied by one turbine is as follows:

$$Area\ occupied\ by\ 1\ turbine = (5 \times Rotor\ diameter)^2$$

The above equation is taken from Koerner (2015b). The rated power definition implies that this is the maximum power output that the turbine could produce in ideal conditions. According to the above calculations, the maximum number of turbines that can occupy an area of one km^2 while considering the spatial limitations is approximately three.

Moreover, in order to calculate the energy produced by the wind turbines, the capacity factor should also be factored in. The capacity factor is "the actual output over a period of time as a proportion of a wind turbine or facility's maximum capacity". Industry estimates have a range of 30-40% but in reality, the capacity factor is much lower. (National Wind Watch, n.d.) Assuming a capacity factor of 30%:

Table 6: The calculation of the approximate wind potential

Max Power per km^2	9*	MW/km^2
Usable area for wind energy	3,346	km^2
Capacity factor	30	%
Energy produced per km^2	23,558	MWh/km^2
Total Potential	78,827,809	MWh
Total Potential	79	TWh

*Approximation

The Energy produced per km^2 is calculated using the following formula (National Wind Watch, n.d.);

$$E = rated\ power\ \times 365\ days\ \times 24h \times capacity\ factor$$

The total potential is calculated as follows:

$$Total\ Potential\ (MWh) = E\left(\frac{MWh}{km^2}\right) \times Usable\ Area(km^2)$$

According to the calculations performed, the wind energy potential should be much smaller. The wind potential reduction factor or the ratio of the Total Potential calculated above divided by the previously calculated wind energy potential in this case is:

$$Wind\ Potential\ Reduction\ Factor = \frac{79\ TWh}{473\ TWh} = 16\%$$

To further validate our results, a comparative analysis of the annual energy yields (AEY) per municipality estimated by WP2 was performed with the potentials on a municipal scale calculated by the state of BW in 2019 and taken from the Energy Atlas of BW, (https://www.energieatlas-bw.de). Because the study area was the municipalities of BW, the comparison could only be performed on BW municipalities. As a first step, the municipality wind energy potential data and usable area calculated by the energy atlas were extracted for each municipality in BW (a total of 234 municipalities). Then, a comparative analysis was done for the BW data and the WP2 data. Among the 234 municipalities:

1) It was estimated that the potential of 49 municipalities was found to be zero either by WP2 or the energy atlas or both. These municipalities were then excluded from the comparison.
2) The municipalities for which the energy atlas potential was much larger (that are larger than the standard deviation of the ratio of the energy atlas potential and the WP2 potential) amounted to 11 and they were also excluded from the calculations

The average ratio of energy atlas potentials divided by WP2 potentials was calculated and found to be 0.39. Meaning that on average, the wind energy potential per municipality estimated by the energy atlas is 39% of the WP2 potential. In this case, the reduction factor was calculated to be 39%.

The wind potential reduction factor is assumed to be the average of the two obtained reduction factors. (around 27%).

Finally, the wind potential is reduced by the above reduction factor and the results are found in the table below:

Table 7: The new wind potential

Previous Wind Energy Potential	473	TWh
Wind Potential Reduction Factor	27	%
New Wind Energy Potential	128	TWh

The New and Refined Potentials

Table 8: The new and refined wind and solar PV potentials

RES	**Potential (in TWh)**	**Usable Area (in km²)**	**Potential (in TWh/km²)**
Agro-PV	91.5	5,399.2	0.017
GM-PV	68.0	1,509.7	0.045
Rooftop PV	52.2	2,855.2	0.018
Wind	128	3346.1	0.038

According to the above table, the sum of the potentials in the URR is now 339.7 TWh. Solar is still the largest renewable energy source in the region with a total potential of 211.7 TWh. Within the solar PV potentials, the type with the largest potential is Agro-PV followed by GM-PV and then Rooftop PV. However, when it comes to the energy produced per km^2, GM-PV has the highest potential and agro-PV and rooftop PV show comparable energy densities.

Comparison with WP3 Max & Min Range

Table 9: Comparison of the WP2 and WP3 potentials

	WP3 Worst Case Scenario	**WP2 Potential**	**WP3 Best Case Scenario**
RES	**Potential in TWh/km2**	**Potential in TWh/km2**	**Potential in TWh/km2**

Wind	0.013	0.038	0.042
Solar	0.038	0.027	0.059

As can be observed from the above table, the WP2 potential for wind and solar PV falls within the range of maximum and minimum energy densities, best and worst case respectively, calculated by WP3 for the region. It is important to mention that the above potential is the technical potential and that the economic and feasible potential is much less and can differ on a case-to-case basis.

Despite the significant reduction in the potentials, the wind and solar potentials still theoretically cover the electricity demand of the region.

Modified Result Figures from Part 1

Wind

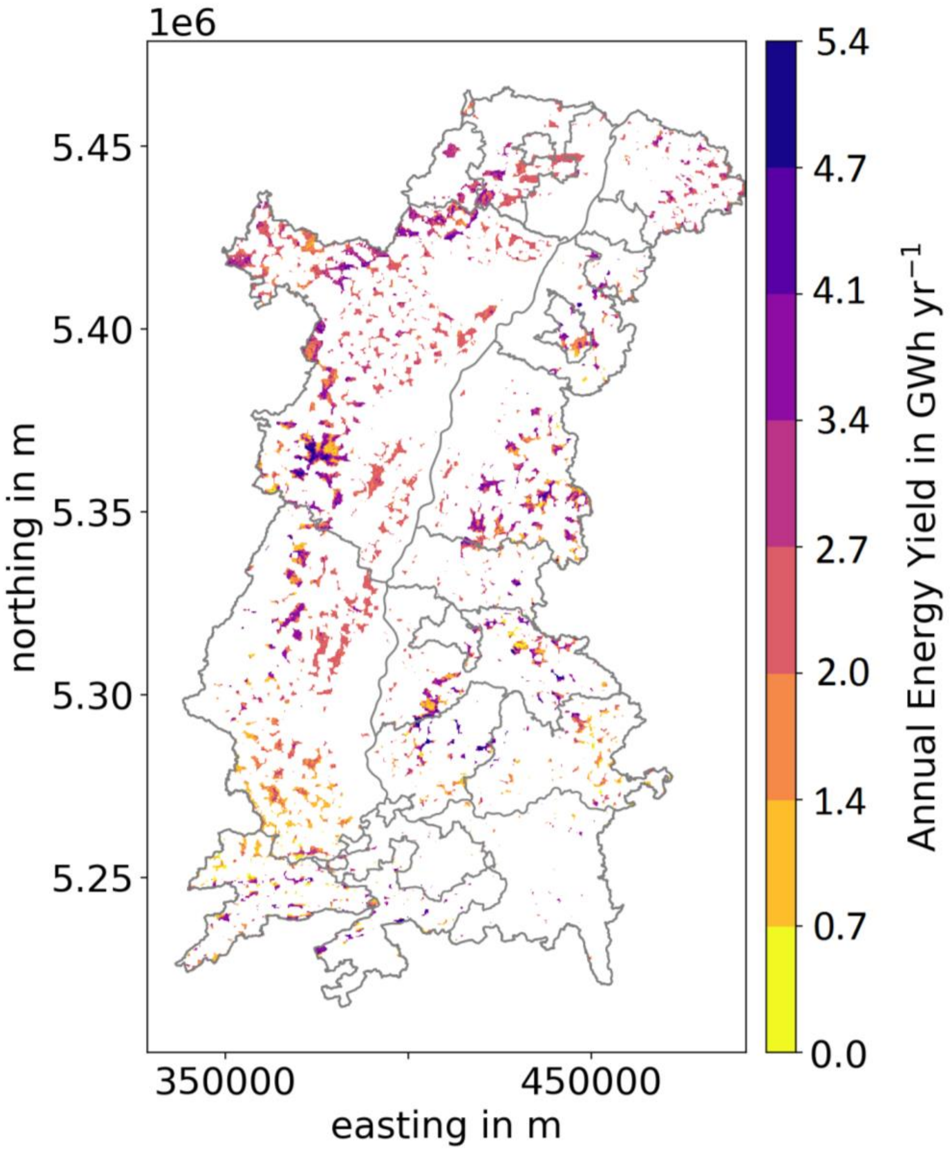

Figure 20: The refined wind energy potential distribution in the URR

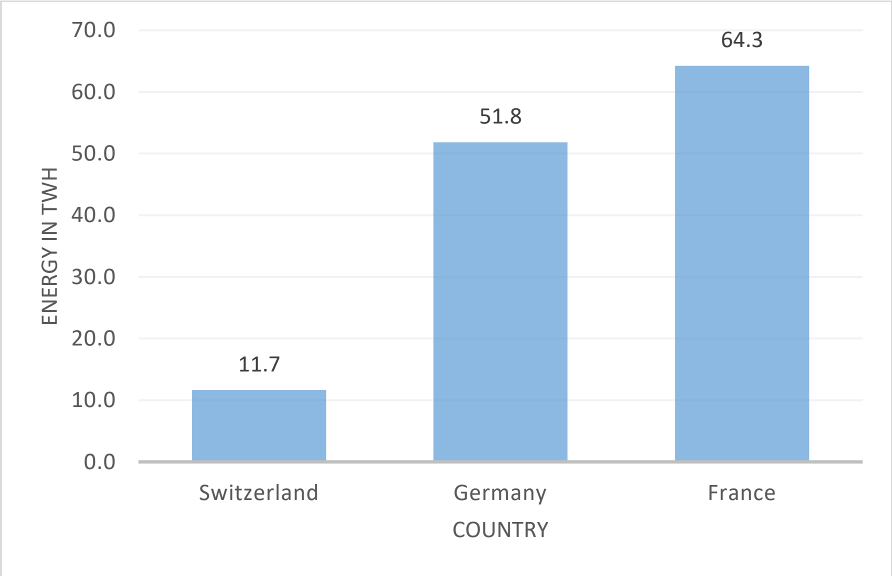

Figure 21: The refined wind energy potential distribution per country in the URR in TWh/yr

Agro-PV

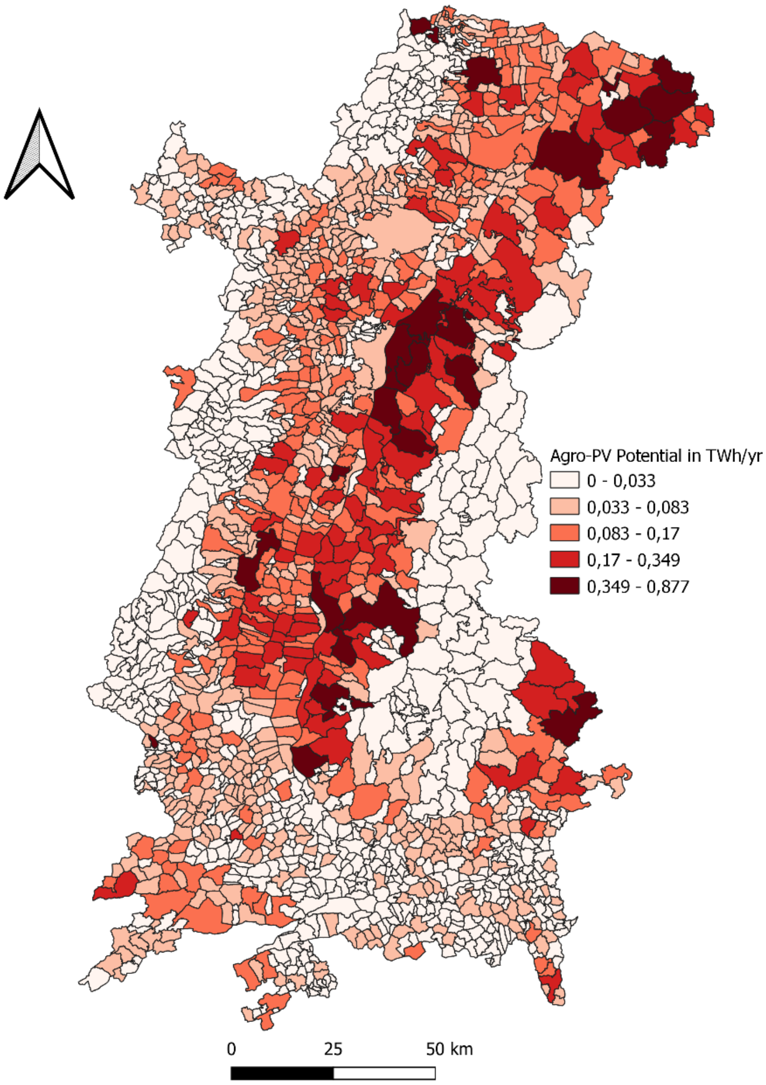

Figure 22: The refined Agro-PV Potential in the URR in TWh/ yr per municipality

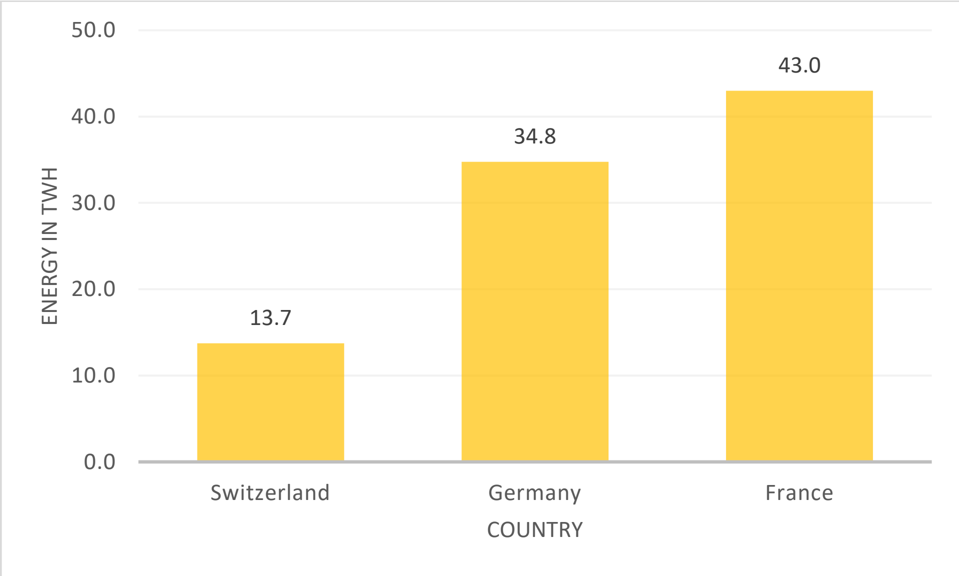

Figure 23: The refined Agro-PV potential distribution per country in the URR in TWh/yr

GM-PV

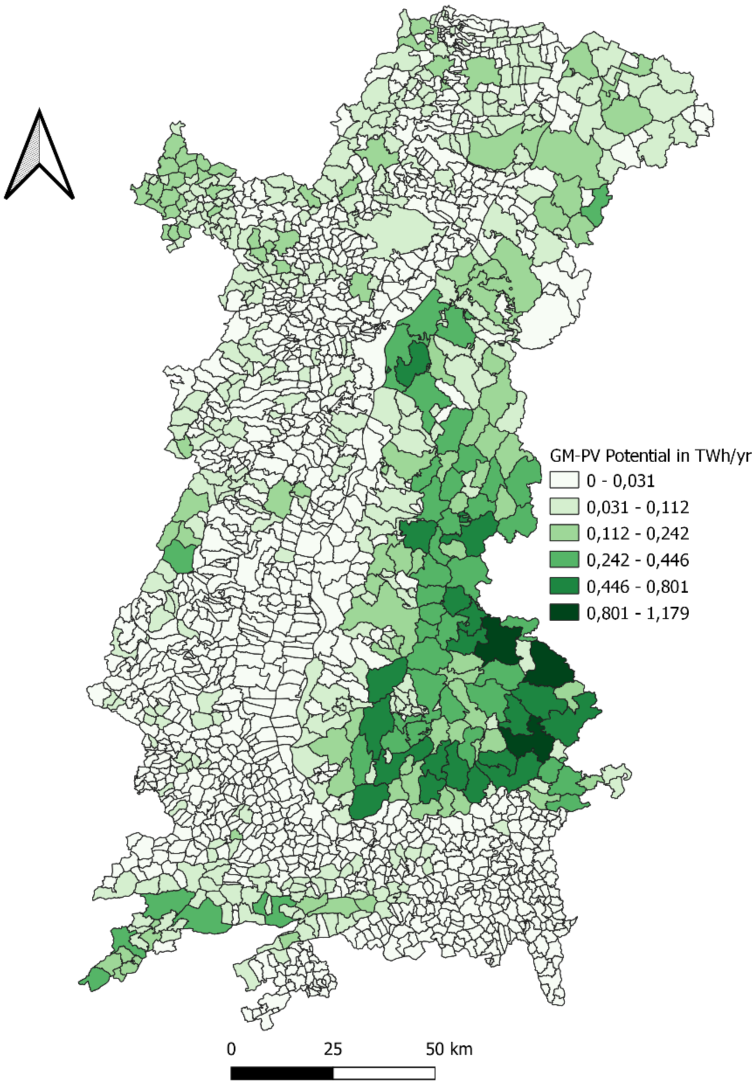

Figure 24: The refined GM-PV potential in the URR in TWh/yr per municipality

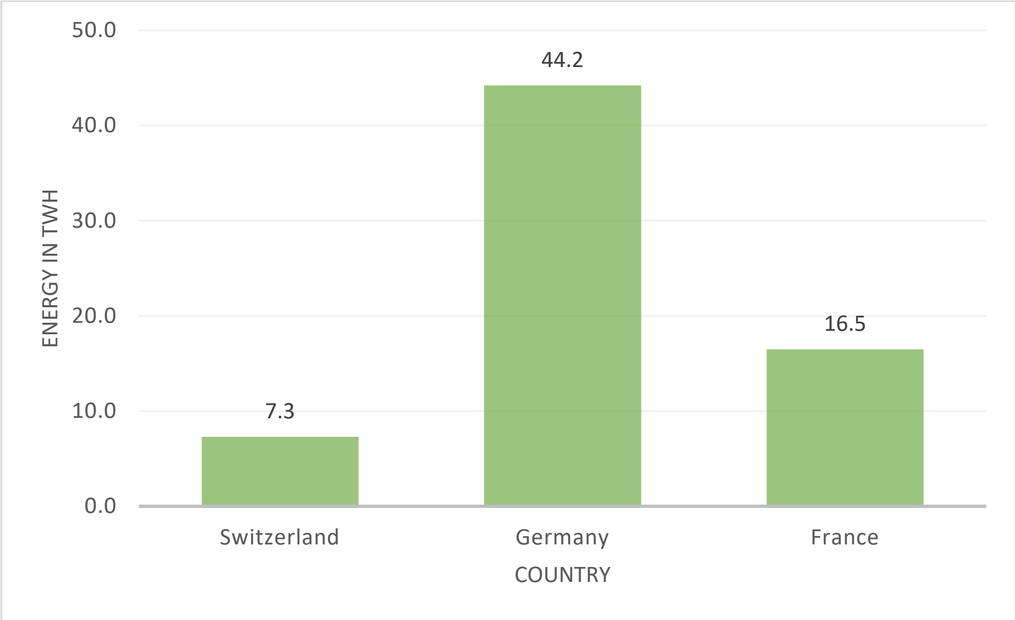

Figure 26: The refined GM-PV potential distribution per country in the URR in TWh/yr

Total Refined RE Potential of the URR

Finally, the table below shows the refined RE potentials in the URR while accounting for the changes:

Table 10: The final RE Potential in the URR including the refinements done for wind and solar

RE Source	Annual Potential (in TWh)
Wind	128
Solar PV Rooftops	52.2
Solar PV Agro	91.5
Solar PV GM	68
Biomass	5.2
Hydropower	13.6

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