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Clean energy technologies in coal regions: Opportunities for jobs and growth

Deployment potential and impacts

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Abstract

In this report, we analyze the opportunities in coal regions stemming from the deployment of power generation technologies from wind, solar photovoltaics, bioenergy and geothermal sources, as well as on coal-fired power plants with carbon capture. In this context, we also address energy demand technologies and specifically assess the opportunities arising from energy efficiency in buildings. Starting from an existing scenario (EURCO3232.5), we find that in total by 2030, between 106 681 and 314 416 jobs can be created in the coal regions from the deployment of clean energy technologies, reaching 460 000 by 2050. Toward meeting the agreed 2030 targets and objectives, the jobs created by clean energy technologies in the coal regions would be comparable to the nearly 200 000 direct jobs relevant to coal related activities. By 2050, job creation can more than double that figure. We identify a range of potential for the different regions regarding job creation and resilience to coal related employment. We estimate a technical potential of 1 516 GW from clean energy technologies in the coal regions. Fully tapped, it would be enough to contribute to more than half of the deployment required in achieving Europe's ambitious vision for carbon neutrality by 2050.

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Executive summary

Policy context

To implement the Energy Union and the EU's commitments under the Paris Agreement signed in December 2015, the European Commission proposed in 2016 the "Clean Energy for All Europeans" package. This legislative package is supported by a number of measures also considering initiatives for coal mining regions in transition. These include the launch of the Coal and Carbon Intensive Regions in Transition Platform, which this work particularly aims to support.

Over the past few decades the production and consumption of coal in the EU has been in steady decline, due to coal mines closure and coal use phasing out for power generation. At the same time, with Europe embarking on an energy transition within an Energy Union based on clean energy, efficiency and innovation, regions face a number of challenges. In our previous work,[1] we identified the regions that rely on coal mining for employment and economic activity. We estimated that the EU coal sector employs nearly half a million people. Around half of the relevant direct jobs could be lost by 2030 representing a major challenge in the transformation of coal regions. Moreover, by 2030, approximately two thirds of the current coal-fired power generation capacity could retire, posing a challenge on energy sufficiency too. This study adopts a forward-looking approach to focus on and quantify the opportunities of such transition for these coal regions.

In November 2018, the European Parliament’s budgets committee signed off on a proposal to allocate funds to help regions undergo the transition. Members of the European Parliament (MEP) have called on the European Commission (EC) for a proposal establishing this fund. The Just Transition Fund, is now included in the political guidelines of the next European Commission (2019-2024). In light of these developments, this work is particularly relevant in providing information to support such a proposal.

This work has been undertaken under an Administrative Arrangement with the European Commission's Directorate General for Energy, focusing on the potential impact of specific clean energy technologies to coal regions.

Key conclusions

The European coal regions do not have to stay behind in the frame of a continued economic and social evolution. On the contrary, these regions can play an active role in the European energy transition. While the transition is already happening, the clean energy potential in coal regions can enable them to be active participants in the energy transition and move, in many cases, from a single- to a multi-industry model. The deployment of this potential would contribute to energy security and provide economic value and jobs to post-mining communities. The development of clean energy projects benefits from the availability of infrastructure, land, skills and industrial heritage already in place.

According to our estimations, there is a range of potential for renewable energy and jobs creation across the coal regions. Close cooperation in EU, national and regional levels between companies, regulators, investors, land-use planners and local communities is essential to identify the most sustainable options, exploit regional potential and maximize social and economic development.

Moving away from coal mining activities is largely about alleviating impacts on people and communities. With a forward-looking approach, this study shows the different degrees of available resources and employment potentials to achieve this goal.

In taking policy decisions, it is very important to reconcile the key factors driving the transition. We propose analyzing each region considering their comparative

[1] Alves Dias, P. et al., EU coal regions: opportunities and challenges ahead,
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decarbonizing employment potential that takes into account the technical potential available per clean energy resource as well as their competitiveness and their contribution to the optimal achievement of the current and future policy targets.

Main findings

In this study, we have estimated the technical potential on a regional level for the coal regions identified. The focus is on energy technologies from wind, solar photovoltaics and geothermal sources, bioenergy and power plants with carbon capture. We find the highest onshore wind potential (228 GW) in Castilla y León (ES41). The United Kingdom, Germany and Poland appear as the leading countries on offshore wind potential. Germany also hosts the coal region with the highest potentially induced employment for wind energy (Brandenburg (DE40), ~16 300 jobs).

For ground-mounted solar PV systems, we again identify Castilla y León (ES41) as the region with the highest potential (~80 GW), while for rooftop-mounted solar PV systems that is the case in Düsseldorf (DEA1, ~ 5 GW). Spain and Germany are also the coal region-hosting countries where the higher induced employment is calculated, particularly for Castilla y León (ES41 with 4 170 employees) and Brandenburg (DE40 with 2 840 jobs). These regions largely coincide with those identified with the highest technical potential for solar PV systems in their respective countries.

The technical potential helps to identify options that regions might have in their transition from coal and could indicate routes for further development in the regions. Castilla y Leon, for example, the region with the highest estimated onshore wind potential, is already leading in the number of wind component manufacturing facilities. In the case of solar PV, we find that the coal regions in countries that have incentivised the technology over the last ten years (for example Germany, UK and Italy) have a significant PV industry sector. In terms of numbers this is 857, 815 and 63 of companies for Germany, the UK and Italy in the coal regions alone.

Coal mines located in the coal regions in transition could become attractive locations for conversion into wind and solar PV sites and facilitate the regional transition. The highest total technical potential for wind and solar PV systems combinations on mine sites is estimated for Dytiki Makedonia (EL53, 983.2 MW).

For bioenergy we estimated potentials from difference sources, i.e. from crop residues, municipal solid waste, livestock methane as well as forest bioenergy. We find Castilla y León (ES41) to be the region with the highest bioenergy potential from crop residues and from livestock methane (730 MW and 110 MW, respectively). Municipal solid waste estimates indicate the highest potential for Silesia (PL22, 97 MW), Poland. Brandenburg (DE40, 1270 MW; 700 MW; 530 MW) is the region where we estimate the highest potential throughout the scenarios on forest bioenergy.

For geothermal energy, we find Castilla y León (ES41, 500 MW) to be the region with a high sustainable potential. For coal-fired power plants with carbon capture, the highest technical potential to retrofit CO_2 separation technologies in existing plants is found in Bulgaria, namely the Yugoiztochen (BG34, 3 960 MW) region.

Regarding energy efficiency in buildings, Germany, namely, Düsseldorf (DEA1, 18.76-49.02 TWh), Köln (DEA2, 18.76-49.02 TWh), Brandenburg (DE40, 10.40-26.72 TWh), Münster (DEA3, 10.18-26.06 TWh) and Saxony-Anhalt (DEE0, 8.76-22.65 TWh) show the highest potential in energy savings.

According to the in-depth analysis accompanying the European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy (European Commission, 2018b) nearly 2 500 GW of power generation capacity will need to come from wind, solar, and other renewable energy sources (mostly hydro and biomass) to achieve an ambitious target of carbon neutrality by 2050[2]. We estimate the technical

[2] Scenario 1.5TECH. For more information please refer to (European Commission, 2018b).

potential at the coal regions alone, enough to satisfy 60% of this technology deployment projection.

In this study, we have mapped activities related to Li-ion batteries in the coal regions. A number of announced investments include projects in the 42 coal regions with substantial industrial developments in Poland and in Germany. There are a very limited number of activities related to raw materials for Li-ion batteries in the European coal regions but recycling is increasing in volume and is expected to grow substantially in the next few years.

Based on the EUCO3232.5 scenario projections at national level[3], we derive the associated plausible employment evolution and the investments required to deploy the projected technology capacity at regional level. Toward 2030, we find that the projected capacity deployment will translate to regional investments ranging from EUR 5 million for Západné Slovensko (SK02) to EUR 3.17 billion for Castilla y León (ES41). By 2050, these range from almost EUR 50 million for Yugozapaden (BG41) to EUR 3.52 billion for Wielkopolskie (PL41). When it comes to employment, we estimate a broad range up to nearly 30 000 in Koln (DEA2).

In our previous work (Alves Dias et al., 2018) we estimated that there are more than 200 000 direct coal related activity jobs in the coal regions. Coal related jobs are not necessarily directly substituted by clean energy technology jobs and precisely locating where a job will be created is also a limitation. In absolute numbers, we find that by 2030, up to 315 000 jobs can be created in total by deploying clean energy production technologies as projected in EUCO3232.5, reaching more than 460 000 by 2050.

To contextualize the foreseen development of the coal regions, we have analysed their potential resilience considering their starting point of reliance on the coal sector in terms of jobs. By comparing the size of the regional coal sector and the expected growth in clean energy technologies and energy efficiency in terms of employment, we cluster regions to:

- Regions with a High Decarbonizing Employment Potential (HDEP), i.e. jobs plausibly derived by 2030 from the regional impact of EUCO3232.5 scenario, can account for at least 90% of current coal related jobs by those, reaching 100% by 2050.
- Regions that show Slow Decarbonizing Employment Potential (SDEP). This means that they have significant decarbonisation potential, but by 2030 jobs created would be below 90% of the coal related ones. This potential could only be fully realized by 2050.
- Regions that show Restricted Decarbonizing Employment Potential (RDEP). That implies that the foreseen EUCO3232.5 derived regional employment potential may not suffice to fully account for the associated coal related jobs.

HDEP regions
Aragon (ES24), Brandenburg (DE40), Castilla-La Mancha (ES42), Castilla y Leon (ES41), Derbyshire and Nottinghamshire (UKF1), Dolnoslaskie (PL51), Dresden (DED2), Dusseldorf (DEA1), East

SDEP regions
Észak-Magyarország (HU31), Lodzkie (PL71), Lubelskie (PL81), Małopolskie (PL21), Munster (DEA3), Saarland (DEC0) and Vest (RO42)

RDEP regions
Dytiki Makedonia (EL53), Moravskoslezsko (CZ08), Severozápad (CZ04), Silesia (PL22), Sud-Vest Oltenia (RO41), and Yugoiztochen (BG34)

[3] The EUCO3232.5 scenario is part of a group of EUCO scenarios used in EU energy and climate policy development. The EUCO3232.5 scenario is designed to achieve a 32% share of renewable energy in gross final energy consumption and a 32.5% energy efficiency target in the EU. See: https://ec.europa.eu/energy/en/data-analysis/energy-modelling/euco-scenarios for the public release of the latest EUCO3232.5 scenario.

Wales (UKL2), Eastern Scotland (UKM7), Koln (DEA2), Leipzig (DED5), North Yorkshire (UKE2), Northumberland and Tyne and Wear (UKC2), Peloponnisos (EL65), Principado de Asturias (ES12), Sardegna (ITG2), Saxony-Anhalt (DEE0), Shropshire and Staffordshire (UKG2), South Yorkshire (UKE3), Southern Scotland (UKM9), Vzhodna Slovenija (SI03), West Central Scotland (UKM8), West Yorkshire (UKE4), West Wales and The Valleys (UKL1), Wielkopolskie (PL41), Yugozapaden (BG41) and Západné Slovensko (SK02)

As such, support mechanisms for coal regions should take into account the diversity of circumstances by:

- Ensuring the realization of potential for HDEP regions.
- Facilitating faster or more intense mobilization of existing resources for the SDEP regions
- Enabling adaptation schemes and mobilization of additional resources for the RDEP regions, to ensure their fair transition.

1 Introduction

In 2018, the Joint Research Centre (JRC) identified the European regions that will be affected by the decline of coal mining and coal power-plant activities, and assessing the impact on regional jobs (Alves Dias, et al., 2018).

In this report, the approach is forward-looking: we identify options for each region to not only cope with the transition but also harness the opportunities available for growth and job creation. The energy technologies of focus are from wind, solar photovoltaics (free standing and rooftop) and geothermal sources, bioenergy and coal-fired power plants with carbon capture. The potential for energy efficiency refurbishments in residential buildings is also analysed. Where identified, activities concerning Li-ion batteries are addressed giving a concise insight concerning planned or ongoing activities in coal regions, set against the general backdrop of initiatives to develop a European battery industry.

The report presents a concise overview of the role that clean energy technologies can play in the path to decarbonisation for the identified regions with coal mining activity. One detailed fact sheet per region summarises the main findings (Annex 2). We present estimates on the renewable energy and clean energy technical potential in each region and in addition present assessments on the potential impact this could have on job creation and regional economic development in terms of potential investments.

Many European regions are already examining or have started implementing activities to support their transition. The Platform on coal regions in transition[4] launched by the European Commission (EC) in December 2017 is where working groups meet regularly to discuss projects and best practices and where many EU coal regions have presented their approaches. Different initiatives are identified in coal regions such as hydrogen production from coking process waste gases or the use of fossil plants' sites for energy storage purposes. The region of Silesia, Poland's main coal region already examines the prospect of hydrogen separation in one of Jastrzębska Spółka Węglowa (JSW) Group coking plants. The high purity hydrogen obtained is expected to facilitate the implementation and development of a zero-emission urban transport plan in the region. In the German region of Lusatia, Brandenburg, Germany, LEAG (the joint brand of Lausitz Energie Bergbau AG and Lausitz Energie Kraftwerke AG) is embarking on building a battery storage facility with a utilisation capacity of 53 megawatt hours (MWh) at the Schwarze Pumpe power plant industrial site.[5] At Hamburg-Altenwerder, electric thermal storage (ETES) is an option tested as an alternative form of energy storage.[6] The project developers claim offering a second life for thermal power plants by transforming them to energy storage plants, reusing existing equipment in combination with new technology. Transitions are already happening in the region of Visonta, HU as well as in Klettwitz, DE where 72 500 photovoltaic (PV) panels and five wind farms have been installed in a coal mine sites, respectively.

While coal regions are also looking at projects such as repurposing land and infrastructure for recreation such as and touristic development, this report will focus only on "mainstream" low carbon energy technologies and energy efficiency. Renewable energy potential and clean energy technology options are presented as an alternative to the continuation of the current model for economic development, power generation and job creation in each region. The objective is to identify options for the coal regions for their transition to a low carbon economy so that no region is left behind.

In Chapter 2, we estimate the potential[7] for each technology taking into account the specificities of each region (e.g. land cover/availability/use, meteorological aspects; wind

[4] https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/coal-regions-in-transition

[5] https://www.leag.de/en/business-fields/bigbattery-lausitz/

[6] https://www.siemensgamesa.com/en-int/newsroom/2018/09/20180926-sgre-storage-hamburg-etes

[7] Referring to the technical potential that takes into account geographic constraints and system performance, but not economics (see section 2).

speeds, solar irradiation etc.) as described in Annex 5. Additionally, we have made a distinction between the technologies that are used in power generation (wind, solar PV, bioenergy, geothermal and coal fired power plants with carbon capture) and energy demand, i.e. energy efficiency in residential buildings.

Chapter 3 presents analysis taking into account the value chain of the regionally prominent technologies, i.e. wind and solar, mapping of manufacturing or processing facilities, the supply of resources as input into these technologies or the provision of services in relation to these.

The technical potential available is not the only driver guiding the actual site selection for investment decisions. As such, in Chapter 4 we present technology deployment projections that start from existing scenarios in line with current climate and energy framework policies in place. Based on modelling results, these projections inherently consider technology cost efficiency. We estimate the regional job creation from the clean energy technology deployment as projected in the EUCO3232.5 scenario, disaggregated for the coal regions we focus on. The regional disaggregation of national capacity needs is driven by a wider set of indicators which are analysed by scientific fields presented in the Chapter. For each region the range of resulting assigned capacities is considered, distributing the related investments and jobs accordingly, offering a plausible range of jobs and investments as final output of the assessment. In Chapter 4 we present cost trends based on literature as well as the underlying cost data of the EUCO32325 scenario. In line with this scenario choice, the related investments are estimated and analysed following the cost assumptions as proposed by the project (De Vita *et al.*, 2018), which provided the underlying data for the EUCO3232.5 modelling exercise. For all estimations, our calibration year is 2015, so at the time of conducting this analysis, any values referring to 2020 are based on our estimations.

Our approach allows ranking technologies as to their impact on job creation as well as in terms of associated investments needs, taking into account their cost efficiency and deployment potential, and projected reductions of energy technology costs. A prioritisation for potential investments is enabled making estimates of the total investment needs relative to the number of jobs created to support the transition of the regions.

Our analysis is based primarily on modelling results and not on regional/local data and information. In this study, we present estimated investments needs and not investment projections or forecasts as in for example studies presenting market potential of technologies for specific countries and regions. Our results represent potential investments within a context in line with current policies as set in Europe, accounting for incentives only as included in the original modelling exercise, i.e. within the EUCO3232.5 scenario.

2 Clean energy technologies

In this section we focus on energy technologies from wind, solar photovoltaics (free standing and roof-top) and geothermal sources, bioenergy and power plants with carbon capture, providing key operational characteristics of these technologies. To facilitate comparison with conventional power generation, in each of the tables we also provide the corresponding values for the pulverised coal (PC) fired power plant.[8] The potential for energy efficiency refurbishments in buildings and activities regarding batteries are also presented in this chapter.

The technology potential is presented on a regional level. The definition of the technology potential used in this analysis is based in the principle proposed by the US National Renewable Energy Laboratory (NREL) (Brown *et al.*, 2016), shown in Figure 1.

The largest potential, resource potential, is the amount of energy physically available. Technical potential takes into account geographic constraints and system performance, but not economics. Economic potential is the subset of the technical potential that is available when the cost required to generate the energy is below the revenues.[9] Lastly, market potential is the amount of energy expected to be generated through market deployment of technologies after considering the impact of current or future market factors, such as incentives and other policies, regulations, investor response, and the economic competition with other generation sources (Brown *et al.*, 2016).

In this section, we present the estimated technical potential for the coal regions in transition.[10] As such, the results presented correspond to the second layer of the potentials described in Figure 1. In most publications, the technical potential is the achievable electricity production in a certain region with a chosen technology, given land use and other restrictions. There is a broad range of options and assumptions adopted within different studies. Technical potentials differ among different sources mainly from different assumptions regarding restrictions and as such are not directly comparable.

This technical potential is: 1) an upper limit for alternative development pathways and 2) one of the data used for translating national projections into a range of regional projections. In this section we present the first which does not necessarily translate to investments or capacities that will be readily installed. Technology investments needed for these alternatives in each country are based on the existing measures in place to reduce greenhouse gas (GHG) emissions in Europe. As such, this analysis is done in the context set by the new EUCO3232.5 scenario (Section 4.1.1). These are country projections and need to be translated into regional (NUTS 2) projections. The result is a range of plausible technology deployment and investments in the envisaged coal regions in transition.

[8] On emissions, this refers to global median values as reported by (IPCC, 2014).

[9] The cost determines the minimum revenues required for the development of the resource.

[10] The results provided refer to capacities (GW). Please see Annex for associated power production (GWh/y) results.

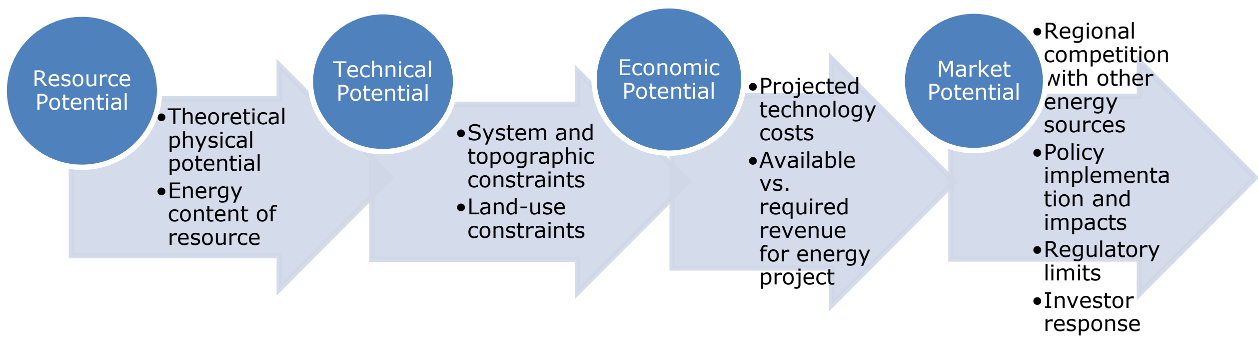

Figure 1. Resource, technical, economic and market potentials schematic (adapted from (Brown *et al.*, 2016))

2.1 Wind

For wind energy technologies, emission intensity is mainly related to indirect emissions, mostly produced upstream during raw materials extraction, components manufacturing and wind farm construction. Based on JRC (2014), current GHG emissions (expressed in CO_2-equivalent) for onshore wind energy account for about 9 to 10 tCO_2-eq/GWh whereas those of offshore wind are slightly higher at about 14 to 16 tCO_2-eq/GWh. These values are in line with studies analysing the life-cycle emissions which range for European onshore wind energy from 5 to 15 tCO_2-eq/GWh. This range results from assumptions made concerning the turbine model, average wind speed and the location of the power plant. Case studies that calculate the life-cycle emissions of offshore wind projects show a slightly broader range between 9 to 32 tCO_2-eq/GWh (Nugent and Sovacool, 2014; Asdrubali *et al.*, 2015; Bonou, Laurent and Olsen, 2016). This is because indirect emissions produced during offshore wind farm construction, operation and maintenance become higher than onshore and increase when the distance to shore becomes longer.

The capacity factor[11] for onshore wind in Europe ranges from 13 to 30 % at country level, with European average of 22 %. This range is based on wind resource assessments for a period of more than 30 years (1986-2018) considering current wind portfolio and hourly wind speeds at hub heights. The European capacity factor for offshore wind averages at about 36 % (Gonzalez Aparicio, Zucker, *et al.*, 2016; González-Aparicio *et al.*, 2017).

[11] Simply, capacity factor is the ratio of actual electricity production to the maximum possible electricity output of a power plant, over a period of time.

Table 1. Key operational characteristics of the investigated energy technologies based on (European Commission, 2014a; Gonzalez Aparicio, Zucker, Andreas Careri, Francesco Monforti, *et al.*, 2016; González-Aparicio *et al.*, 2017) and on (Tsiropoulos, Tarvydas and Zucker, 2018b). PC fired plant characteristics based on (IPCC, 2014) and (European Commission, 2014a).

Technology	**Emission intensity** (tCO_2-eq/GWh)	**Average capacity factor** (%)	**Technical lifetime** (years)
Onshore Wind	9-10 (indirect)	22	25
Offshore Wind	14-16 (indirect)	36	30
PC fired plant	880 (direct) 95 (indirect)	85	40

The wind technical potential shows significant variability across the investigated coal regions in transition. The distribution of the technical wind potential across the European coal regions ranges significantly going up to 228.2 GW in Castilla y León (ES41) based on the assumptions and restrictions defined (see Annex 5). The total technical onshore wind potential across all investigated coal regions is found to be about 821 GW.

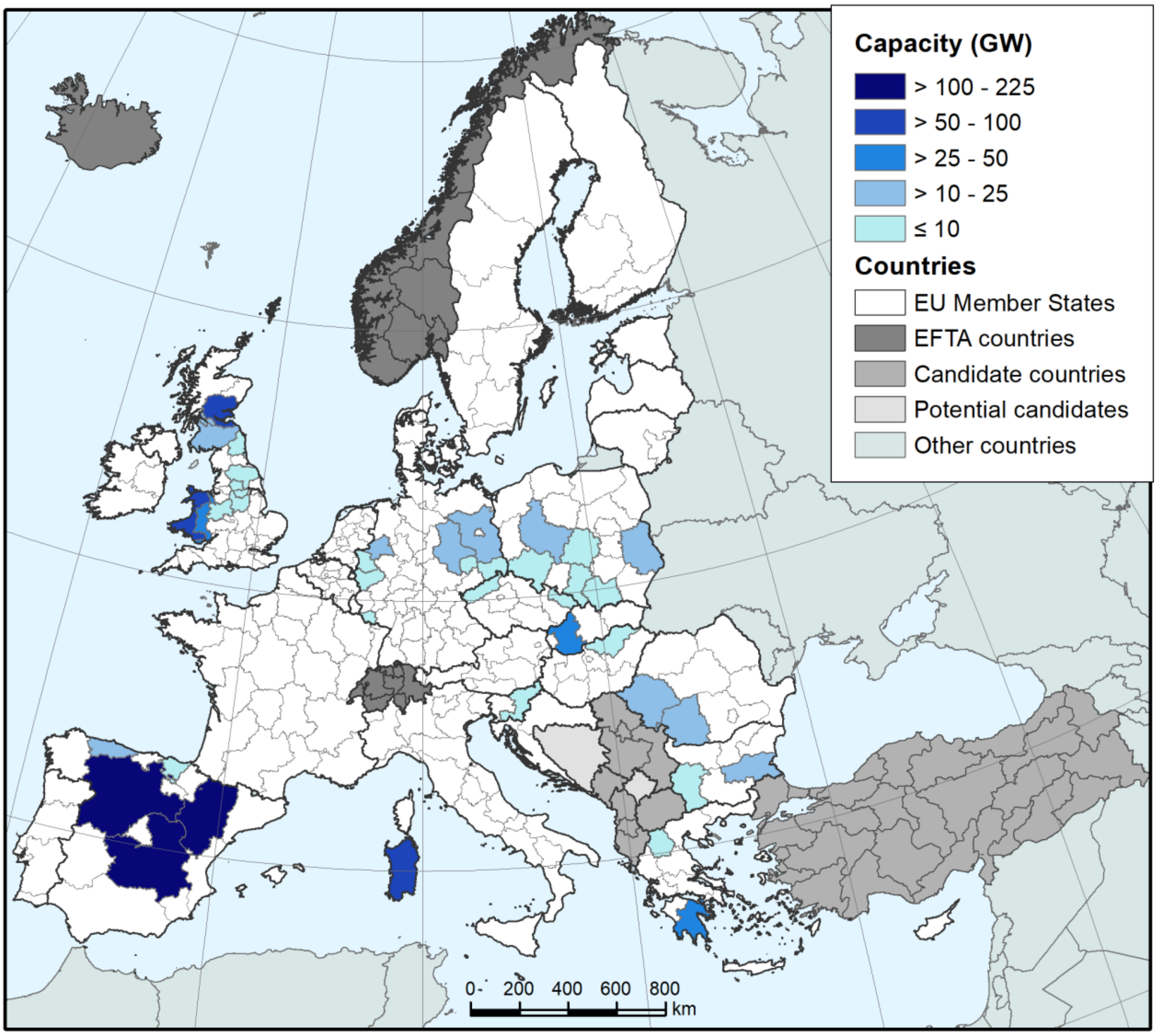

Figure 2. Technical potential (GW) for onshore wind energy in coal regions

The top 5 regions with high onshore wind potential are in Spain, Italy and Greece, namely Castilla y León (ES41), Castilla-La Mancha (ES42), Aragón (ES24), Sardegna (ITG2) and Peloponnisos (EL65). It is worth noting that some regions have a good wind resource but they show insignificant technical potential (for example Észak-Magyarország (HU31),[12] Saarland, (DEC0)) due to regionally imposed restrictions to install wind arrays.

Some of the investigated countries hosting the coal regions show a significant offshore wind potential. These potentials cannot be directly allocated to a particular coal region, as offshore territories cannot be classified on a NUTS 2 level. Offshore potential could affect the expansion of the wind industry in the respective country. Therefore, we report the offshore potentials on a country level. The total offshore wind potential on a country level hosting coal regions accounts for about 159 GW. The United Kingdom (104 GW), Germany (28 GW) and Poland (12GW) are the leading countries (see Annex 3) in terms of potential.

In 2017, the installed capacity in EU-28 reached nearly 169 GW (Eurostat, 2019b). The potential we estimate for the coal regions alone is nearly six times this capacity.

2.2 Solar photovoltaics

For PV systems, GHG emissions depend significantly on the energy-mix in the production process of the PV cells, on the geographic location, the system efficiency and the system lifetime. The values quoted in Table 2 refer to the average of results reported in literature (Wetzel and Borchers, 2015) for crystalline silicon technology manufacturers in Europe. These averages are with respect to a northern location (1 000 kWh/m^2/y), e.g. northern Germany, and at a southern one (1 700 kWh/m^2/y), e.g. southern Italy/Spain. Regarding technologies, thin-film modules have the lowest emissions, followed by poly-crystalline silicon and then mono-crystalline silicon.

PV systems capacity factor depends on the nominal yield ratio (kWh/kWp) at a given location and the installation conditions. The Product Environmental Footprint Category Rules for PV (European Commission, 2018c) assumes an average annual energy yield for EU-installed systems of 975 kWh/kWp (including the effects of degradation over the lifetime), implying a capacity factor of 0.11. If the degradation effects are excluded, the yield is 1 090 kWh/kWp and the capacity factor is 0.12. Values of annual system energy yield at NUTS level are provided using the JRC's PV-GIS methodology (see Annex 3). The corresponding capacity factors range from 0.09 in south-western Scotland (UKM8) to 0.19 in Castilla-La Mancha (ES42).

The Product Environmental Footprint Category Rules for PV (European Commission, 2018c) states an expected lifetime of the PV system of 30 years, with correspondingly an annual degradation rate 0.7% per year with respect to the initial power rating.[13]

[12] In HU31, the potential is insignificant due to low capacity factors observed in the region. As such, it is considered zero for simplification purposes.

[13] N.B. The manufacturer warranties of the main components (PV modules and inverters) typically use lower values.

Table 2. Key operational characteristics of PV power systems (without battery storage).

Technology	**Emission intensity** (t CO_2-eq/GWh)	**Average capacity factor** (%)	**Technical lifetime** (years)
PV system	47 (indirect)	11	30
PC fired plant	880 (direct) 95 (indirect)	85	40

Note: PC fired plant characteristics based on (IPCC, 2014) and (European Commission, 2014a).

For ground-mounted solar PV systems, the technical potential in the coal regions ranges from 0.85 GW for South Western Scotland (UKM8) to nearly 80 GW for Castilla y León (ES41). The top 5 regions with high potential are in Spain, Poland and Romania: Castilla y León (ES41), Castilla-La Mancha (ES42), Wielkopolskie (PL41), Sud-Vest Oltenia (RO41), and Vest (RO42).

For rooftop-mounted solar PV systems, the technical potential ranges from 0.37 GW for Dytiki Makedonia (EL53) to 4.81 GW for Düsseldorf (DEA1). The Top 5 regions with high potential are Germany and Spain: Düsseldorf (DEA1), Brandenburg (DE40), Köln (DEA2), Sachsen-Anhalt (DEE0) and Castilla y León (ES41).

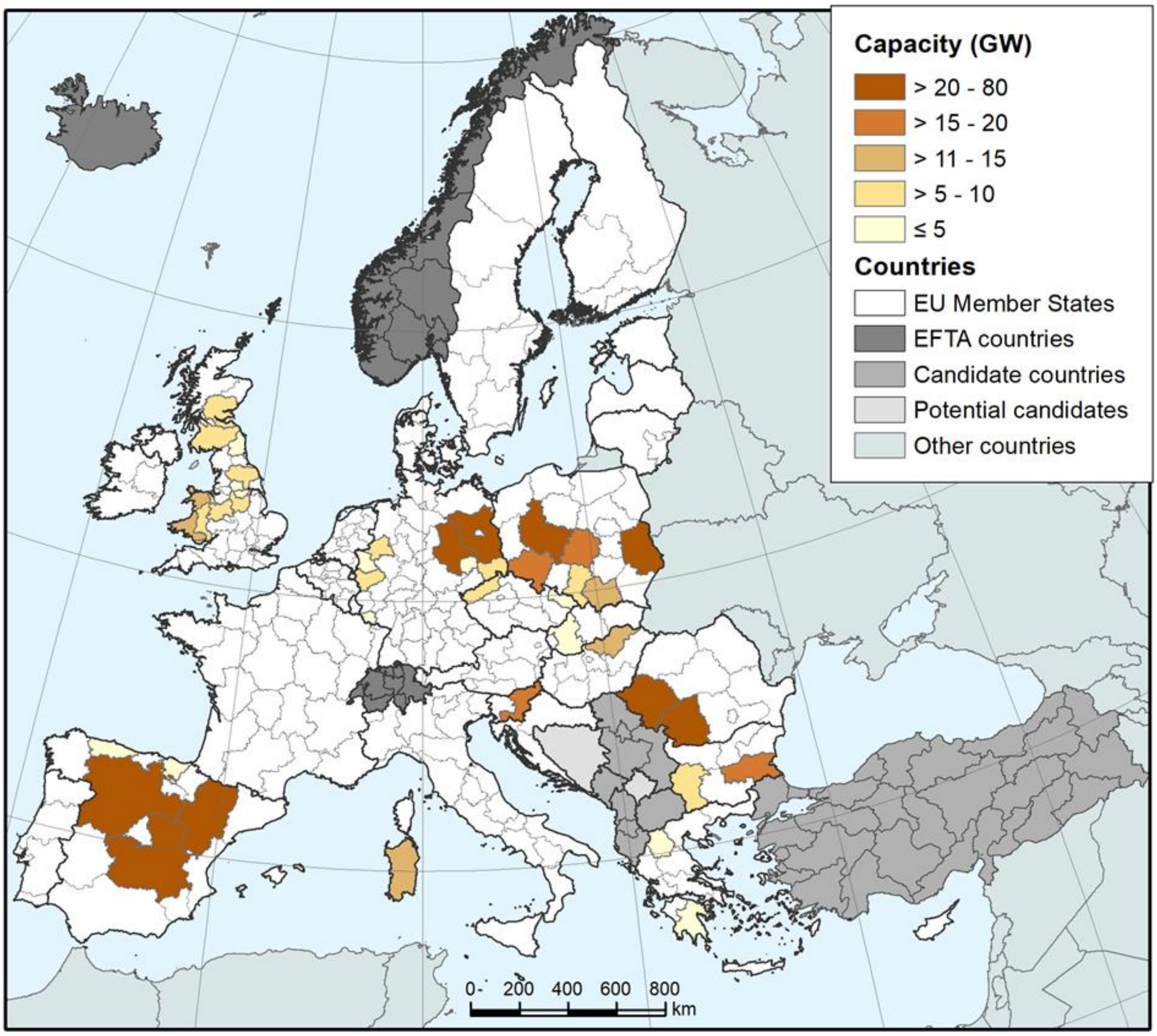

Figure 3. Cumulative technical potential (GW) for ground-mounted solar PV energy in coal regions

Both ground and rooftop-mounted solar PV potential estimated for the coal regions is more than six times the currently installed capacity in the European Union (Eurostat, 2019b).

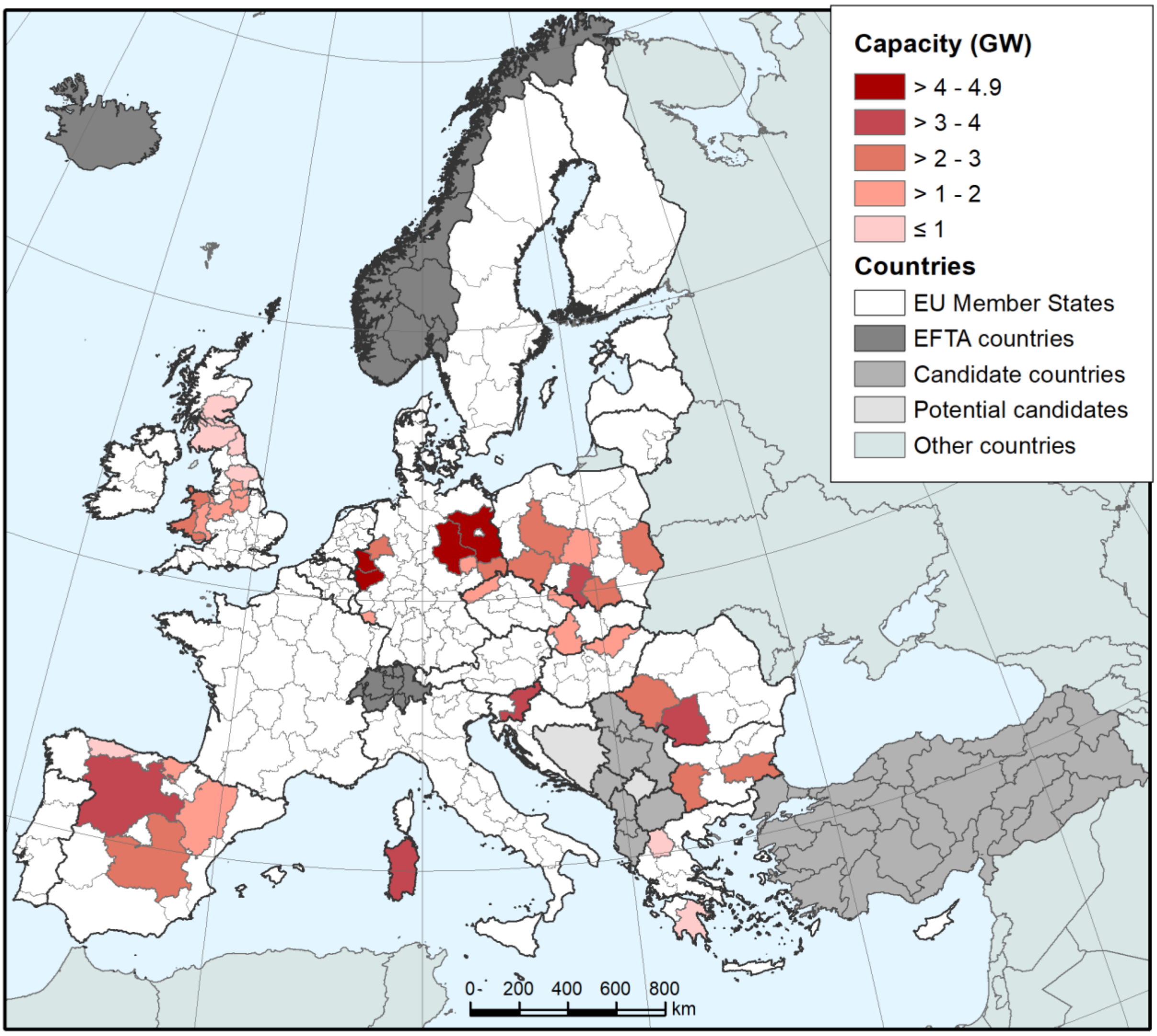

Figure 4. Cumulative technical potential (GW) for rooftop solar PV energy in coal regions

2.3 Coal mine reclamation

Coal mines located in the coal regions in transition could become attractive locations for renewable energy systems for electricity (RES-E) conversion. Relevant projects already exist in Europe (see Annex 6, Table 25 and Table 26), demonstrating an already ongoing transition.

In this study, the developed model estimates the optimum wind power and solar PV share to maximize the available technical potential in the operating open-pit coal mines in Europe. For each coal mine the model calculates the best share of wind and solar deployment based on the mine's site-specific resources, technical variables and land availability (for further information on the methodology please refer to Annex 6). This analysis has been performed for areas with operating open-pit mining only. In particular, 75 open-pit coal mines in operation in 2017 in the coal regions in transition have been identified. Underground coal mines have not been considered as the surface area covered by these mines cannot be identified. The areas around the coal mines are considered in our estimation of the potential on a NUTS 2 level.

The technical capacity of wind and solar PV in the operating open-pit coal mines shows a significant variability across the coal regions in transition. Figure 5 illustrates the distribution of the technical capacity (MW) and the calculated optimum share of wind and solar PV capacity that could potentially be installed in the operating coal mines across the European coal regions in transition.

The total technical potential across all operating open-pit coal mines is found at about 1.4 GW and 2.7 GW of wind power and solar PV respectively. It ranges up to 0.36 GW for wind energy and up to 0.63 GW for solar PV at regional level (see also Annex 4).

The technical potential is highly dependent on the resource potential and the area available in the coal mines although the latter has the highest impact on the resulting figures.

With almost 1 GW (0.36 GW of wind energy and 0.63 GW of solar PV), the highest total technical potential is found in Dytiki Makedonia (EL53). This region has 8 operating open-pit coal mines with a very high solar resource (Alves Dias, et al., 2018) and around 50.2 km^2 of area available for RES-E conversion representing the highest value among the coal regions. Regions also found to have a good technical potential include Severozápad (CZ04) and Wielkopolskie (PL41), resulting from the high area availability and a favourable solar resource in these regions. The technical capacity in the operating open-pit mines is found to reach around 0.18 GW of wind energy and 0.33 GW of solar PV in Severozápad (CZ04) and around 0.15 GW of wind energy and 0.28 GW of solar PV in Wielkopolskie (PL41). In spite of having only one operating open-pit coal mine, the region of Yugoiztochen (BG34) also shows a high technical potential of about 0.12 GW of wind energy and 0.21 GW of solar PV. This is due to the area available for renewable energy systems conversion in this mine (about 16.3 km^2) and the site being characterized by a high solar resource. Brandenburg (DE40) is completing the top five regions with a capacity of approximately 0.25 GW, resulting from wind and solar PV (0.09 and 0.16 GW, respectively).

Some regions characterized by good resource availability show a low technical potential due to the limited area for RES-E conversion in the operating coal mines. For example, the coal regions in Central Spain (Castilla y León, Aragón and Castilla-La Mancha) show a low technical potential. This falls in the range of 11-22 MW of wind energy and 23-45 MW of solar PV even if having a very high solar resource. The technical potential decreases in Central and Eastern United Kingdom, where in spite of having the highest wind resource, the area available for RES-E conversion is very limited.

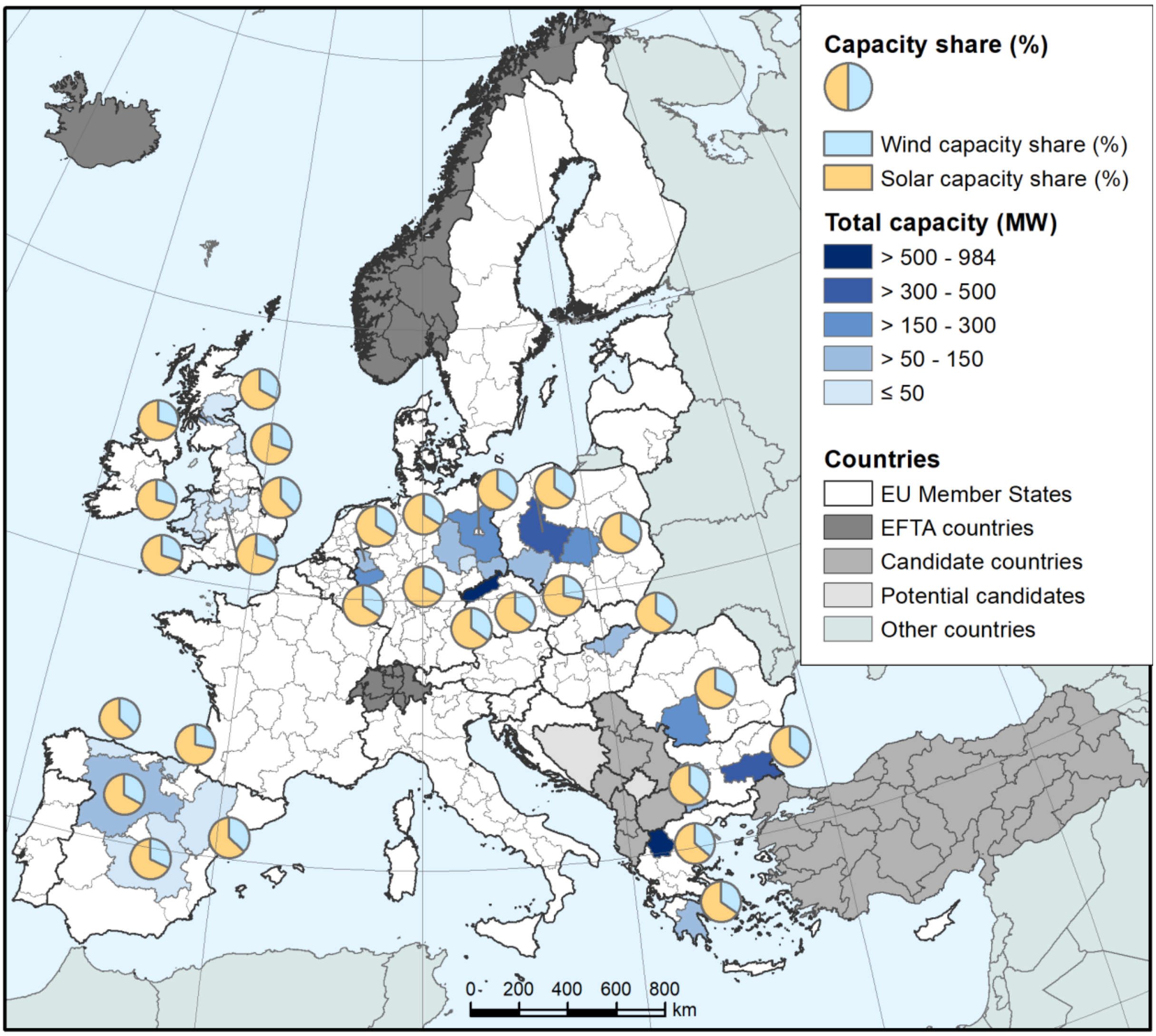

Figure 5. Technical potential (MW) and optimum share of wind and solar PV capacity (pie charts) in the operating coal mines of the regions in transition

For coal mines, we also present the technical potential in terms of electricity production (Figure 6) given that these sources have different capacity factors. For example, in the UK, the share in solar capacity may be dominant but in terms of production it is wind that provides a higher share in GWh/y.

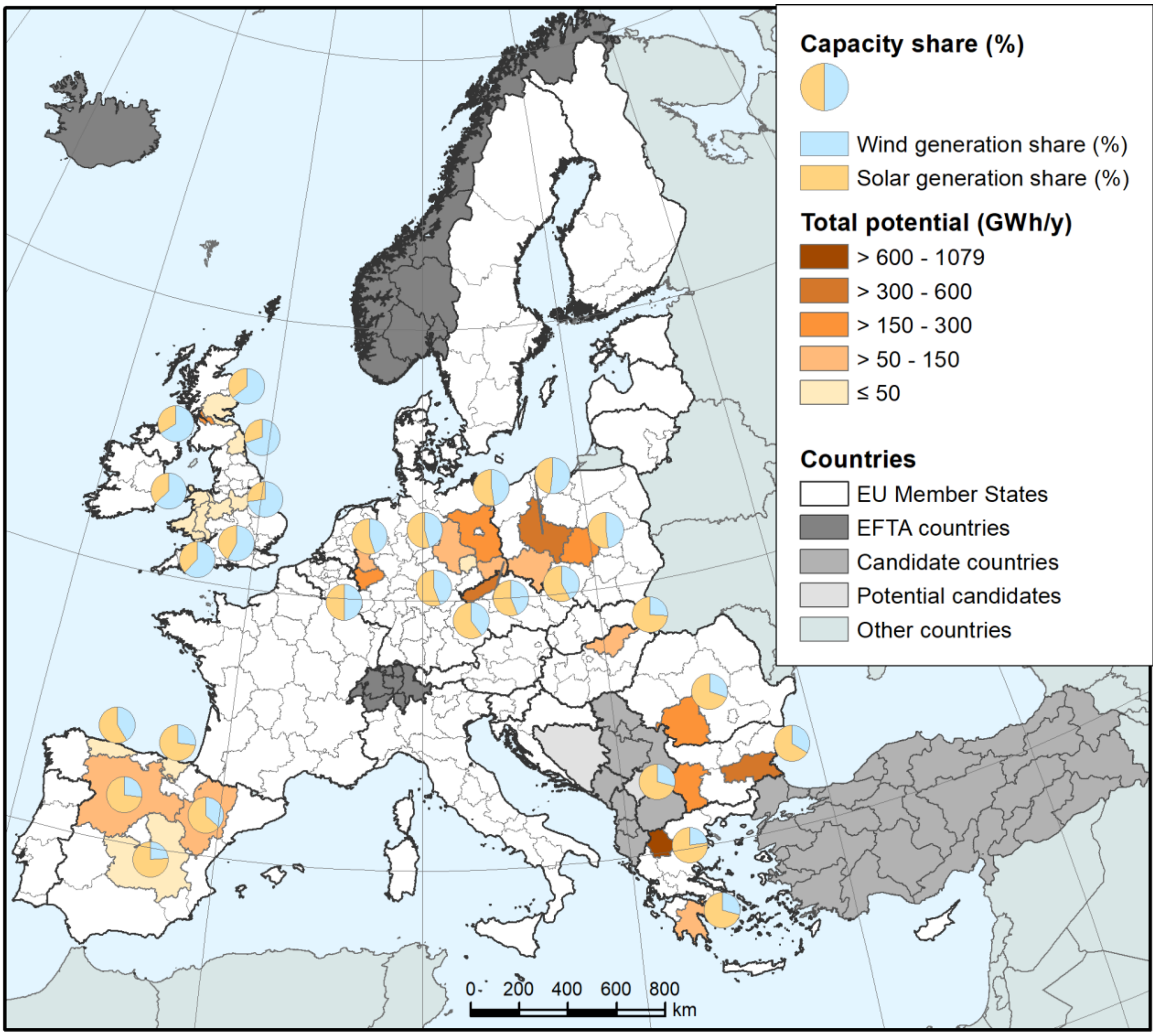

Figure 6. Technical potential (GW/h) and optimum share of wind and solar PV generation (pie charts) in the operating coal mines of the regions in transition

2.4 Bioenergy

For the bioenergy plants, we considered the following options using different biomass feedstock:

- Biomass combustion with steam turbine using forestry or agricultural residues
- Anaerobic digestion for biogas production with electricity generation and gas engine
- Waste incineration with energy recovery

Table 3 provides the key operational characteristics. The emission intensity and capacity factor value is dependent on the technology type. For the present analysis, values of annual system bioenergy are provided separately for the technology. The corresponding capacity factors range from 0.91 for biomass combustion and anaerobic digestion and biogas production to 0.86 for waste incineration with energy recovery.

The technical lifetime varies between different bioenergy options: the operational lifetime for biomass combustion and waste incineration is 25 years and the operational lifetime for biogas production is 20 years.

Table 3. Key operational characteristics of bioenergy systems.

Technology	**Emission intensity** (t CO_2 /GWh)	**Average capacity factor** (%)	**Technical Lifetime** (years)
Biomass combustion	45	91	25
Anaerobic digestion	-302.4	91	20
Waste incineration	106	86	25
PC fired plant	880 (direct) 95 (indirect)	85	40

Note: PC fired plant characteristics based on (IPCC, 2014) and (European Commission, 2014a).

For bioenergy from crop residues the sustainable technical potential (Figure 7) reaches 0.73 GW for Castilla y León (ES41). The top 5 regions with high bioenergy potential from crop residues are in Spain, Germany and Poland: Castilla y León (ES41), Castilla-La Mancha (ES42), Saxony-Anhalt (DEE0), Wielkopolskie (PL41) and Brandenburg (DE40). These top five regions account for almost 2 GW of potential from crop residues.

Municipal solid waste estimates indicate a technical potential (Figure 8) of up to 0.10 GW. The top 5 regions with the highest estimates are for Silesia (PL22), Yugozapaden (BG41), Castilla y León (ES41), Castilla-La Mancha (ES42) and Wielkopolskie (PL41). The potential estimated for Silesia alone, accounts nearly eight times the primary energy from municipal waste in all Poland in 2016 (Eurostat, 2019a).

For bioenergy from livestock methane, the technical potential (Figure 9) reaches 0.11 GW for Castilla y León (ES41). The top 5 regions with high bioenergy potential from livestock methane are in Spain, Poland and Germany: Castilla y León (ES41), Wielkopolskie (PL41), Aragón (ES24), Castilla-La Mancha (ES42) and Münster (DEA3). The three regions identified in Spain sum up to more two times the biogas primary production in Spain (Eurostat, 2019a).

The evaluation of forest bioenergy potentials has been carried under three scenarios with different sustainability assumptions: High, Medium and Low biomass availability for energy (see Annex 4).[14] Brandenburg (DE40), Západné Slovensko (SK02), Vest (RO42), Castilla y León (ES41) and Łódzkie (PL71) are the top five regions in terms of technical potential (Figure 10).

[14] We refer to the medium scenario estimation. For estimations of all scenarios please refer to Annex 3 and for the description to scenarios to Annex 5.

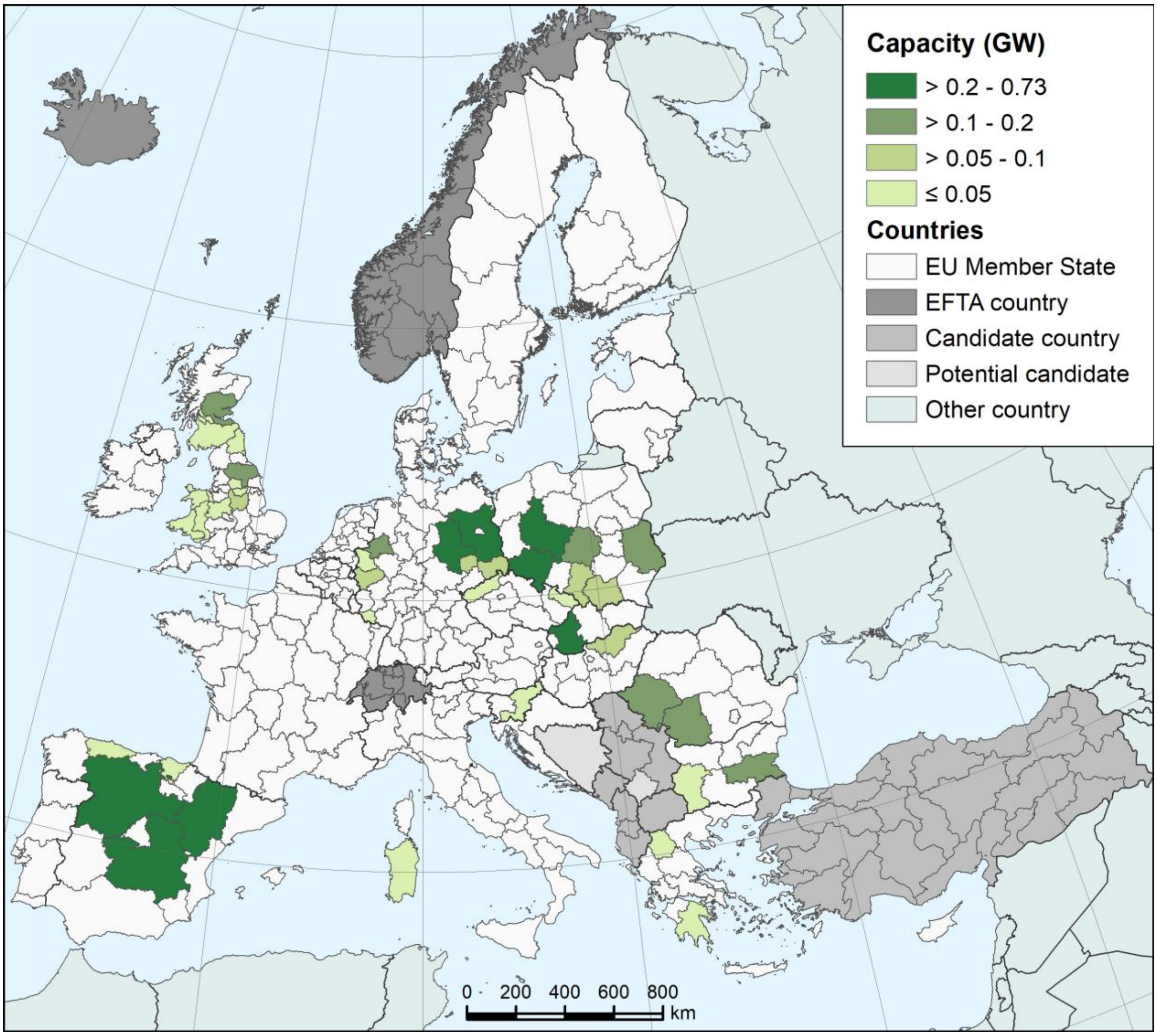

Figure 7. Technical capacity potential (GW) for bioenergy from crop residues in coal regions

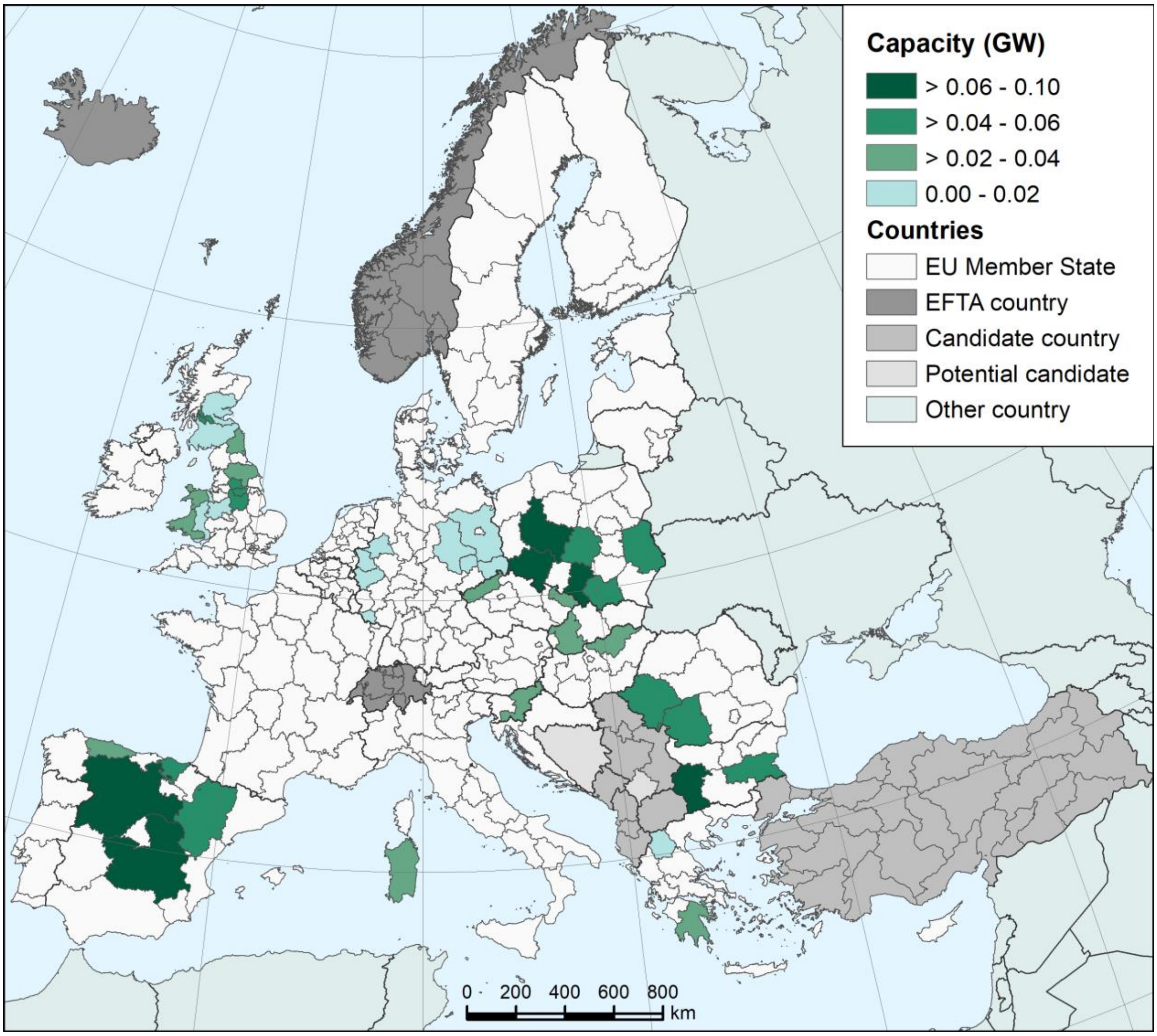

Figure 8. Technical potential (GW) for bioenergy from municipal solid waste in coal regions

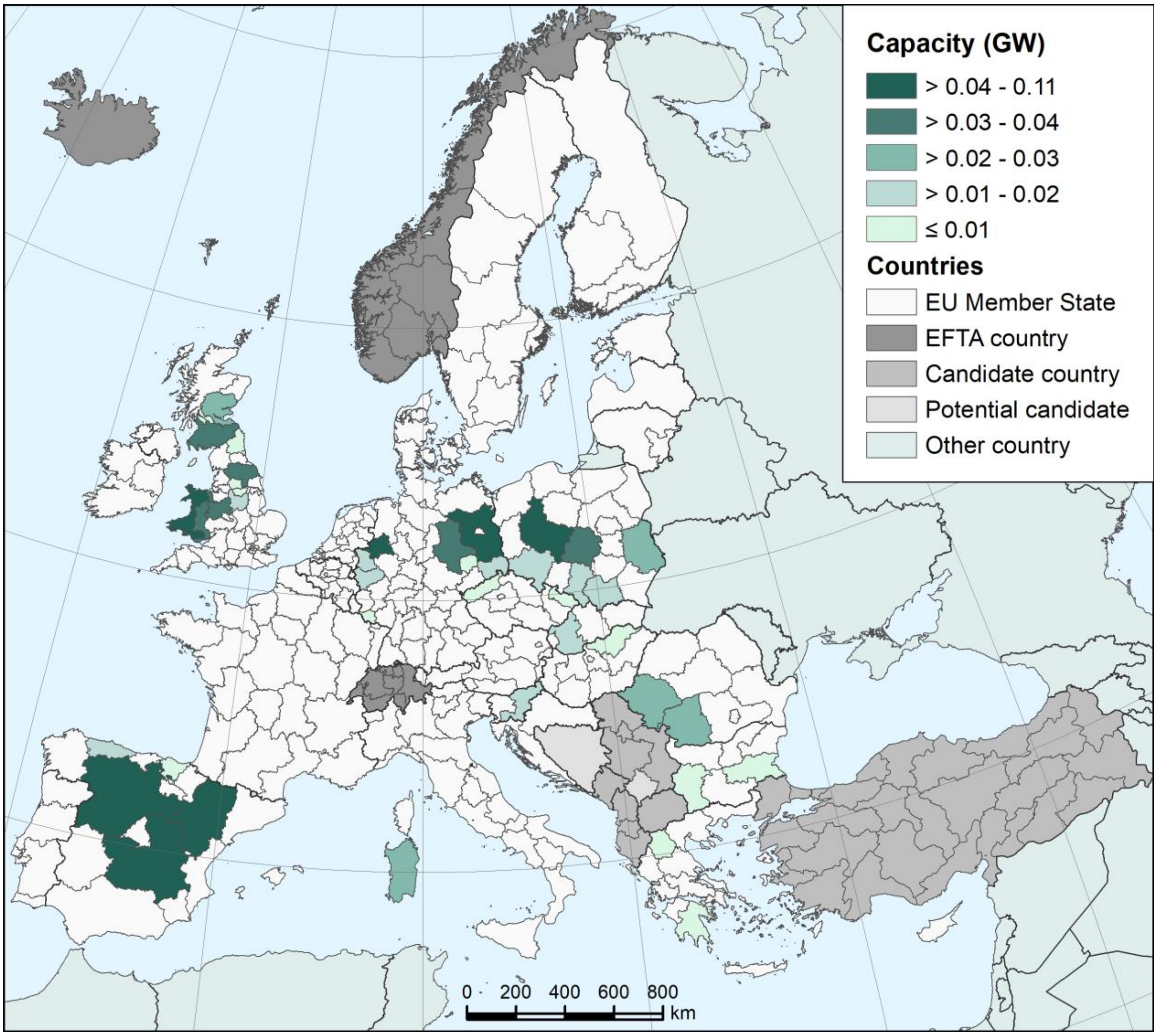

Figure 9. Technical potential (GW) for bioenergy from livestock methane in coal regions

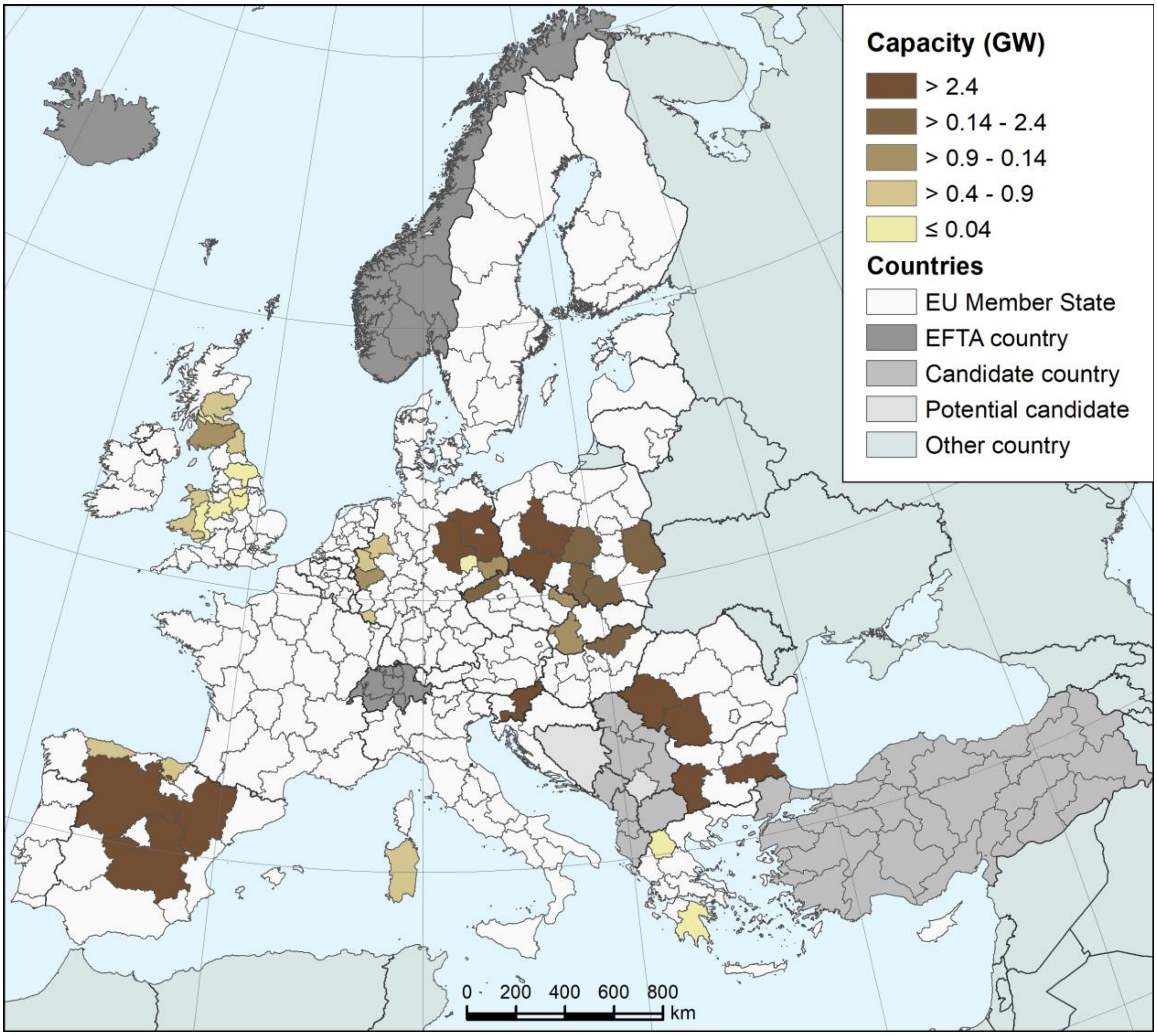

Figure 10. Technical potential (GW) for bioenergy from forest biomass (medium scenario) in coal regions

The above values refer to potential for electricity. In Annex 3 we also provide the corresponding heat potential from bioenergy which can be either used for electricity or heating.

2.5 Geothermal energy

For geothermal energy, Table 4 provides the key characteristics for the three most common types of geothermal power plants: flash power plants, hydrothermal binary Organic Rankine Cycle (ORC) plants and Enhanced Geothermal Systems (EGS).

Table 4. Key operational characteristics of geothermal power.

Technology	Emission intensity[1)] (tCO_2-eq /GWh)	Average capacity factor[2)] (%)	Technical lifetime[3)] (years)
Flash power plant	50 direct 92 indirect	91	30
Hydrothermal ORC	4 direct 92 indirect	91	30
EGS ORC	0 direct 55 indirect	91	30
PC fired plant	880 (direct) 95 (indirect)	85	40

1) Based on (Goldstein *et al.*, 2011; Carlsson, 2014)
2) Assumed 8 000 full load hours according to GEOELEC economic model (van Wees *et al.*, 2013);
3) Sources: (Sigfússon and Uihlein, 2015; Tsiropoulos, Tarvydas and Zucker, 2018a)

GHG emissions from geothermal power plants are dominated by CO_2 emissions. CO_2 and other gases are contained in geothermal fluids and gas composition depends on the geological conditions. IRENA states that the range of GHG emissions of geothermal power plants is between 6 and 79 t CO_2-eq/GWh (*Geothermal Power Technology Brief*, 2017). While a 2015 study (Asdrubali *et al.*, 2015) gives values between 16.9 and 142 t CO_2-eq/GWh, a field study in 2001 found a great diversity of CO_2 emissions between power plants. Values varied from 4 to 740 t CO_2/GWh with an average emission of 122 t CO_2/GWh (Bertani and Thain, 2002). However, this study also includes some open-loop facilities with high dissolved CO_2 concentrations which emit CO_2 at very high rates, which is not the case for the majority of the installed capacity.

Lifecycle CO_2 emission estimates give values of less than 50 t CO_2-eq/GWh for flash steam plants and less than 80 t CO_2-eq/GWh for projected EGS plants (Goldstein *et al.*, 2011). (Carlsson, 2014) gives direct emissions of 122 t CO_2-eq/GWh for flash, 4 t CO_2-eq/GWh for hydrothermal ORC and 0 t CO_2-eq/GWh for EGS ORC. Indirect emissions are given with 92 t CO_2-eq/GWh for flash and hydrothermal ORC and 55 t CO_2-eq/GWh for EGS ORC. As such, it is realistic to consider direct emissions of 50 t CO_2-eq/GWh for flash steam plants (Goldstein *et al.*, 2011) and for the ORC plants, and a range of 55 – 95 t CO_2-eq/GWh for indirect (Carlsson, 2014).

Previous JRC studies considered a capacity factor for all three types of geothermal EGS power plants of about 95 % (Carlsson, 2014; Sigfússon and Uihlein, 2015). According to IRENA, geothermal power plants capacity factor is more than 80 % globally, and can reach for some plants and units more than 90 % (*Geothermal Power Technology Brief*, 2017).

The lifetime of geothermal power plants is usually assumed to be 30 years (*Towards more geothermal electricity generation in Europe*, 2014; Carlsson, 2014; Sigfússon and Uihlein, 2015; Tsiropoulos, Tarvydas and Zucker, 2018a).

When it comes to the specific potential of the coal regions, we find that the sustainable potential ranges from 0.01 MW for South Yorkshire (UKE3) to 0.50 GW for Castilla y León (ES41) (Figure 11). The top 5 regions with high potential are in Spain, Romania and Germany: Castilla y León (ES41), Castilla-La Mancha (ES42), Aragón (ES24), Vest (RO42) and Brandenburg (DE40). Specifically, the estimated values indicate a potential that is so far untapped in these countries. Besides Germany with a 0.03 GW capacity of geothermal energy in 2018 (IRENA, 2019), Spain and Romania have insignificant geothermal power capacity.

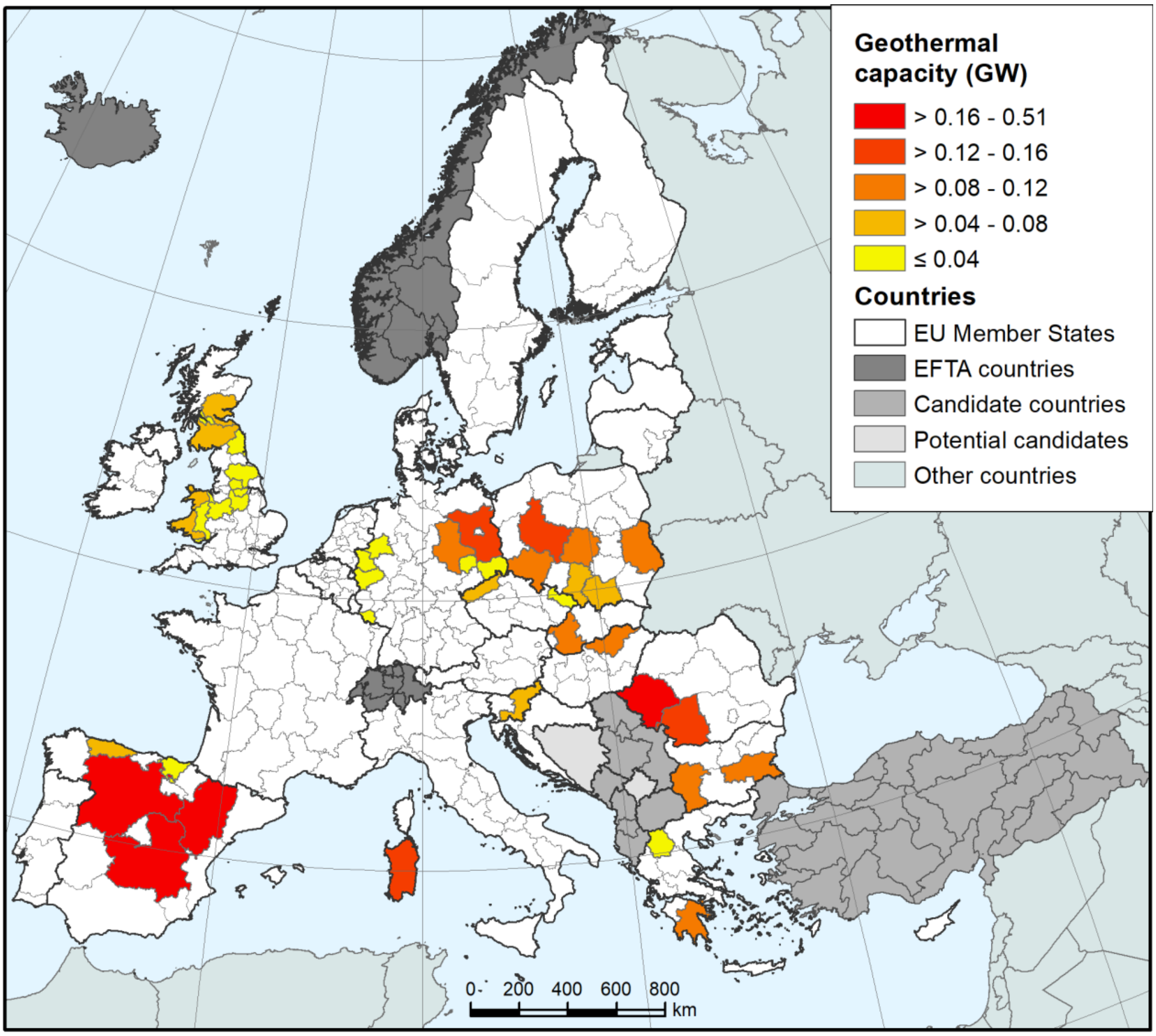

Figure 11. Sustainable potential (GW) for geothermal energy in the coal regions

The above values refer to potential for electricity. In Annex 3 we also provide the corresponding geothermal heat potential which can be either used for electricity or heating.

2.6 Carbon capture

The application of CO_2 capture, transport, and storage in coal fired power plants requires additional energy, linked with corresponding emissions. Depending on the CO_2 capture rate, the emissions can be reduced by 82 % to 89 % per kWh (Rubin, E. S., Davison, J. E., & Herzog, 2015). Direct emissions associated with CCUS[15] have been estimated in the range of 60-140 tCO_2eq/GWh and indirect in the range of 98-160 tCO_2eq/GWh (European Commission, 2014a; Global CCS Institute, 2015; US DOE/NETL, 2015b, 2015a).

The capacity factor for power plants with carbon capture is considered in the range of 80-90 % (Rubin, E. S., Davison, J. E., & Herzog, 2015; Global CCS Institute, 2017; ZEP, 2017). As there are no coal-fired power plants with CO_2 capture operating in Europe, these values are assumed averages. The lifetime of power plants with CO_2 capture projects is in the range of 30-35 years on average. The first large scale CCUS project in

[15] "CCUS" is used as an "umbrella" term for projects where CO_2 is captured and permanently stored, either geologically or by enhanced oil recovery, even if the latter is not developed in Europe.

power generation operating since 2014 in Canada, is considering a lifetime of 30 years (IEAGHG, 2015).

Table 5. Key operational characteristics of Pulverised Coal (PC) plants.

Technology	**Emission intensity (tCO_{2eq}/GWh)**	**Average capacity factor (%)**	**Technical lifetime (years)**
Pulverised coal/lignite plants	890-1 010 (direct) 95- 110 (indirect)	85-90	35-40
Pulverised coal plants, post-combustion	105 (direct) 120 (indirect)	85-90	35-40

Sources: (Spisto *et al.*, 2014; Tsiropoulos, Tarvydas and Zucker, 2018b)

For carbon capture, we estimate the technical potential deployment primarily based on the carbon capture readiness of existing plants. The criteria are based on what is prescribed within the CCS Directive (please see Annex 5 for methodology). Based on existing publically available CO_2 storage data (Poulsen *et al.*, 2014; BGR, 2019) we assume that there is enough storage capacity nationally[16] to accommodate the captured CO_2. Currently, there is no transportation network routing CO_2 to storage locations. In the UK for example, the assumptions that some developers have made in the permitting process with regard to feasible CO_2 transport pipe routes, place some doubt on the realism of any future CO_2 capture for some of the plants (Triple-e, Ricardo-AEA and TNO, 2015). However, the potential developments regarding CO_2 networks in Europe within the Projects of Common Interest (PCI) instrument may unlock an associated potential. Nevertheless, a detailed and focused analysis would be required to accurately match the associated CO_2 sources and sinks.

35 units of pulverised coal fired power plants, which is 12% of those operating in the coal regions, could be fitted with carbon capture subject to considerations as set in Annex 5. Figure 12 presents the technical potential estimated which ranges from 0.10 GW in Castilla-La Mancha (ES42) to 3.96 GW for Yugoiztochen (BG34). The top 5 regions with high potential are in Bulgaria, Germany and Poland, namely Yugoiztochen (BG34), Düsseldorf (DEA1), Silesia (PL22), Dresden (DED2) and Leipzig (DED5). While three out of these five regions are in Germany, discussions on phasing out coal are ongoing. Recommendations from the so-called German "Coal Commission" proposed coal exit by 2038 (German Commission on Growth Structural Change and Employment, 2019). These are only advisory and the actual implementation lies with Germany’s government so it is unknown when and how much of the German capacity will eventually remain online.

In this analysis, we also consider the new standards for Europe’s large coal-fired power stations published by the European Commission in 2017. Previous work indicated the risk of early retirement of coal fired power plants due to these new standards (Alves Dias et al., 2018). These standards primarily refer to toxic pollutants and not CO_2 as such. We assume the best available techniques (BAT)[17] incorporated to comply with the Industrial Emissions Directive (IED) as a driver to the plants' continued operation, subsequently

[16] Currently, there is a legal barrier imposed by the non-ratification of the London Protocol CCS amendment to exporting CO_2 from one country to another for offshore storage.

[17] It refers to the Best Available Techniques (BAT) that large combustion plants must use to improve their efficiency and address emissions to air such as dioxides of sulphur (SOX) and nitrogen oxides (NOX), mercury, hydrogen chloride and hydrogen fluoride from the combustion of solid fuels. The standards also tighten the existing emission limits for pollutants including sulphur dioxide (SO2) and nitrogen oxides (NOx).

facilitating carbon capture technologies' retrofit. Considering compliance with the Industrial Emissions Directive (IED), Severozapad (CZ04) substitutes Silesia (PL22) in the list of top 5 regions (Figure 13).

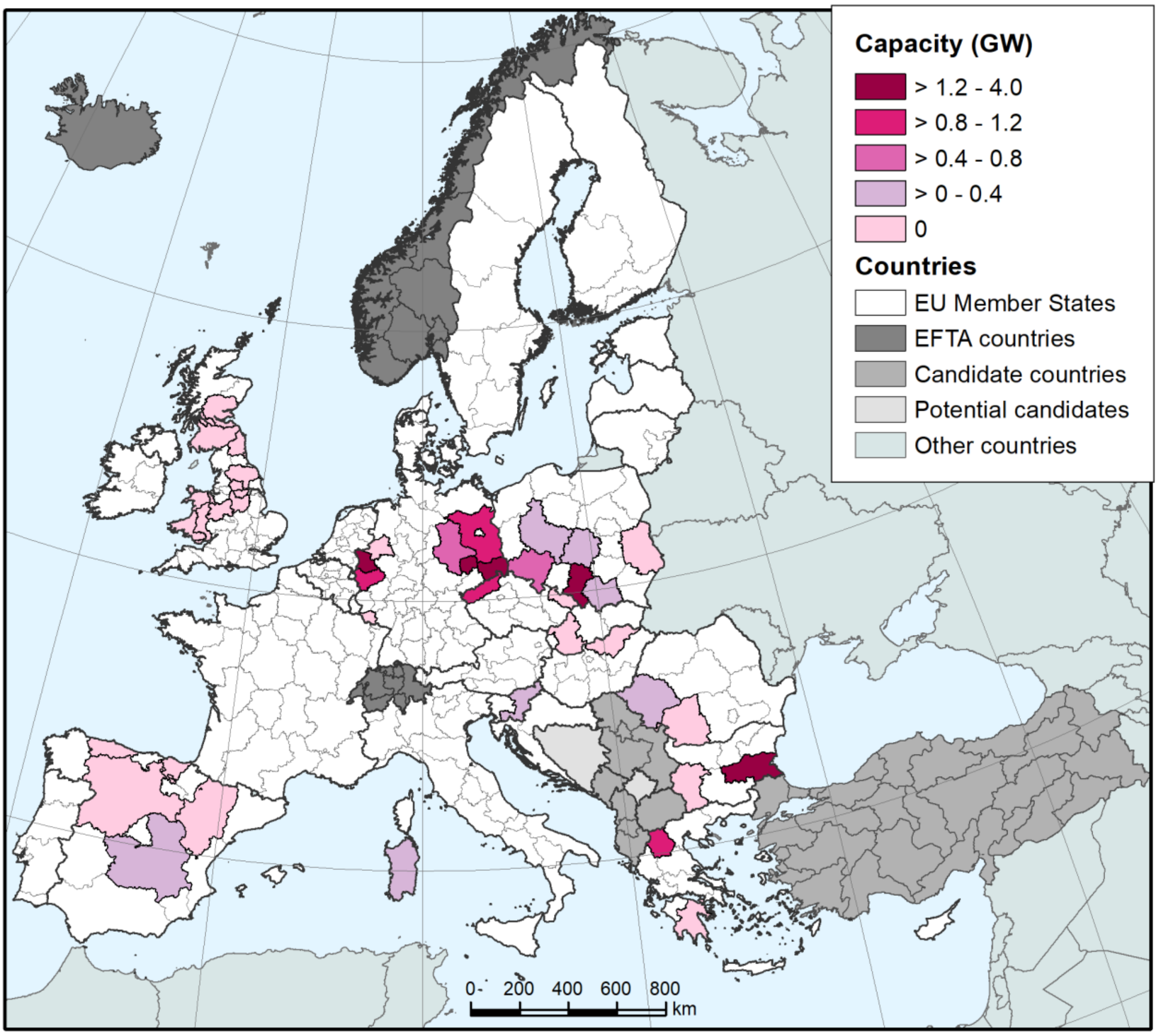

Figure 12. Carbon capture potential capacity (GW) for PC power plants in the coal regions

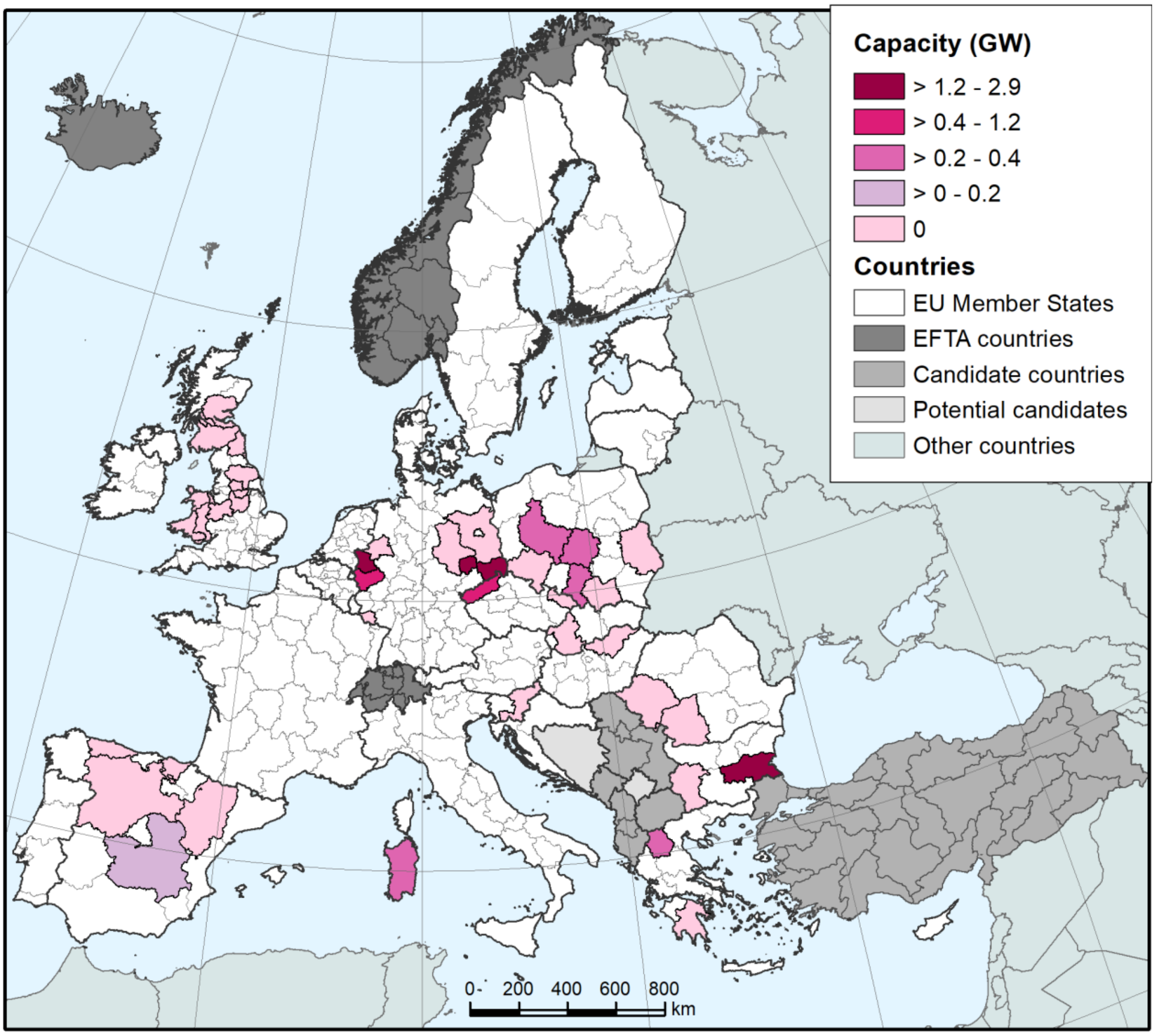

Figure 13. Carbon capture potential capacity (GW) for PC power plants in the coal regions considering IED BAT

2.7 Energy efficiency in residential buildings

In the frame of the implementation of the Energy Performance of Buildings Directive (EPBD) recast (2010/31/EU) (European Parliament & Council, 2009), the EU Member States were asked to develop policies appropriate to their national situations and provide the necessary financing to foster the transition to Nearly Zero-Energy Buildings (NZEB). However, acknowledging the variety in building culture and climate throughout Europe, the EPBD does not prescribe a uniform approach for implementing NZEB. Member States were required to draw up National Plans for increasing the number of NZEBs, with targets that may be different for different building categories. According to paragraph 3 of Article 9, these plans shall include NZEB definitions reflecting national, regional or local conditions, and numerical indicators of primary energy use and ratio covered by Renewable Energy Systems (RES) (D'Agostino *et al.*, 2016).

The EPBD recast asked Member States to calculate cost-optimal levels of minimum energy performance requirements for new and existing buildings by using the comparative methodology framework established by the European Commission. This cost-optimal calculation framework involves the following steps: i) definition of national reference buildings representing the national building stock; ii) identification of energy efficiency measures and packages to be evaluated; iii) calculation of primary energy demand of the reference buildings with the identified energy efficiency measures; iv) calculation of global costs related to each of the energy efficiency measure and package considering long term expenditures and savings during the calculations period; v) sensitivity analysis for input data; vi) derivation of cost-optimal levels of energy performance requirements.

While the Member States are updating their plans and calculations (Boermans *et al.*, 2015) in line with the regulatory background, a recent research project (ENTRANZE[18]) provided primary energy levels and benchmarks for building renovation which may represent the cost-optimal and NZEB targets across Europe (Zangheri *et al.*, 2018). According to this study, the NZEB area appears characterized by medium-high and high recurrences of efficiency and RES technologies in all countries. For instance, a typical NZEB building has a well-insulated envelope[19] (including insulation layers of 10-30 cm and double or triple low-e windows), efficient generators (e.g. condensing boiler or ground source heat pump or district heating) in some case assisted by heat recovery strategies, and installed renewable solar systems (normally both thermal and photovoltaic). Otherwise the cost-optimal benchmarks are more heterogonous. Various are the retrofit solutions able to reach this target, that overall is characterized by the competition between the deepest actions regarding envelope, thermal systems and solar renewable systems. As expected, it is difficult to minimize the global costs applying a high-performance envelope, very efficient generators, a heat recovery strategy and a PV plant at the same time. This occurs only in some particular locations.

The data included in Table 6 can be used as key operational characteristics of the technical renovation solutions reaching the cost-optimal and NZEB energy levels.

[18] https://www.entranze.eu/

[19] the physical barrier between the exterior and interior environments enclosing a structure (Hagentoft, 2001).

Table 6. Energy saving with respect to the pre-retrofit primary energy level and associated investment costs (EUR/m^2) for the cost-optimal and NZEB renovation levels of single family houses (SFH) and multi-family houses (MFH).

NUTS2	SFH				MFH			
	Cost-optimal level		NZEB level		Cost-optimal level		NZEB level	
	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]
BG34	60%	215	90%	425	60%	150	75%	230
BG41	60%	215	90%	425	60%	150	75%	230
CZ04	70%	290	90%	451	45%	135	70%	224
CZ08	70%	290	90%	451	45%	135	70%	224
DE40	75%	560	90%	733	50%	343	80%	429
DEA1	75%	560	90%	733	50%	343	80%	429
DEA2	75%	560	90%	733	50%	343	80%	429
DEA3	75%	560	90%	733	50%	343	80%	429
DEC0	75%	560	90%	733	50%	343	80%	429
DED2	75%	560	90%	733	50%	343	80%	429
DED5	75%	560	90%	733	50%	343	80%	429
DEE0	75%	560	90%	733	50%	343	80%	429
EL53	80%	330	80%	330	75%	220	75%	220
EL65	70%	320	70%	320	70%	160	75%	170
ES12	80%	520	95%	570	75%	300	85%	280
ES21	80%	520	95%	570	75%	300	85%	280
ES24	80%	520	95%	570	75%	300	85%	280
ES41	80%	520	95%	570	75%	300	85%	280

Table Continued: Energy saving with respect to the pre-retrofit primary energy level and associated investment costs (EUR/m^2) for the cost-optimal and NZEB renovation levels of single family houses (SFH) and multi-family houses (MFH).

NUTS 2	SFH				MFH			
	Cost-optimal level		NZEB level		Cost-optimal level		NZEB level	
	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]
ES42	80%	520	95%	570	75%	300	85%	280
HU31	80%	500	95%	620	55%	290	80%	330
ITG2	60%	170	75%	340	50%	105	65%	150
PL21	75%	310	90%	450	50%	150	80%	255
PL22	75%	310	90%	450	50%	150	80%	255
PL41	75%	310	90%	450	50%	150	80%	255
PL51	75%	310	90%	450	50%	150	80%	255
PL71	75%	310	90%	450	50%	150	80%	255
PL81	75%	310	90%	450	50%	150	80%	255
RO41	60%	215	90%	425	60%	150	75%	230
RO42	60%	215	90%	425	60%	150	75%	230
SI03	65%	200	95%	400	60%	140	95%	250
SK02	90%	450	95%	475	80%	255	85%	270
UKC2	20%	130	60%	450	30%	160	65%	400
UKE2	20%	130	60%	450	30%	160	65%	400
UKE3	20%	130	60%	450	30%	160	65%	400
UKE4	20%	130	60%	450	30%	160	65%	400
UKF1	20%	130	60%	450	30%	160	65%	400
UKG2	20%	130	60%	450	30%	160	65%	400

Table Continued: Energy saving with respect to the pre-retrofit primary energy level and associated investment costs (EUR/m^2) for the cost-optimal and NZEB renovation levels of single family houses (SFH) and multi-family houses (MFH).

NUTS 2	SFH				MFH			
	Cost-optimal level		NZEB level		Cost-optimal level		NZEB level	
	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]	Energy saving	Investment costs [€/m^2]
UKL1	20%	130	60%	450	30%	160	65%	400
UKL2	20%	130	60%	450	30%	160	65%	400
UKM7	20%	130	60%	450	30%	160	65%	400
UKM8	20%	130	60%	450	30%	160	65%	400
UKM9	20%	130	60%	450	30%	160	65%	400

The investment costs are considered constant over a period of 30-40 years, as generally assumed by Member States for their cost-optimal calculations (Boermans *et al.*, 2015). When it comes to technology deployment projections, a direct comparison to the data supporting the EC Reference Scenario (De Vita *et al.*, 2018), is not trivial. This is because the type of renovation measures used are not described in detail and it is not clear how the geographical regions (Centre/West, North, South and East) were defined. However the investment costs used in (De Vita *et al.*, 2018) seem lower that those collected for this study. The main reason for these discrepancies likely is the technological packages associated to our renovation levels. Usually, these also include energy efficiency measures regarding the thermal building systems (e.g. condensing boilers, heat pumps, heat recovery, etc.) and renewable technologies (i.e. thermal solar and photovoltaic).

The obtained primary energy saving potential is presented in the following figures. These map the final results obtained by considering 3 scenarios:

– "Theoretical NZEB" refers to the total technical potential related to the renovation of all occupied existing dwellings to the NZEB level. We consider it as the theoretical maximum amount of energy that could be saved with energy efficiency measures, disregarding all non-engineering constraints such as economic or market barriers. It takes into account the size and the current characteristics of the building stock and the technical factors associated to the renovation measures.

– With "Theoretical cost-optimal" we refer to a more realistic technical potential related to the renovation of all occupied existing dwellings to the cost-optimal level, which minimise the global cost of the building over a period of 30 years.

– And "Business As Usual at 2050", which considers a realistic dynamic of renovations (rate of 1.5% yearly) and an equal distribution between cost-optimal and NZEB refurbishments.

Due to the high number of occupied dwellings, the top five coal regions with the highest potential in energy savings for all scenarios are in Germany. Namely, Düsseldorf (DEA1, 34.34, 49.02 and 18.76 TWh), Köln (DEA2 31.92, 44.02 and 17.09 TWh), Brandenburg (DE40 19.52, 26.72 and 10.4 TWh), Münster (DEA3 19.2, 26.06 and 10.18 TWh) and Saxony-Anhalt (DEE0 16.28, 22.65 and 8.76 TWh), respectively to the three scenarios considered. The maximum energy saving potential (associated with the "Theoretical NZEB" scenario) resulting in all the German regions under investigation represents 5.9% of the national primary energy consumption in 2017. This ratio increases up to 9.2% for Slovenia, while the lowest potential (0.6%) is observed in Italy (represented by only one region, ITG2, Sardegna).

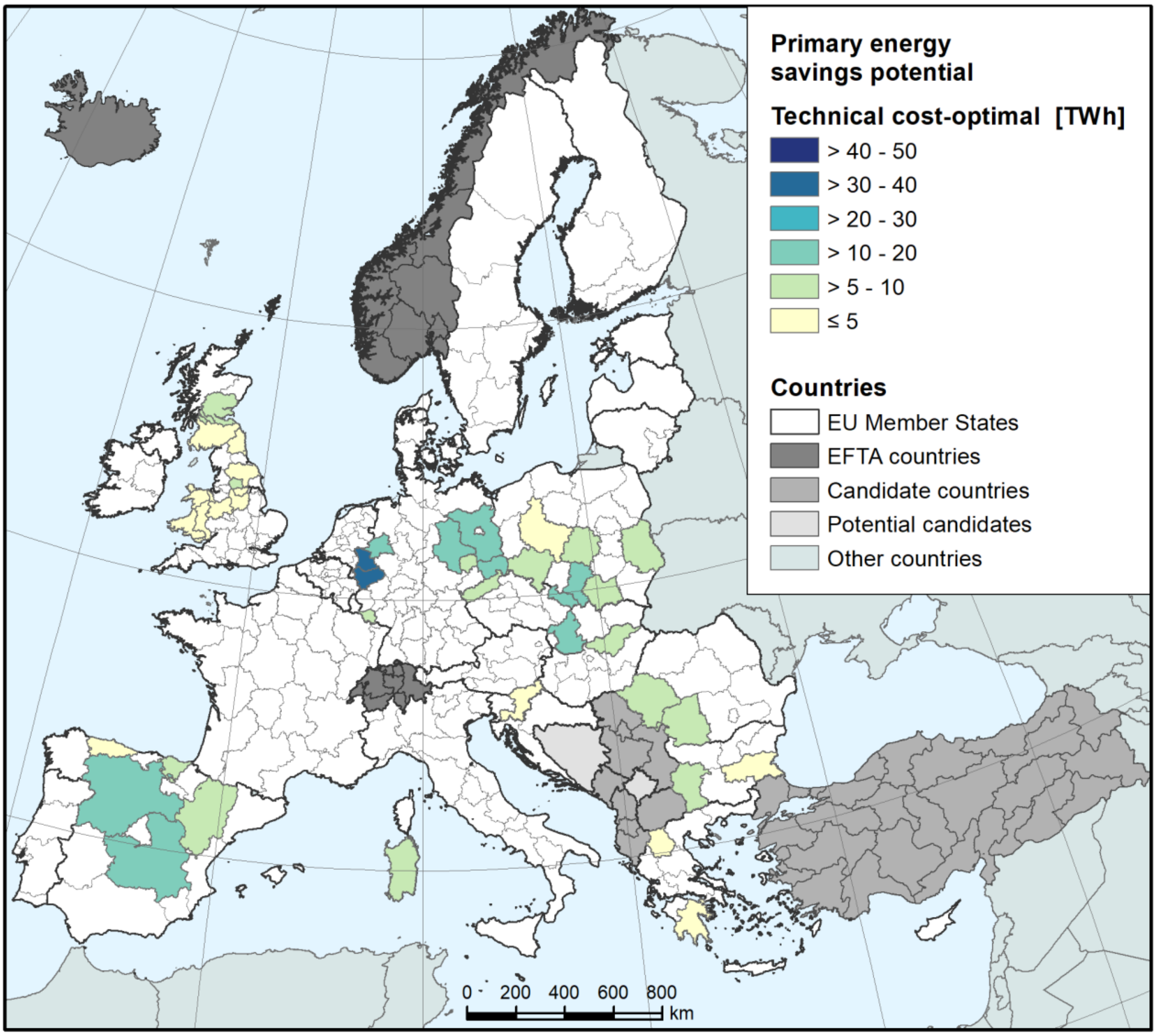

Figure 14. Primary energy saving potentials under technical cost-optimal scenario

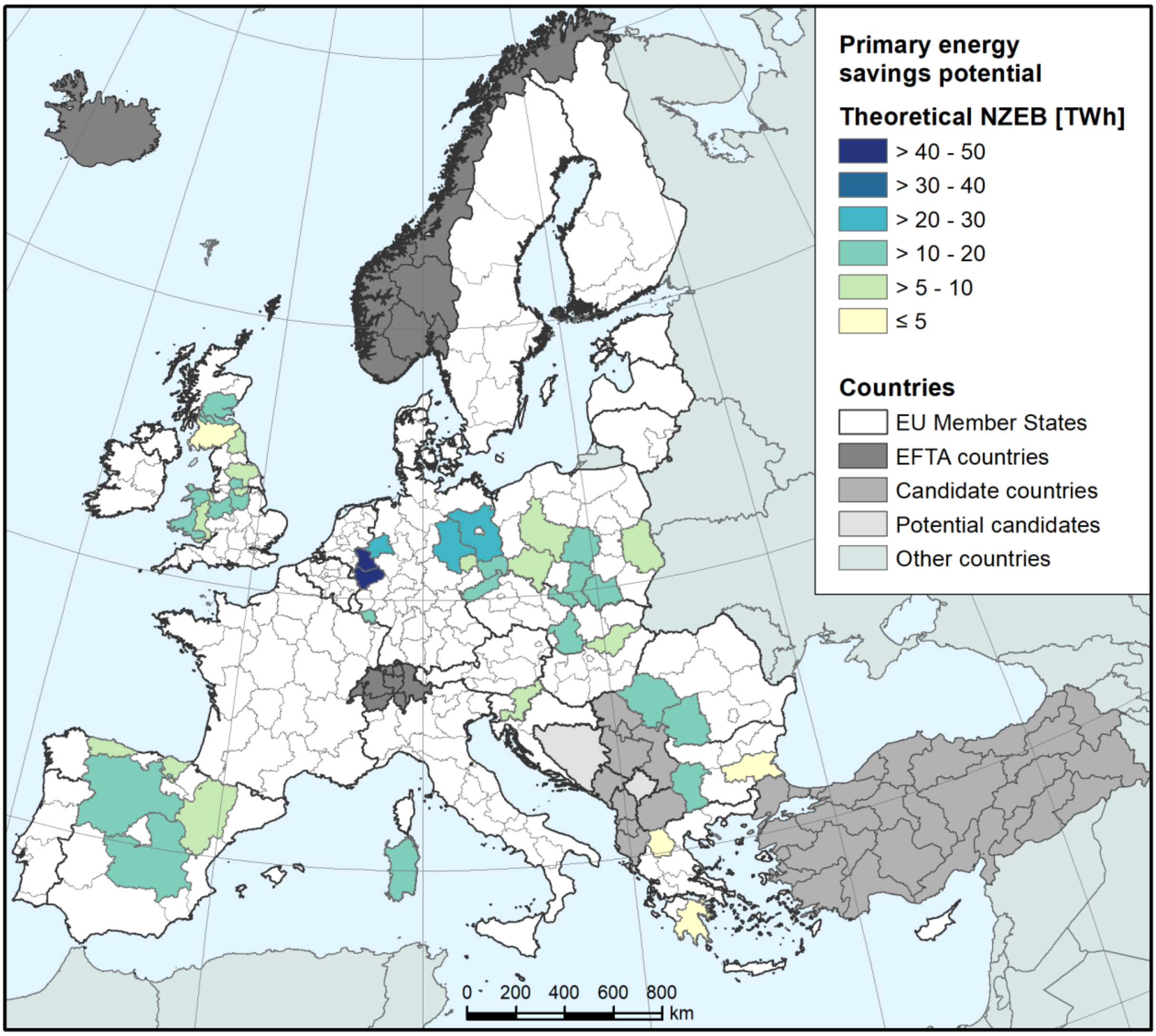

Figure 15. Primary energy saving potentials under technical NZEB scenario

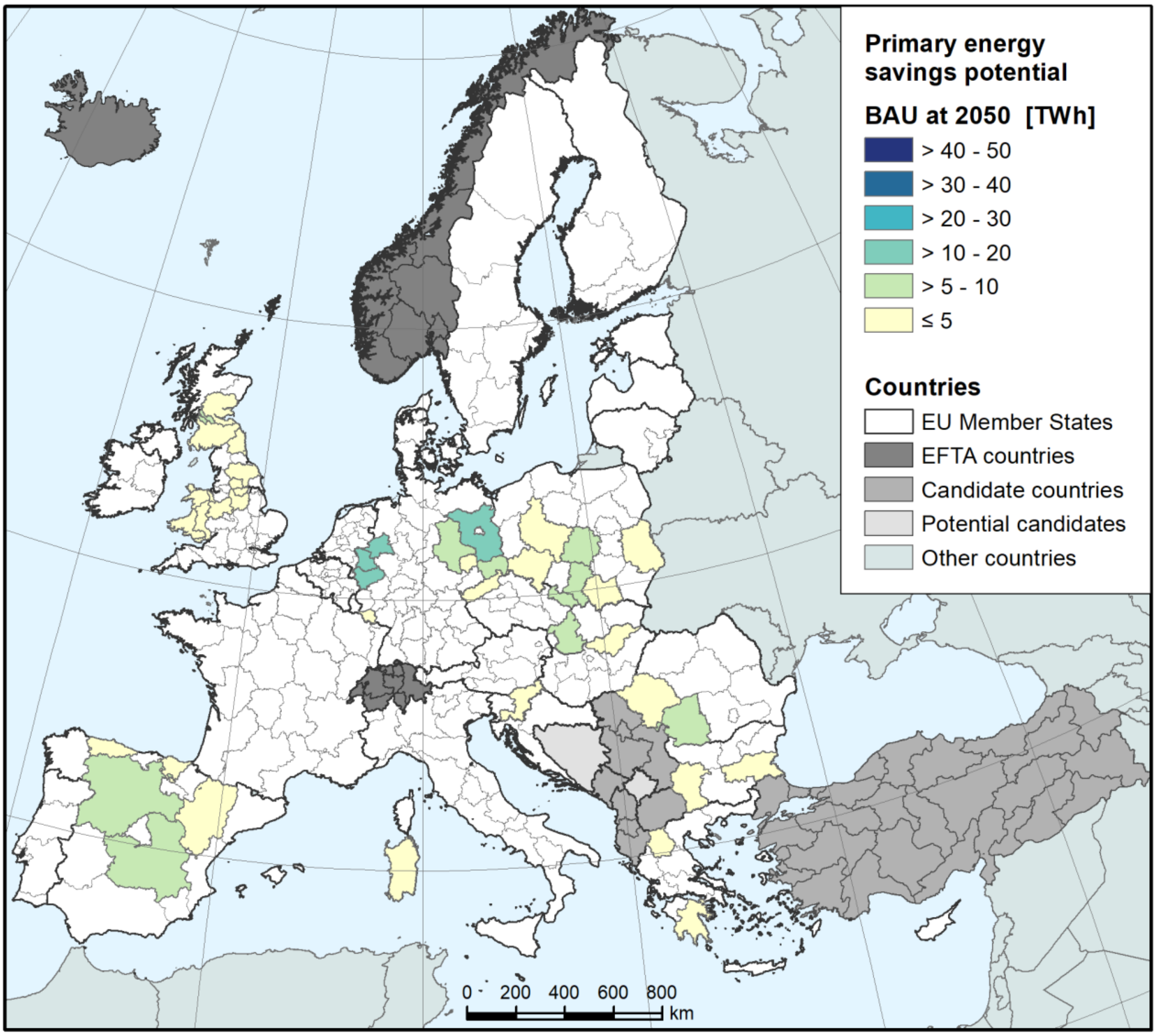

Figure 16. Primary energy saving potentials under business as usual at 2050 scenario

2.8 A glance on batteries

Driven by the EU's transition to a clean, secure, sustainable and competitive energy system, where batteries are recognised as a key enabling technology for decarbonisation of transport and accelerated deployment of intermittent renewable energy such as wind and solar, demand for batteries is expected to grow very rapidly in the coming years (Tsiropoulos, Tarvydas and Lebedeva, 2018; European Commission, 2019a). Li-ion batteries are presently the technology of choice for electric vehicles and are quickly gaining ground in energy storage applications (Tsiropoulos, Tarvydas and Lebedeva, 2018). For this reason, the present analysis focuses on Li-ion battery technology and describes recent developments within the Li-ion battery value chain in the coal regions considered in this study.

The Partnership on Advanced Materials for Batteries for Electro-mobility and Stationary Energy Storage [20] was launched in October 2018 in the framework of the Smart Specialisation Platform on industrial modernisation. This partnership aims to develop joint R&D&I projects on topics of advanced materials, their characterisation, durability, suitable for extreme working conditions with the goal to deploy them in the field of batteries. 3 out of the 42 coal regions (Basque Country (ES21), Aragón (ES24) and Castilla y León (ES41)) are within the regions involved.

Recognising the strategic importance of establishing a globally competitive, sustainable and integrated European battery value chain (European Commission, 2017), the European Commission launched an industry-led initiative - the European Battery Alliance (EBA)[21] - and adopted the Strategic Action Plan on Batteries as part of the third 'Europe on the Move' mobility package (European Commission, 2018a). The main objective behind these initiatives is to support the scaling up of innovative solutions for battery manufacturing in Europe and to foster cooperation between industries and other actors across the value chain, with support at both the EU-level and from EU Member States (European Commission, 2019a).

Significant progress in establishing a European Li-ion battery value chain has subsequently been made and industry has announced several major investments (European Commission, 2019a).[22] A number of these include projects in the 42 coal regions this study focuses on (please see Annex 8 for a list of identified industrial battery-related activities). Substantial developments take place in Poland and in Germany and some noteworthy examples of facilities being set up and/or expanded for domestic production of various battery functional materials, battery cells, modules and packs include:

<u>Functional battery materials (cathode, anode, electrolyte and separator):</u>

- Konin (PL, Wielkopolskie, PL41), where construction of a large factory for novel cathode material (eLNO) is announced by Johnson Matthey (HQ in UK) with the start of manufacturing envisaged in 2021-2022.
- Wrocław (PL, Dolnośląskie, PL51), where Capchem Poland (HQ in CN) will be producing electrolyte for Li-ion batteries (after acquisition of the former BASF business).

<u>Battery cells, modules and packs:</u>

- Kobierzyce (PL, Dolnośląskie, PL51) hosts currently the biggest factory in the EU for production of Li-ion battery cells, and is owned by LG Chem (HQ in KR). Its manufacturing capacity is planned to be expanded from 10 GWh today to 70 GWh by 2022.

[20] http://s3platform.jrc.ec.europa.eu/batteries

[21] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

[22] http://europa.eu/rapid/press-release_IP-18-6114_en.htm

- Bitterfeld-Wolfen (DE, Sachsen-Anhalt, DEE0), where Farasis Energy Europe (HQ in CN) plans to establish production of Li-ion battery cells, modules and packs for automotive traction applications by 2022 with initial manufacturing capacity of 6 GWh.
- Jawor (PL, Dolnośląskie, PL51), where Mercedes-Benz Cars (HQ in DE) will start manufacturing battery packs for automotive traction applications at the beginning of the next decade.
- Kamenz (DE, Dresden, DED2), Deutsche Accumotive (HQ in DE) further expands its manufacturing capacity of Li-ion battery packs for e-mobility.
- Lutherstadt Wittenberg (DE, Sachsen-Anhalt, DEE0), will see this year a start of operations of Tesvolt (HQ in DE) facility for production of battery packs and systems for stationary energy storage with annual capacity of >1 GWh.

Due to geology, there are a very limited number of activities related to raw materials for Li-ion batteries in the European coal regions (P. Alves Dias *et al.*, 2018) (please also see Annex 8). Recycling, on the other hand, continues increasing in volume and is expected to grow substantially in the next few years (P. Alves Dias *et al.*, 2018) (please also see Annex 8).

In establishing the above-mentioned activities, proximity to the clients (mainly European automotive industry and their suppliers) is often named among the most important considerations.[23] This is to ensure short transport distances, allow quick response time and improved flexibility and to minimise safety hazards related to handling and transport.

As setting up a battery-related activity often requires a multi-million-euro investment, favourable investment aid conditions in the EU for such activities[24] stimulate and already support major initiatives such as the Nissan facility in Sunderland (UK, Northumberland and Tyne and Wear, UKC2),[25] LG Chem factory in Kobierzyce (PL, Dolnośląskie, PL51)[26] and Northvolt in Sweden.[27]

Brown-field investments, i.e. re-profiling of existing facilities to launch a new production activity, offer a significant advantage due to lower capital costs compared to green-field investments.[28] The access to skilled workers, who may become available upon phasing out of existing activities, also plays a major role. This approach was successfully used by e.g. Samsung SDI in setting up their facility in Göd (HU)[29] (albeit not one of the regions of focus) and to some extent by Farasis Energy Europe in Bitterfeld-Wolfen (DE, Sachsen-Anhalt, DEE0)[30] for the production of Li-ion battery cells.

Fully in line with priorities of the EBA, considerations on manufacturing and use sustainability, such as reduction of the carbon footprint and "greening", gain progressively more attention from the new battery-related initiatives. The Battery pack manufacturing facility of Tesvolt in Lutherstadt Wittenberg (DE, Sachsen-Anhalt, DEE0) will operate exclusively on solar power to achieve "full carbon neutrality".[31] Also battery

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[23] See, for example, https://www.electrive.com/2019/05/09/farasis-energy-plans-battery-plant-in-germany/; https://matthey.com/news/2019/johnson-matthey-achieves-two-major-milestones-in-commercialisation-of-elno

[24] https://www.ft.com/content/097ff758-cec3-11e8-a9f2-7574db66bcd5

[25] https://uk.nissannews.com/en-GB/releases/release-85686-european-investment-bank-to-provide-eur-220m-to-nissan

[26] LG Chem investment aid: https://www.electrive.com/2019/01/29/poland-lg-chem-factory-plans-take-shape/

[27] https://www.bestmag.co.uk/content/northvolt-set-€400m-swedish-gigafactory-loan

[28] https://www.investopedia.com/terms/b/brownfield.asp

[29] http://www.samsungsdi.com/sdi-news/1642.html

[30] https://www.mdr.de/sachsen-anhalt/dessau/bitterfeld/video-299012_zc-b509df00_zs-978d5271.html

[31] https://www.bestmag.co.uk/content/tesvolt-races-claim-european-gigafactory-first?utm_source=ESPL+contacts+010215&utm_campaign=57ff8bbf2d-EMAIL_CAMPAIGN_2019_05_12_12_09&utm_medium=email&utm_term=0_26465d901f-57ff8bbf2d-406291157

producing facilities of Mercedes-Benz Cars in Jawor (PL, Dolnośląskie, PL51)[32] and in Untertürkheim (DE)[33] will be carbon-neutral.

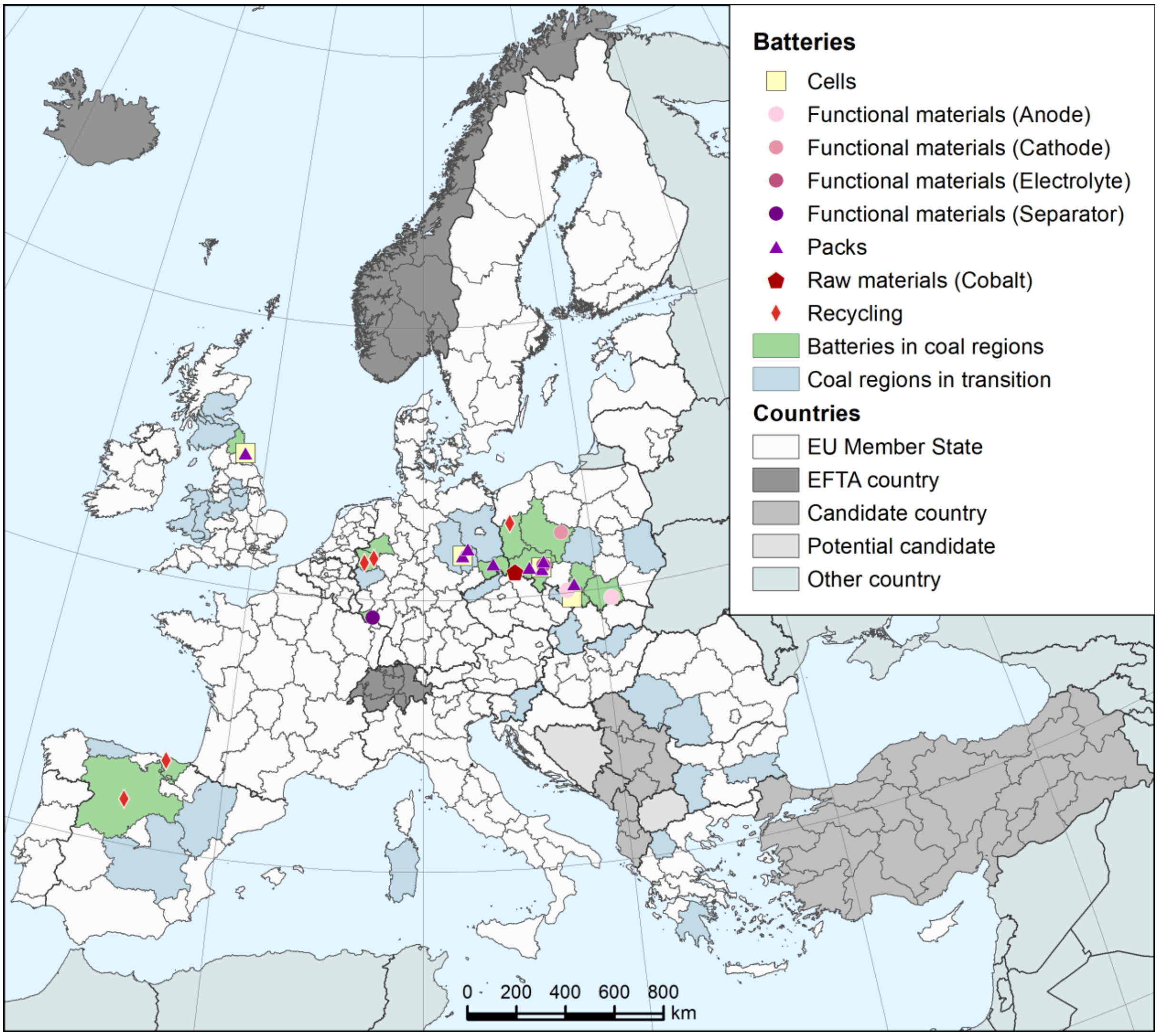


Figure 17. Industrial Li-ion battery activities in the coal regions in transition

Modern battery cell, module and pack production plants are automated to a large degree to ensure high precision manufacturing required to match quality requirements. Nevertheless, battery cell and pack manufacturing creates between 90 and 180 direct jobs per GWh/y production capacity (Steen *et al.*, 2017).[31] Recycling of batteries is likely to create a larger amount of direct jobs as sorting of batteries is often done manually at present.[34,35] Development and strengthening of a highly skilled workforce in all parts of the value chain is recognised as one of the priorities in the Strategic Action Plan on Batteries (European Commission, 2018a).

[32] https://www.daimler.com/company/locations/battery-factory-jawor.html
[33] https://www.daimler.com/company/locations/battery-production-untertuerkheim.html
[34] https://www.batterysolutions.com/capabilities/sorting/
[35] https://accurec.de/sorting

3 Developing value chains

Renewable energy technologies cover a broad variety of stages involving a number of individuals with different professional profiles, private and public institutions, and domestic and foreign companies (IRENA, 2017b, 2017c). In this section, value chains take into account the potential that exists on the overall prominent technologies, i.e. wind and solar.

The wind energy supply chain can be divided in three stages including (1) development and planning, (2) installation and manufacturing and (3) operation of the wind farm (Magagna *et al.*, 2017). The scope of the current analysis for wind focuses on the supply of turbine components based on the JRC analysis.

JRC analysis indicates that coal regions in Spain, Germany and the United Kingdom capture a significant part of the European wind energy supply chain. The leadership of these countries in the development of wind energy explains the high concentration of facilities. Germany is the European country with the largest installed wind power capacity, followed by Spain and the United Kingdom. Moreover, the United Kingdom also leads the European offshore wind energy market. Even though different cost factors and requirements affect the location of a manufacturing facility, wind industry vendors tend to locate their supply facilities close to the customer markets in order to cut logistics costs and speed up delivery time.

In total, the coal regions in Spain, Germany and the United Kingdom amounted to 24 facilities in operation by the end of 2018. More than half of these installations are located in Spain. In particular, Castilla y León (ES41) has six manufacturing facilities followed by País Vasco (ES21) with four and Castilla-La Mancha (ES42) with three facilities (Table 7).

Table 7. Number of wind component manufacturing facilities in operation in coal regions in transition.

CRiT with manufacturing facilities in operation	Region	Number of facilities
ES41	Castilla y León	6
ES21	País Vasco	4
ES42	Castilla-La Mancha	3
DE40	Brandenburg	2
DEA1	Düsseldorf	2
DEE0	Sachsen-Anhalt	2
DEC0	Saarland	1
ES12	Principado de Asturias	1
UKC2	Northumberland and Tyne and Wear	1
UKE4	West Yorkshire	1
UKL2	East Wales	1

Figure 18 displays the location of the wind component manufacturing facilities in the EU28 at NUTS 2 level. At least 11 out of the 42 coal regions have manufacturing facilities in operation and 39 out of the 42 coal regions have facilities in the surrounding regions or close-by regions (see factsheets by region, Annex 2). Regarding the type of facility, the wind industry in coal regions has high capabilities in nacelle assembling, manufacturing of components with a high value in the wind turbine cost (blades, gearboxes and power generators), and components with synergies to other industrial sectors (power converters).

The manufacturing activity in these regions shows little diversification level in terms of wind turbine components with a few exemptions in Spain (ES41, ES21 and ES42) and Germany (DE40, DEA1 and DEE0). For example, Castilla y León (ES41), identified as the coal region in transition with the highest wind technical potential (see 2.1), could source in-house blades, gearboxes, power generators and nacelles.

In terms of average nominal capacity (in component units per year) of the manufacturing facilities in countries with coal regions in transition, the largest average capacities are found in facilities in Germany for gearboxes, Spain for power converters, and the United Kingdom for nacelle assembly. Coal regions in Poland, could benefit from the country's high capabilities in blade manufacturing.[36]

Figure 18 displays that some coal regions in transition have limited or no manufacturing capabilities of wind turbine components. Still, they may benefit from facilities placed in surrounding or close-by regions (28 out of 31 coal regions with no manufacturing capabilities have facilities in their surroundings). Any such observation is still qualitative and further analysis is required to identify this benefit quantitatively. Some preliminary observations include the following regions.

[36] Please refer to Annex 9 for a list of the average nominal capacity (units/year) of manufacturing facilities installed in countries with coal regions in transition.

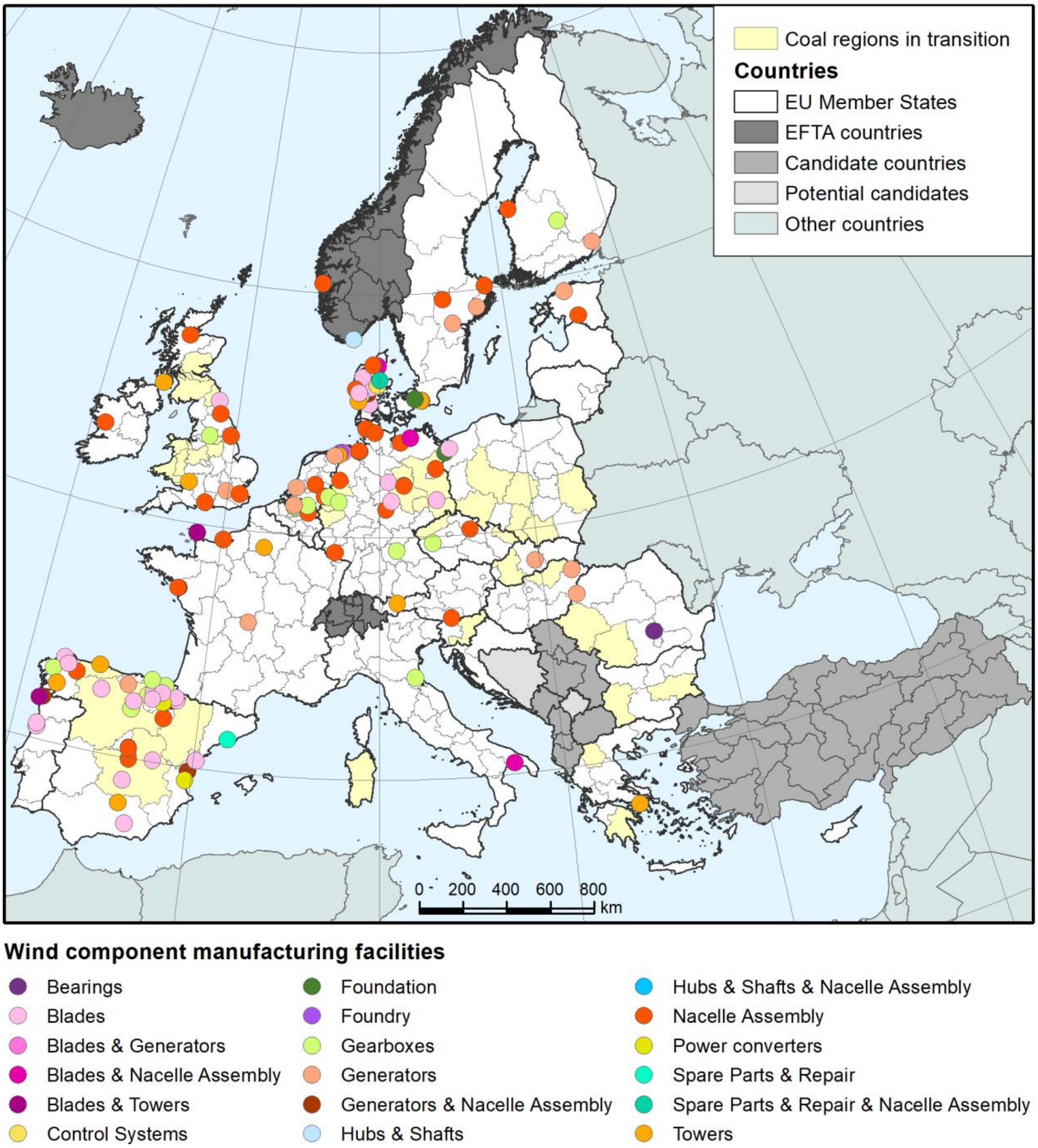


Figure 18. Location of wind component manufacturing facilities in the EU28 (Source: JRC analysis, last update in December 2018)

Among the coal regions with only one manufacturing facility and high wind technical potential we find East Wales (UKL2). Even if this region has only one tower manufacturing facility, it could source nacelles from the close-by region of Hampshire and Isle of Wight (UKJ3). East Wales (UKL2) could also source wind turbine components from other coal regions in the country: blades from Northumberland and Tyne and Wear (UKC2) and gearboxes from West Yorkshire (UKE4). Furthermore, it could get power generators, towers and nacelle assembly from other locations in the country. With tower manufacturing capabilities and good wind technical potential, Principado de Asturias (ES12) can be another example. This region could source wind turbine components from different regions in Spain where 36 facilities have been identified in total, 13 of which are in close-by regions (see also regional factsheets, Annex 1).

In 31 out of the 42 coal regions in transition we have not identified any wind component manufacturing facility in operation. Nevertheless, coal regions could source some components from other regions in their country. Aragón (ES24) and West Wales and The Valleys (UKL1), the third and fourth highest wind technical potential coal regions have also no manufacturing facility in operation. Aragon could source almost all wind turbine components from the rest of Spain and West Wales and The Valleys could benefit from blades, gearboxes and towers manufacturing along with nacelle assembly in other locations in the United Kingdom (see also regional factsheets, Annex 2).

New wind component manufacturing facilities in coal regions in transition can empower the regions' local industrial network and offer new employment opportunities for former coal workers. Siemens Gamesa Renewable Energy is currently the Original Equipment Manufacturer (OEM) with the highest number of facilities (10) in operation in coal regions in transition, followed by Vestas (3) and Enercon (2). LMWindPower, the world leading wind blade supplier, is also already expanding their manufacturing activity in these regions. The company is gradually implementing an additional production line in the blade manufacturing plant in Ponferrada, Castilla y León (ES41), expected to be in operation by summer 2020 (LMWindPower, 2019).

Concerning solar PV, the industry consists of an extensive value chain from raw materials to PV system installation and maintenance (Figure 19).

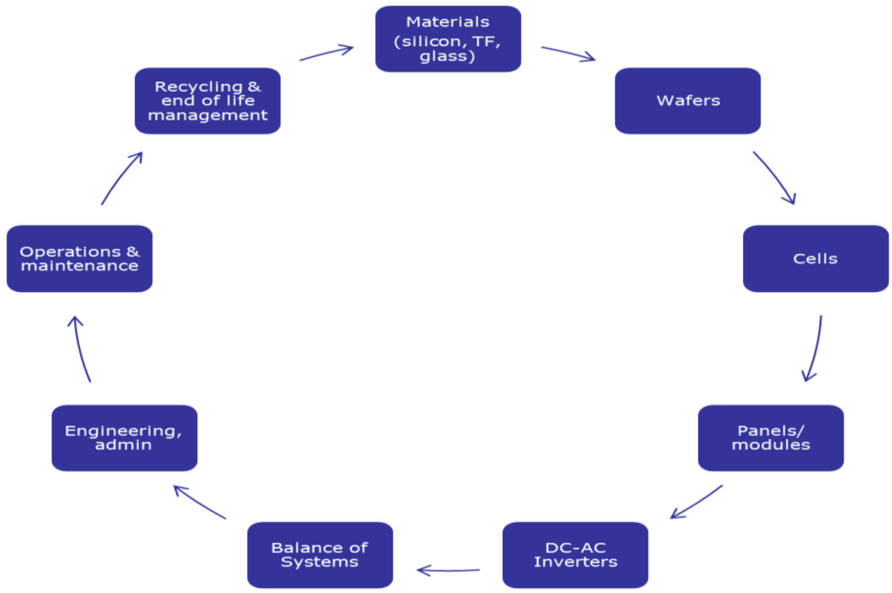


Figure 19. Outline of the PV value chain

The upstream part includes materials production and equipment manufacturing, while the latter encompasses inverters, balance of system (BOS) components, system development, project development, financing, installations and integration into existing or future electricity infrastructure, plant operators, operation and maintenance, etc. This could be further broadened to cover (super)-capacitor and battery manufacturers, meteorological forecasting services and IT providers to support digitisation of supply and demand.

European Union companies and institutions still have a reasonable market position in the areas of manufacturing equipment, polysilicon production, materials & chemicals, inverters and electrical components, project development, project development, operation and maintenance as well as topics related to grid integration, electrical system design. While the EU's basic and applied research on photovoltaic is world class, solar cell and module manufacturing has declined since 2010, while at the same time the global market has grown dramatically.

In terms of the breakdown over the value chain, the trade body Solar Power Europe's analysis (Solar Power Europe, 2017) concluded that the upstream part (materials supply and component manufacturing) accounts for 25%, with 75% on downstream side (engineering, installation, O&M and decommissioning). The ENF solar industry directory[37] includes 18 400 European-based companies, of which 85% are categorised as installers (Figure 20).

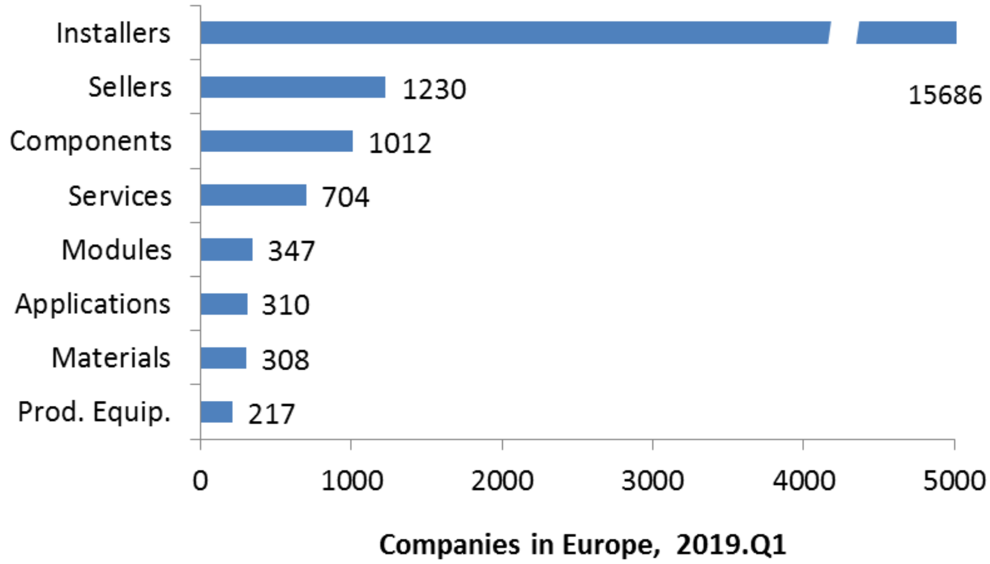


Figure 20. Sectorial breakdown of PV sector companies in the EU and Switzerland. (source data: ENF Industry Directory 2019/Q1, analysis : JRC)

The ENF solar directory has been used to provide a snapshot of the PV industry current situation in the coal regions. A breakdown of the companies and organisations in the pre-defined categories used by the directory can be found on Annex 9. Installers are by far the largest group, accounting for almost 80% of entries. The PV sector is strongest in the German regions, reflecting that country's role as technology and deployment leader in Europe.

Distributed PV systems on roofs of residential and commercial buildings are associated with generating local employment for installation, operation and associated services. Regions can accelerate such development by ensuring efficient administrative procedures at local level. Sustainable urban development policies (for instance, under the Covenant of Mayors) can also play an important role.

The PV cell and module manufacturing has become an industry that requires GW-scale production and currently even major players are confronted with very tight profit margins. The analysis here shows that none of the coal regions we focus on currently host major manufacturers. On other hand, the PV manufacturing is considered to have relatively low technical barriers to entry. The challenges are rather related to factors such as: price/quality of the proposed product in a highly competitive market, achieving sufficient economy of scale, supply chain control for competitiveness and, crucially, access to financing.

The coal regions in countries which have incentivised PV over the last ten years (Germany, UK, Italy) have a significant PV industry sector in terms of number of companies (Figure 21). The reverse is true for regions in several central and eastern member states, where the sector has not developed yet due to a combination of relatively low electricity prices and the lack of incentives. Installers and other downstream services dominate the distribution of companies, reflecting the prevalence, up to now, of small-scale roof-top systems. Activities on the upstream part of the value

37 The ENF directory (https://www.enfsolar.com/industry-directory) provides a listing of companies and certain details on the category (or categories) in which they are active. It does not provide indication of the extent of operations, either by turnover, staff or volume of output. In many cases, solar PV may be only one part of a company's activities and it may not report disaggregated operational data. Also the rapid growth and changes in the PV industry and its dispersed nature pose challenges for keeping information up to date. Despite these caveats, we consider the directory to provide a good indication of the breakdown and scale of activities.

chain (materials, production equipment, module manufacturing etc.) are also focused in countries which have high deployment of PV combined with a research and industry base in the sector.

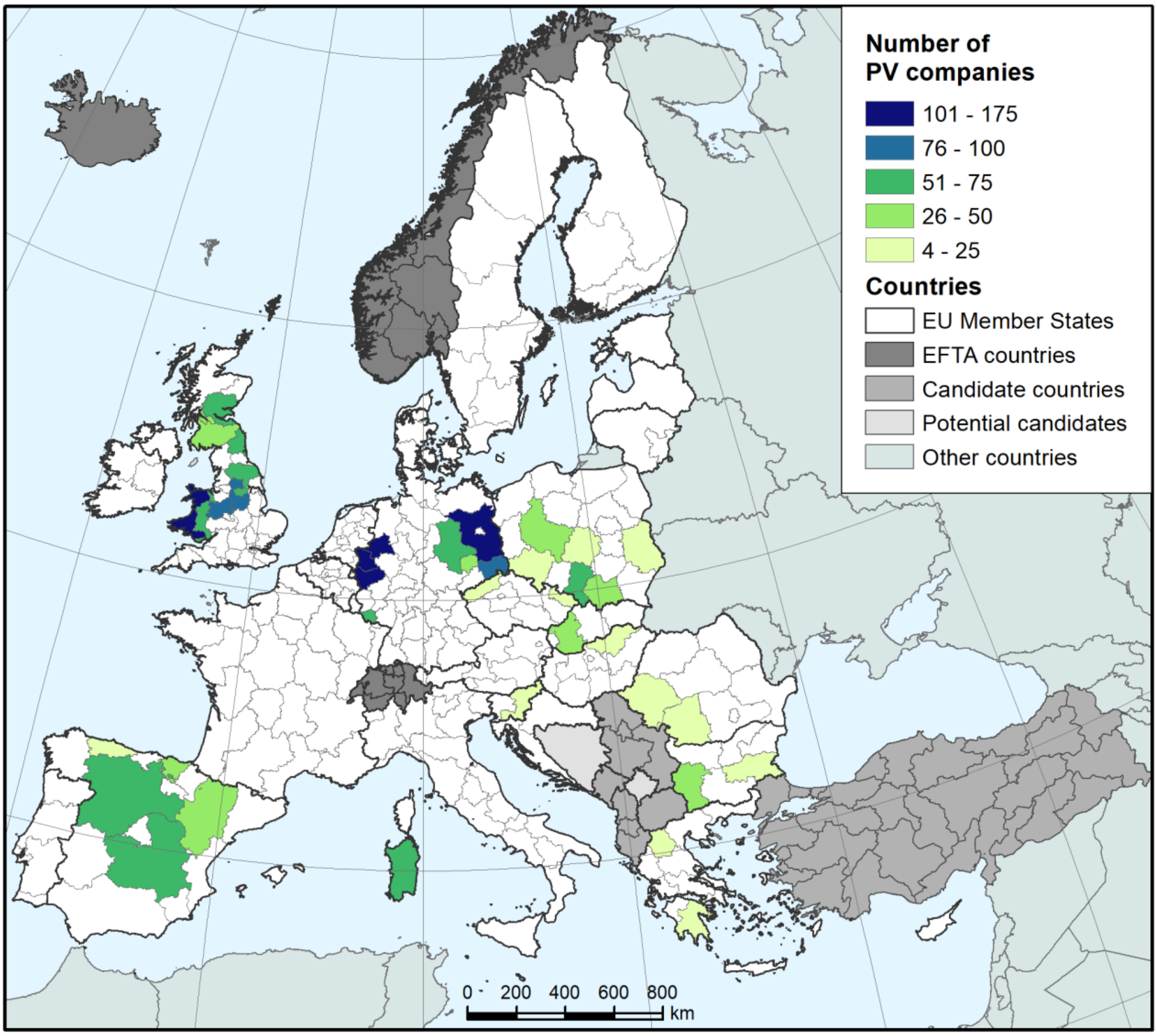


Figure 21. Number of PV companies in the European coal regions in transition

4 Regional transition

4.1 Clean energy production technologies

This section describes the job impact assessment method and its main results in each corresponding subsection.

Figure 22. Main job impact assessment steps

Our approach in evaluating future job generation entails three main steps. First, we select a EU28-wide coherent foresight scenario that estimates how the energy system may evolve under assumed policy targets and economic and technical conditions. The context and details of the foresight selected EUCO3232.5 are given in section 4.1.1.

Due to their computing and data requirements, energy system models producing the required foresight scenarios typically have a supra-national or national scope (NUTS 0 level). A EU28-wide energy system model with NUTS 2 level of detail is not publicly available. Therefore, a disaggregation method must be established to derive NUTS 2 regional scenarios from those generated by energy system models at NUTS 0 level. This is the second main step and the description and main outputs of such disaggregation method are given in section 4.1.2.

Thirdly, once the regional energy system evolution has been estimated, its associated job impact can be derived. For estimating this, we apply two different methods.

For solar and wind technologies, a detailed value chain analysis is done, assessing the potential jobs created in the manufacturing, installation and O&M activities. This is done for wind and solar as these technologies are prominent in terms of installed capacity of renewable energy currently in Europe. According to Eurostat (Eurostat, 2019b) there were 169 GW of wind power installed capacity and 107 GW of solar photovoltaic power in the European Union in 2018. While different technologies have very different capacity factors, resulting in different electricity production, analysis shows that wind is dominating followed by solar generation (Agora Energiewende and Sandbag, 2019).[38]

The jobs assessment is done following the method proposed in (Ortega *et al.*, 2015). By using Eurostat COMEXT and PRODCOM databases we characterise the manufacturing and trade of wind and PV technologies, enabling to assign the related manufacturing and installation jobs to the corresponding countries and regions.

For biomass and energy efficiency a "trace the investment" approach inspired by EurObserv'er method (Marsidi *et al.*, 2017) is applied. Following the trace the investment approach, the investments required for each technology development are assigned to NACE[39] sectors in each country, and through labour intensity of each sector, related employment is evaluated.

Both methods and their main results are described in more detail in section 5.1.1.

4.1.1 Foresight scenario - EUCO3232.5

The previous report on the coal regions (Alves Dias et al., 2018) analysed the potential employment impact of the foreseen retirement of coal power plants as they approach their end of life, in the context of a decarbonising Europe. We assess the employment alternatives and opportunities that the energy system evolution may bring, in a context

[38] Except for 2015 and 2016 where generation from solar and biomass are nearly equal.

[39] Deriving from the French phrase "Nomenclature statistique des activités économiques dans la Communauté européenne", i.e. statistical classification of economic activities in the European Community,

of a plausible energy system evolution. We do this by conducting our estimations starting from a foresight scenario which can serve as tools to get a glimpse of such plausible evolution. Given the focus of this report on specific coal regions, such scenario has to go through a model that gives an updated vision of this evolution for the European energy system, in a coherent and comprehensive view for all the Member States hosting coal regions. The most updated and established EU-wide modelling exercise including the current policy targets in force has been the EUCO3232.5.

The EUCO3232.5 includes the main EU-wide policy targets for 2030 currently in force:

- 32% renewable energy
- A two-sided energy efficiency target:
  - 32.5% primary energy consumption reduction, achieving 1 272 Mtoe.
  - 32.5% final energy consumption reduction, achieving 960 Mtoe.
- A 40% GHG reduction (compared to 1990).[40]

The main results and full details of the EUCO3232.5 scenario are described in (European Commission, 2019b).

4.1.2 Regional distribution

While the EUCO3232.5 provides coherent and connected results for each Member State, the employment assessment in the coal regions requires analysing the national energy system evolution implications at regional level.

As shown by (Celik, Muneer and Clarke, 2009), the optimal regions from the available potential point of view are not always the ones experiencing higher installed capacity. The decision to install capacity for a certain technology is determined by a more complex set of variables and decisions. Three main perspectives determine the regions where the new capacity needed at national level will be installed (for examples of these perspectives please see Annex 10):

- *Macro to micro economic and activity models*. This approach entails the use of regional data to assign national projections according to indicators available.
- *Technology diffusion theory*. From this perspective, the introduction of new energy technologies is analysed as new products entering established markets. This theory attempts to explain why some non-technically optimal regions may experience a faster development especially in the earlier phases of market uptake. In short, places with more initially installed capacity may have a higher chance of being further developed to a greater extent.
- *Investment decision making*. Finally, the most detailed approaches to establish not only regional, but specific site decision making are those decision-support tools used by investors. The Analytic Hierarchy Process (AHP) is the most commonly used method. Technological maturity, sustainability, capital cost, job creation, land requirements and the alike are some of the most prominent criteria considered within these methods.

To allocate regionally the capacity needed in the future, we propose a method including analysis of the critical set of variables (indicators).[41] The analysis of candidate indicators has included three main groups: Macro, Regional Competitiveness Index (RCI) and technical capacity and potential (for more details please see Annex 10). Consequently, we formulate weights scenarios for those indicators, obtaining the range of national capacities that each weight scenario assigns to each coal region.

[40] Nevertheless, "the scenario indicates that full implementation of the targets would result in reduction of emissions in 2030 of 45.6%."

[41] For more details on the indicators please refer to Annex 10.

The final set of indicators chosen as distributors for installed capacity includes Gross Domestic Product (GDP), technical potential available in the region, installed capacity in the region by 2015, our methodology calibration year, and the technical potential available in the region. From these indicators we built the following distribution scenarios:

- Economic: considers that new capacity will be distributed across regions mainly driven by GPD in those regions with faster initial development
- Technology diffusion: models a development driven assuming the regions adopt early the technology. This is determined mostly by the capacity installed by 2015.
- Market size: models regional capacity distribution mostly driven by the total regional technical potential available.
- Market saturation: models regional capacity distribution mostly driven by the total regional technical potential available after considered the already installed capacity.
- Combined: considers similar weights for all the indicators obtained, modelling a kind of "mixed forces" distribution of the capacities.

Such method results in ranges of national capacities percentage installed in the region. We have derived these percentages for all regions in different countries. Figure 23 and Figure 24 present a demonstration of our estimations, showing these ranges for Germany and Slovakia for which we also provide corresponding examples.

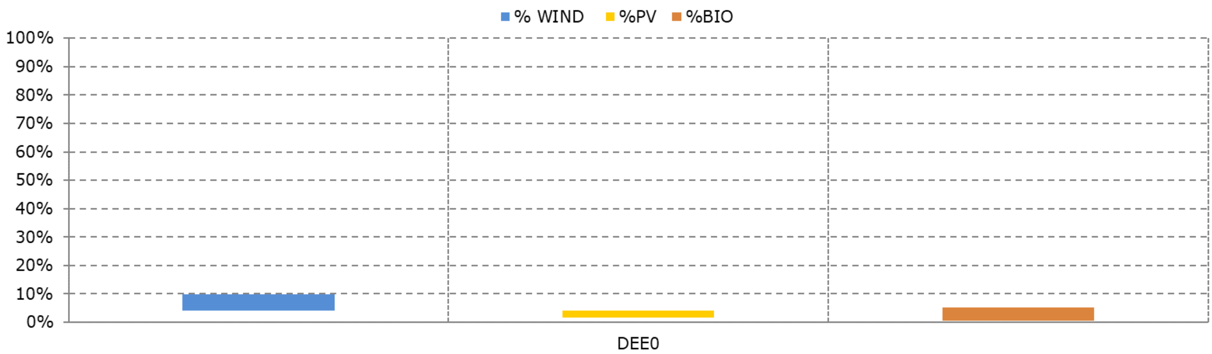


Figure 23. Range of percentage of national capacity estimated likely to be installed for DEE0 (example coal region)

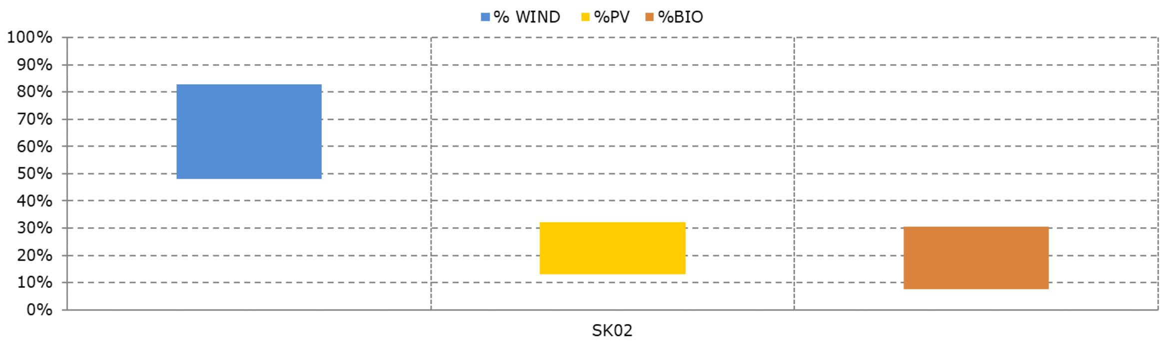


Figure 24. Range of percentage of national capacity estimated likely to be installed in SK02 (example coal region)

The percentages obtained provide quantitative information on the economical, competitiveness and resource availability weight of the region. For example, Münster

(DEA3) occupies almost 2% of the national surface and around 2.6% of the GDP. Weighting the estimated resource available as in the scenarios described, it would correspond to attracting between 2.1 and 3% of the national capacity needs of wind energy. In the other extreme, the SK02 region (Západné Slovensko) contributes with a 30% of national surface and GDP. The region's mountain-rich area entails around 87% of the national wind resource available, resulting in a weighted range of 35% to 50% of the national capacity to be attracted in the region for the three technologies. These ranges can be considered as quantifiers of the regional volume in the national context within the foresight scenario.

However, these percentages do not have a deterministic nature, neither are they hard qualifiers. They are magnitude indicators of the national capacity likely to be installed in the regions. It is also not possible to deterministically determine where the jobs will be induced. The capacity may be installed in a given region while the associated jobs could be created, for example, in a well-connected city between different regions hosting similar capacities. Section 4.3 further elaborates on these results implications.

4.1.3 Cost trends and EUCO3232.5

Different local aspects could affect the economic viability of clean energy deployment. These include:

- The technology in association with the local technical potential of the energy source;
- The local cost of material, labour and other matters that vary locally;
- The location of the power system in relation to the transmission lines and to the consumers (Khellaf, 2018).

Technology deployment trajectories and competition in the energy system are typically discussed in scenarios that are regularly published by international organisations with a forward-looking approach, i.e. toward 2030 and 2050. Previous JRC analysis (Tsiropoulos, Tarvydas and Zucker, 2018b) estimated investment costs of low carbon energy technologies globally under different scenarios. Figure 25 presents information for the technologies we focus on in this study. Starting from this analysis, we have examined cost trends also as presented in the literature.

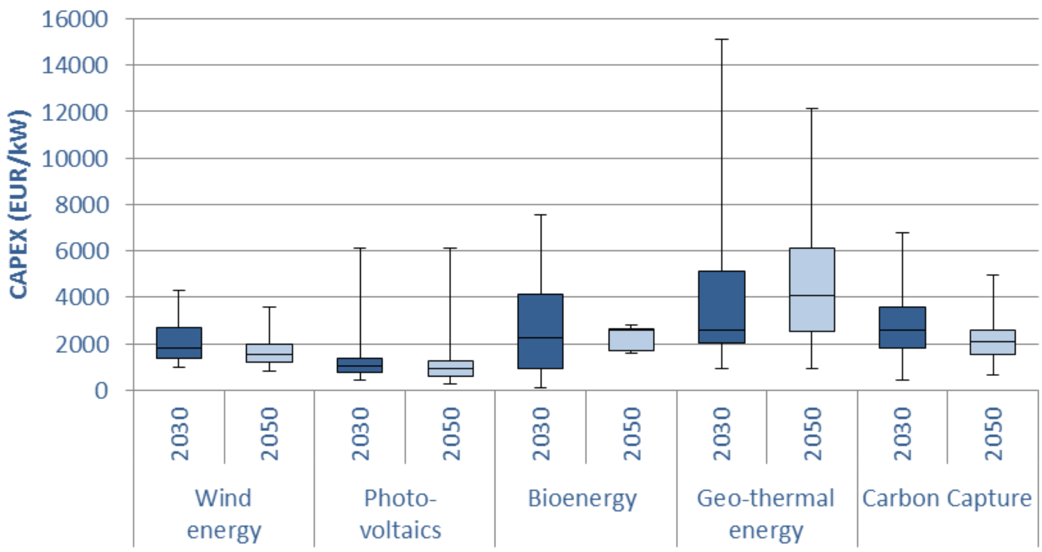


Figure 25. Investment costs of low carbon energy technologies according to literature (adapted from (Tsiropoulos, Ioannis; Tarvydas, Dalius; Zucker, 2018))

Wind energy

For onshore and offshore wind, major studies providing Capital Expenditure (CAPEX) values are in accordance with the JRC analysis (Tsiropoulos, Tarvydas and Zucker, 2018b). In the period up to 2020 onshore wind CAPEX values vary between 1 000 EUR/kW and 1 800 EUR/kW depending on the region. With increasing competition such as for example the introduction of competitive auctions in Europe, a further drop in CAPEX values to about 960 EUR/kW to 1 570 EUR/kW is expected until 2040 (Greenpeace, 2015; IEA, 2017, 2018). With respect to turbine maintenance, the IEA (2017) estimates Operational Expenditure (OPEX) costs depending on the lifetime of the turbine. OPEX cost during the first 10 years of a turbine's lifetime range between 18 to 26 EUR/kW/year and increase to 30-40 EUR/kW/year for turbines older than 20 years.

An even stronger decrease until 2050 can be observed for the estimated CAPEX for offshore wind. In the long run (Greenpeace, 2015; IEA, 2018) expect CAPEX to range between 2 050 EUR/kW and 2 730 EUR/kW for an average offshore wind project. Again these values are in line with the JRC assumption for offshore wind, excluding long distance offshore wind floating technology. The CAPEX reduction in the reviewed studies is mainly driven by the increase in average turbine sizes (e.g. from about 4 MW in 2016 and 8 MW in 2022 to about 12-15MW in 2025) and the increase in offshore wind project size which results in scaling effects. Given this increase in both turbine size and project size until 2025, the IEA (2017) expects that OPEX will decline from about 4% to below 2.5% of CAPEX.

Table 8. CAPEX and OPEX of onshore wind energy.

System		2020	2030	2040	2050
Low specific capacity, High hub height					
CAPEX (EUR_{2015}/kW)	Min	1 670	1 430	1 310	1 230
	Max	1 830	1 800	1 780	1 760
OPEX (%CAPEX)		3	3	3	3
Medium specific capacity, Medium hub height					
CAPEX (EUR2015/kW)	Min	1 220	1 040	960	900
	Max	1 330	1 320	1 300	1 280
OPEX (%CAPEX)		3	3	3	3
High specific capacity, Low hub height					
CAPEX (EUR_{2015}/kW)	Min	990	840	770	730
	Max	1 080	1 060	1 050	1 040
OPEX (%CAPEX)		3	3	3	3

Source: (Tsiropoulos, Tarvydas and Zucker, 2018b)

Table 9. CAPEX and OPEX of offshore wind energy.

System		2020	2030	2040	2050
Monopile, Medium distance to shore					
CAPEX (EUR_{2015}/kW)	Min	2 390	1 550	1 350	1 280
	Max	3 260	3 180	3 140	3 090
OPEX (%CAPEX)		2	2	2	2
Jacket, Medium distance to shore					
CAPEX (EUR_{2015}/kW)	Min	2 460	1 600	1 390	1 320
	Max	3 360	3 280	3 230	3 170
OPEX (%CAPEX)		2	2	2	2
Floating, Long distance to shore					
CAPEX (EUR_{2015}/kW)	Min	3 760	2 440	2 120	2 010
	Max	5 130	5 000	4 930	4 850
OPEX (%CAPEX)		2	2	2	2

Source: (Tsiropoulos, Tarvydas and Zucker, 2018b)

(De Vita *et al.*, 2018) include the cost data underpinning the European Commission's scenario. For onshore wind turbines installed in low wind potential areas, a CAPEX in the range of 1 395 - 1 043 EUR/kW is assumed for the period 2020 up to 2050. In medium wind potential areas, the range is 1295 - 943 EUR/kW toward 2050. In high wind potential areas, the CAPEX becomes lower, from 1 080 EUR/kW for 2020 down to 782 EUR/kW in 2050 (De Vita *et al.*, 2018). For offshore wind, CAPEX values of fixed-bottom structures (monopile and jacket foundations) in (De Vita *et al.*, 2018) are not easy to analyse as the assumptions of the distance to the shore is not disclaimed. For floating offshore platforms installed in very high wind potential locations (De Vita *et al.*, 2018) assumes a CAPEX in the range of 3 684 - 2640 EUR/kW for the period toward 2050.

Solar PV

When it comes to solar PV systems, we considered different sources that present cost data:

- The Photovoltaic Technology Platform report on Levelised cost of Electricity (LCoE) (Vartiainen, Masson and Breyer, 2014), providing values from 2014 to 2030.
- The JRC report on the cost of renewable technologies (Tsiropoulos, Tarvydas and Zucker, 2018a), which compared a large variety of sources and used this to model technology cost learning rates under a baseline (low renewables), diversified (includes nuclear and CCS) and ProRES (no CCS or nuclear) scenarios up to 2050.
- ASSET report for European Commission's reference scenarios (De Vita *et al.*, 2018).
- SET-Plan PV Implementation Plan strategic targets (SET-Plan PV TWG, 2017).

(Tsiropoulos, Tarvydas and Zucker, 2018b) considered technology growth in the context of the following scenarios: "Baseline", "Diversified" and "ProRES".[42] The JRC "diversified" scenario data (Tsiropoulos, Tarvydas and Zucker, 2018b) provide a central trend and has the advantage of extending to 2050. However, the values for large (utility) scale systems for 2020 and 2030 are somewhat above those proposed by EU PVTP. The data underpinning the European Commission's Reference Scenarios (De Vita *et al.*, 2018) indicate values of EUR 690-721 per kW toward 2020 and down to EUR 407-491 per kW by 2050.

Based on JRC analysis, Table 10 summarises the cost trends, for 4 distinct PV system types:

- Utility scale (> 1 MW) without tracking
- Utility scale (> 1 MW) with 1-axis tracking
- Commercial scale (flat surface)
- Residential rooftop (inclined surface)

Table 10 also includes annual operating cost estimates for the 4 system types, expressed as a % of CAPEX. The uncertainty in estimating OPEX rates is widely acknowledged, and some studies (such that by PV ETIP) suggest a decoupling from the CAPEX trend.

Table 10. CAPEX and OPEX of PV systems.

System	2020	2030	2040	2050
Utility fixed				
CAPEX (EUR_{2015}/kW)	740	535	450	370
O&M costs (% of CAPEX)	1.7	1.7	1.7	1.7
Utility tracking				
CAPEX (EUR_{2015}/kW)	968	737	561	451
O&M costs (% of CAPEX)	2.3	2.3	2.3	2.3
Commercial				
CAPEX (EUR_{2015}/kW)	880	670	510	410
O&M costs (% of CAPEX)	2.5	2.5	2.5	2.5
Residential				
CAPEX (EUR_{2015}/kW)	1050	800	600	490
O&M costs (% of CAPEX)	2.0	2.0	2.0	2.0

Source: (Tsiropoulos, Tarvydas and Zucker, 2018b)

Bioenergy

For bioenergy, we considered cost trends for biomass electricity plants using forest biomass residues, crop residues, biogas production from livestock manure and waste to energy in the main scenarios used to model energy technology perspectives (Tsiropoulos, Ioannis; Tarvydas, Dalius; Zucker, 2018). This report compared and used a variety of sources to model technology cost learning rates under the main scenarios up to 2050.

[42] While different in RES-E deployment levels, the "Diversified" portfolio and the "ProRES" scenarios achieve similar emission reduction globally (about 80 % by 2050 compared to 1990), have different technology portfolio with respect to fossil fuels, nuclear energy and CCS, and are amongst those scenarios with highest reduction in primary energy demand. Please refer to (Tsiropoulos, Tarvydas and Zucker, 2018b) for more details.

The "Diversified" scenario data provides a central trend for the investment costs for bioenergy technologies that extends between today and 2050.

Table 11 summarises the CAPEX and OPEX values for the bioenergy plants using different biomass feedstocks. While the values are not significantly different between scenarios, a notable cost reduction is expected toward 2050.

Values presented in the literature indicate a wide range of total installed costs (IRENA, 2018) for Europe, spanning between approximately EUR 450 (USD 500) and EUR 7 200 (USD 8 000) per kW for small scale projects. Fixed operation and maintenance (O&M) costs for bioenergy power plants typically vary from 2-6% (IRENA, 2018), a range in agreement with (Tsiropoulos, Ioannis; Tarvydas, Dalius; Zucker, 2018). The cost values underpinning the European Commission's reference scenarios (De Vita *et al.*, 2018), range from EUR 2 000 to 4 380 per kW for the different bioenergy power technologies and up to EUR 5 630 per kW for waste incineration with CHP. Biomass power generation cost is largely determined by the different technology options resulting as such these wide cost ranges. Other factors affecting the costs reflected in different bioenergy technology options depend on the region, feedstock type and availability, as well as how much feedstock preparation or conversion happens on site (IRENA, 2018).

Table 11. CAPEX and OPEX of bioenergy systems.

Biomass combustion			
	2020	**2030**	**2050**
CAPEX (EUR_{2015}/kW)	3 400	3 310	3 120
O&M costs (% of CAPEX)	2	2	2
Anaerobic digestion			
	2020	**2030**	**2050**
CAPEX (EUR_{2015}/kW)	2 930	2 850	2 680
O&M costs (% of CAPEX)	4	4	4
Waste incineration			
	2020	**2030**	**2050**
CAPEX (EUR_{2015}/kW)	6 372	6 198	5 992
O&M costs (% of CAPEX)	4	4	4

Source: (Tsiropoulos, Ioannis; Tarvydas, Dalius; Zucker, 2018)

Geothermal Energy

For geothermal energy, the three types of geothermal power plants we consider are: flash power plants, hydrothermal binary (ORC) plants and Enhanced Geothermal Systems (EGS). In general, not much information about costs of geothermal power plants exists. IRENA's most recent technology brief on geothermal power presents all CAPEX data available from existing projects (IRENA, 2017a). Investment costs range from 1 000 USD/kW (890 EUR/kW) to 9 000 USD/kW (8 010 EUR/kW). Flash power plants usually need lower investment compared to binary plants (Figure 26). According to IRENA, "global total installed costs for geothermal power plants are typically between USD 1 870 per kW and USD 5 050 per kW […] however, costs are highly site-sensitive".

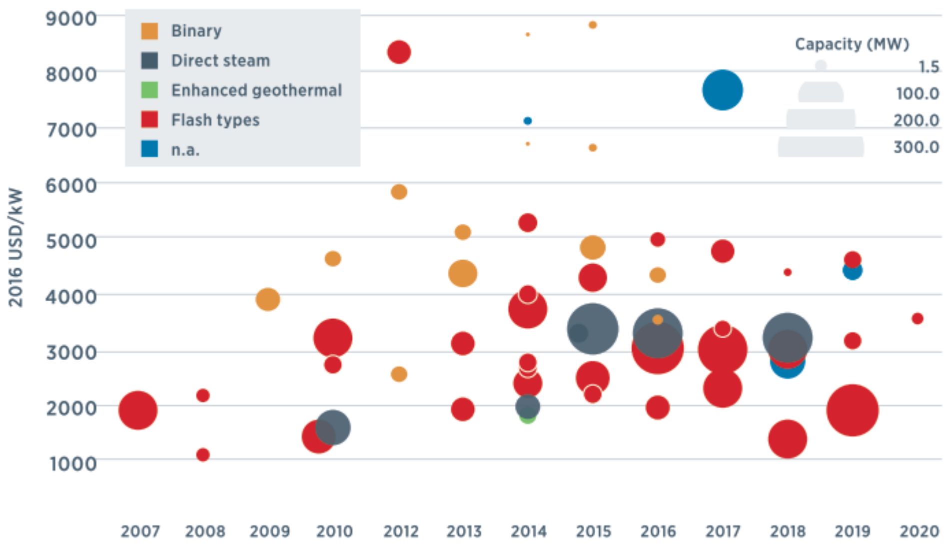


Figure 26. Investment cost of geothermal power between 2007 and 2020. Source: (*Geothermal Power Technology Brief*, 2017)

The most up-to-date information about the cost of those technologies can be found in (Tsiropoulos, Tarvydas and Zucker, 2018a). This study applies the one-factor learning rate method in order to estimate future CAPEX and different deployment scenarios are assumed.

Table 12 displays the CAPEX and OPEX of the three different geothermal power plant technologies from now up to 2050, keeping in mind that geothermal CAPEX is very much site-specific, depending mainly on the drilling depth and underground conditions (e.g. permeability) (Sigfússon and Uihlein, 2015).

Table 12. CAPEX and OPEX of geothermal power plants.

System	2020	2030	2040	2050
Hydrothermal (flash)				
CAPEX (EUR_{2015}/kW)				
Minimum	3 100	2 420	2 130	2 000
Maximum	3 500	3 430	3 390	3 340
O&M costs (% of CAPEX)	2	2	2	2

ORC binary				
CAPEX (EUR_{2015}/kW)				
Minimum	6 110	4 760	4 190	3 930
Maximum	6 880	6 740	6 670	6 580
O&M costs (% of CAPEX)	2	2	2	2
EGS				
CAPEX (EUR_{2015}/kW)				
Minimum	10 330	8 060	7 090	6 650
Maximum	11 640	11 410	11 280	11 140
O&M costs (% of CAPEX)	2	2	2	2

Source: (Tsiropoulos, Tarvydas and Zucker, 2018b)

The European Commission's EUCO scenario data (De Vita *et al.*, 2018) only consider two main types of geothermal power: a High Enthalpy and a Medium Enthalpy resource and have not included cost of EGS in their study. (De Vita *et al.*, 2018) assume costs in the range of 3 901 - 2 613 EUR/kW for the high enthalpy resource in the period 2020 to 2050. For the medium enthalpy resource, costs from (De Vita *et al.*, 2018) are ranging from 4 970 - 3 306 EUR/kW. With regards to O&M costs (Tsiropoulos, Tarvydas and Zucker, 2018a) give FOM ranges between 40 and 70 EUR/kW in the case of hydrothermal and between 79 and 139 EUR/kW in the case of ORC power plants. (De Vita *et al.*, 2018) assume a FOM of 90-105 EUR/kW for high enthalpy and between 92 and 95 EUR/kW for medium enthalpy resources.

Carbon Capture

The Global CCS Institute published a series of publications presenting CCS cost data but with the US Gulf Coast as a reference location (Global CCS Institute, 2015, 2017). Rubin et al. collected information for associated costs from various studies (Rubin, E. S., Davison, J. E., & Herzog, 2015) indicate a mean range of EUR 1 969-3 176 (USD 2 589-4 174) per kW and EUR 35-67 (USD 46-87) for every tonne of CO_2 avoided in different coal fired power generation options.[43] A more recent study presents a range of EUR 50-75 per tonne of of CO_2 avoided in supercritical power plants with CO_2 capture for the different locations. Different production routes as well as capture technologies and configurations result in a broad range of CCUS costs. Tsiropoulos et al. (2018b) provided a range of EUR 2 920 to 4 480 per kW for capital investment costs with 2025 as a start year. Given than in this study we focus on coal regions and on existing coal fired power plants, economic data are given only for this type of plants (Table 13) and for CO_2 separation techniques that can be retrofitted.

[43] Original values in 2013 USD (1 EUR = 1.301 USD).

Table 13. CAPEX and OPEX of CCUS power plants.

System	2020	2030	2040	2050
Pulverised coal plants, post-combustion				
CAPEX (EUR_{2015}/kW)				
Minimum	-	2 630	2 400	2 360
Maximum	-	2 830	2 790	2 740
O&M costs (% of CAPEX)	2.1	2.1	2.1	2.1

Source: (Tsiropoulos, Tarvydas and Zucker, 2018b)

The data underpinning the European Commission's reference scenarios (De Vita *et al.*, 2018), presented values spanning from EUR 3 400 to 3 950 per kW. Rubin et al. (2015) do not provide values for operating cost but the European Platform for Zero Emissions Plants (ZEP, 2011) provide an average range lower to (De Vita *et al.*, 2018) which range from EUR 68.6 to 72.6 per kW annually. For 2030, 2040 and toward 2050 investment cost reductions of up to 16% are considered.

Different studies adopt different assumptions in estimating costs and may not be directly comparable. While the aforementioned values are only indicative, they reflect that many factors influence costs including plant location as well as potential technology deployment. Nevertheless our analysis indicates that the trend is similar with regards to technologies average costs. That is PV, wind, bio energy, geothermal and carbon capture from lower to higher CAPEX requirements.

Given that the most updated and established EU-wide modelling exercise including the current policy targets in force has been the EUCO3232.5, it has been the scenario chosen to contextualize our approach. The EUCO family of scenarios succeed the PRIMES Reference Scenario 2016 modelling, which considers discount rates or "cost of capital" as well as additional risk premium rates for some new technologies at their early stages of development. These are affecting the perceived costs of technologies (Capros et al., 2016) and subsequently the technology deployment projections. As such, the cost efficiency of each technology we focus on in this study is implicit in the scenario projections – the PRIMES model results in technology deployment in a cost effective manner. In line with this scenario choice and to ensure consistency, we adopt for our estimations the cost assumptions as proposed within the underlying data for the EUCO3232.5 modelling exercise.

4.1.4 Estimated investment needs

4.1.4.1 Clean energy technologies

Starting from the projections in EUCO3232.5, using the regional distribution of capacities described in 4.1.2, we derive the Capital Expenditure (CAPEX) investments needed for newly installed capacity for the corresponding technology deployment.

With a view of aiming to initiate a transition in the short to medium term, we present the estimated investments needed for new capacity for technology deployment projected for 2020 and 2030. For geothermal energy and CCUS, EUCO3232.5 does not project deployment by 2030, so we have not assessed relevant investments.

We estimate that the highest investments needs in 2020 for deploying the maximum of the plausible range projected for new wind capacity are in Southern Scotland (UKM9, 2 554 MW, EUR 5.59 billion) and the lowest in Yugoiztochen (BG34, 1 MW, EUR 2.08 million). In 2030, these correspond to Brandenburg (DE40, 1 744 MW, EUR 2.99 billion) and Észak-Magyarország (HU31, 12 MW, EUR 20.61 million), respectively. For Solar PV capacity in 2020, the highest investment needs are estimated for Brandenburg (DE40, 143 MW, EUR 0.12 billion) and the lowest for Západné Slovensko (SK02, 0.32 MW, EUR 0.18 million). In 2030, these are Castilla y León (ES41, 506 MW, EUR 0.36 billion) and Southern Scotland (UKM9, 5 MW, EUR 3.29 million). Investments needs for geothermal energy capacity appear only in limited regions, where deployment is projected, i.e. Germany, Hungary and Italy. The highest and lowest investments to deploy the projected geothermal capacity in 2020 appear in Brandenburg (DE40, 2.52 MW, EUR 11.16 million) and Saarland (DEC0, 0.22 MW, EUR 0.98 million), respectively. There is no projection for geothermal capacity deployment in 2030 within EUCO3232.5. For deploying the maximum plausible projected bioenergy capacity in 2020, the highest and lowest investment needs appear in Brandenburg (DE40, EUR 10.74 million) and in Západné Slovensko (SK02, EUR 0.02 million), respectively. In 2030, these are Castilla y León (ES41, 107.96 million) and Southern Scotland (UKM9, EUR 0.99 million).

Figure 27 shows total values for the 2030 total investments by region, i.e. the investments necessary to deploy the range of capacities we have identified for all different technologies projected for each region. Estimations for all coal regions by technology can be found in the dedicated factsheets (Annex 2).

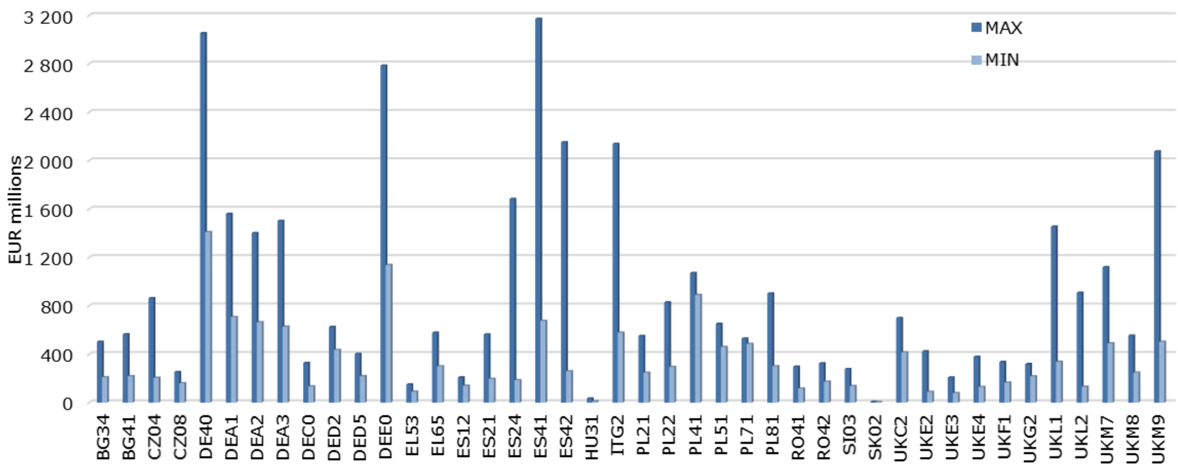


Figure 27. 2030 CAPEX investments needs (EUR millions) to deploy the projected minimum and maximum regional capacity of all technologies considered

Regarding coal mine reclamation, we estimate that lifetime investment costs[44] in wind energy projects ranges from around 2 000 EUR/kW in regions with high wind availability to 2 600/kW in regions with low wind availability. The lower lifetime investment costs of solar PV projects result in a lifetime investment averaging around 850 EUR/kW. The highest investment requirement would correspond to Dytiki Makedonia (EL53) as with 8 operating open-pit coal mines, indicates the highest technical potential. The total capacity of solar PV (2.7 GW) and wind energy (1.4 GW) that could potentially be installed in the 75 operating open-pit mines of the coal regions is estimated to reach a total lifetime investment of around EUR 5.5 billion, with wind energy representing almost 60%.

In the next Chapter we provide estimates on employment. These are linked with the presented investment needs with a ratio of EUR mil/job induced. This ratio is presented for each region in the corresponding factsheet of Annex 2.

[44] Referring to a 25 year project lifetime, please see Annex 10 for methodology and estimations by region.

4.1.4.2 Energy Efficiency

Table 14 shows the results obtained on energy efficiency investments needed for residential buildings based on the scenarios described in 2.7. We find that the highest yearly total investment needs correspond to Dusseldorf (DEA1, EUR 1.39 billion) and the lowest to Dytiki Makedonia (EL53, EUR 37.1 million).

Table 14. Regional capital expenditure under 3 scenarios.

NUTS2	Capital expenditure [M€]		
	Theoretical cost-optimal	Theoretical NZEB	BAU at 2050
BG34	5 819	10 472	3 666
BG41	11 461	20 161	7 115
CZ04	5 321	8 579	3 128
CZ08	6 726	10 779	3 939
DE40	39 945	51 302	20 531
DEA1	81 301	103 726	41 631
DEA2	72 560	93 074	37 268
DEA3	43 632	56 108	22 442
DEC0	20 108	26 047	10 385
DED2	22 532	28 741	11 536
DED5	13 396	17 035	6 847
DEE0	34 298	43 937	17 603
EL53	2 475	2 475	1 114
EL65	5 006	5 023	2 257
ES12	11 999	11 924	5 383
ES21	21 926	20 949	9 647
ES24	16 176	16 373	7 324
ES41	34 143	35 375	15 641
ES42	31 356	32 963	14 472
HU31	25 253	30 498	12 544
ITG2	5 471	9 500	3 368
PL21	13 104	20 367	7 531
PL22	16 987	25 860	9 640
PL41	6 042	9 516	3 501
PL51	12 402	18 756	7 011
PL71	15 800	24 327	9 029
PL81	11 782	18 718	6 862

Table continued. Regional capital expenditure under 3 scenarios.

NUTS2	Capital expenditure [M€]		
	Theoretical cost-optimal	Theoretical NZEB	BAU at 2050
RO41	8 295	15 564	5 368
RO42	7 211	12 977	4 542
SI03	4 758	9 276	3 158
SK02	16 376	17 304	7 578
UKC2	6 983	20 629	6 213
UKE2	3 691	11 281	3 369
UKE3	6 219	18 949	5 663
UKE4	10 385	30 766	9 259
UKF1	9 742	30 269	9 003
UKG2	7 453	23 333	6 927
UKL1	8 699	26 315	7 878
UKL2	5 197	15 681	4 698
UKM7	10 248	29 477	8 938
UKM8	12 439	35 136	10 704
UKM9	2 244	6 646	2 000

5 Employment foresight

5.1.1 Induced employment assessment

Given the massive deployment of wind and solar required to reach a decarbonized power system, the employment associated with these technologies is analysed in detail across their value chain, discussing the potential impact in each production activity. In a first step, employment is considered at national (NUTS 0) level. The distribution scenarios on a NUTS 2 level have been discussed in section 4.1.2. Biomass, energy efficiency (insulation upgrading in residential existing buildings), geothermal employment impacts are considered through the evaluation of their investments in their corresponding activity sectors, following a condense approach as proposed by (Fragkos and Paroussos, 2018).

(Ortega *et al.*, 2015) presented a detailed value chain analysis for wind and PV solar technologies performed using COMEXT and PRODCOM Eurostat data to allocate the effects of manufacturing and trade across Europe. The model also takes into account the effect of technology learning into job intensity, reflecting that future cost reductions will also imply less employment-intense industries. For this study, we have calibrated the model with recent Eurostat data.

In our previous work (Alves Dias et al., 2018) we have estimated that there are more than 200 000 coal related jobs in the coal regions. We also noted that coal related jobs may not necessarily be directly substituted by clean energy technology jobs. On a regional level, we find that in some regions, the jobs created may not be as significant as counting for one to one compared to the previously estimated coal related jobs. These regions are Yugoiztochen (BG34), Severozápad (CZ04), Moravskoslezsko (CZ08), Munster (DEA3), Dytiki Makedonia (EL53), Eszak-Magyarorszag (HU31), Malopolskie (PL21), Silesia (PL22), Lodzkie (PL71), Lubelskie (PL81), Sud-Vest Oltania (RO41) and Vest (RO42). This does not mean that these regions would not or could not actively participate in the transition from coal related activities. Our estimations on the technical potentials (Section 2 and Annex 3) show that under appropriate frameworks, they could deploy clean energies beyond the EUCO3232.5 context increasing potentially their share in technology deployment and jobs.

Using the distribution coefficients introduced in section 4.1.2, we can assess how much of the national employment could be induced by the activity in a given region. These results do not mean that the employment would be necessarily based on that region. It is not trivial to establish a solid link between the resource and characteristics of the region and where in detail the economic activity will be exercised or declared. Yet, it is an indicator of the employment activity that would be carried out in the regions and at a national level. Dedicated corresponding figures for each coal region are included in the corresponding region profile (Annex 2).

All estimations by technology for each region are presented in Annex 10.

5.1.1.1 Wind energy

The estimated 285 000 wind-related Full Time Equivalents (FTE) by 2015,[45] a growing sector more than doubling its size by 2050. The graph shows the manufacturing related jobs associated only with the internal demand. We assume a constant internal/external ratio for the manufacturing activity, implying that European companies will remain the main internal suppliers, keeping their current degree of internationalization in the global market. In this case, the corresponding external demand for manufacturing may require around 90 000 additional FTE. Under assumed technology learning and the EUCO3232.5 context, the whole sector could demand around 700 000 jobs by 2050.

Other key forces driving the results are technology learning and the growing installed capacity that continuously increase the employment associated with O&M activities.

[45] 2015 is the year we use for calibrating our method. Values for 2020 and beyond are based on estimations.

Following the new capacity that countries install in the EUCO3232.5 scenario, Figure 28 shows the corresponding total jobs evolution by country hosting coal regions. Germany leads the employment development, pushed by a very strong national demand for wind and a relevant share of intra-EU28 manufacturing market. For the specific coal regions, i.e. Brandenburg (DE40), Dusseldorf (DEA1), Koln (DEA2), Munster (DEA3), Saarland (DEC0), Dresden (DED2), Leipzig (DED5), Saxony-Anhalt (DEE0) we find that these can count for 18-40% of the jobs we estimate for Germany in 2030.

ES, UK, IT PL and EL also experience a remarkable development of their wind sector, all of them growing over 10 000 FTE by 2050. Spanish coal regions, i.e. Pricipado de Asturias (ES12), Basque Country (ES21), Aragon (ES24), Castilla y León (ES41) and Castilla-La Mancha (ES42), account for a 10-43% of the jobs estimated on a national level. In the UK, the regions' account for 14-21% of the jobs estimated on a country level. In Poland, i.e. the regions of Malopolskie (PL21), Silesia (PL22), Wielkopolskie (PL41), Dolnośląskie (PL51), Lodzkie (PL71) and Lubelskie (PL81) we estimated a 29-50% of the jobs on a country level.

BG, CZ and SK reach also noticeable FTEs over between 2 000 and 6 000 FTE by 2050, while SI shows a modest increase.

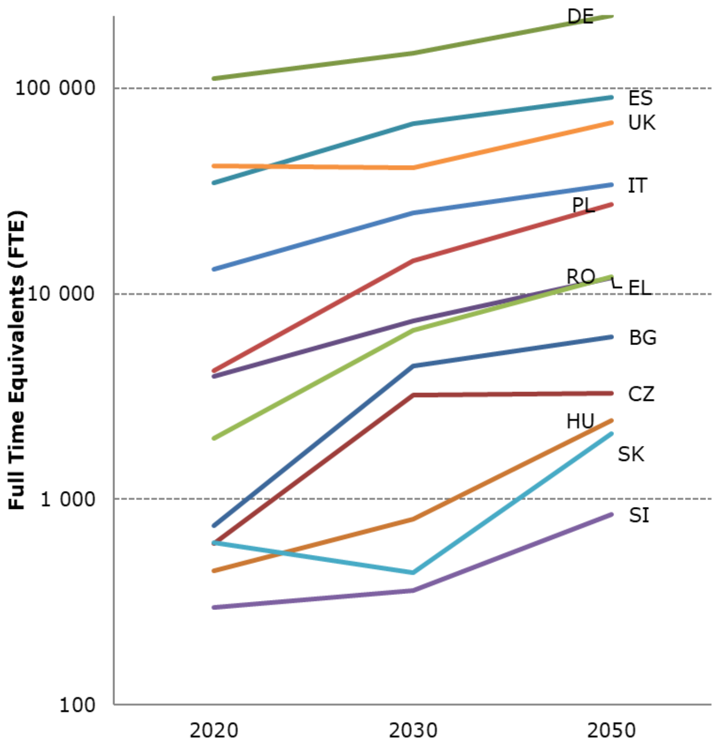


Figure 28. Total wind employment expected evolution for the coal region hosting countries (considering all regions in the country).[46]

5.1.1.2 Solar PV

For Solar PV, a previous study (European Commission, 2014b) considered equivalent Eurostat sources for PV trade analysis as those proposed in (Ortega *et al.*, 2015). The assessment carried out for the coal regions has shown that the use of PRODCOM and COMEXT databases does not fully describe the reality of the market. Our estimations derived from PRODCOM declarations imply that around 58% of the PV market is supplied with internal production. Such a share diverges with those estimated by the own PV industry (Dodd, Espinosa and Bennett, 2018), (Solar Power Europe, 2017) indicating a

[46] Please note that the figure is given in logarithmic scale to increase clarity.

25% of cell manufacturing related jobs being intra-EU in 2016. These discrepancies are also partially explained by (Dodd, Espinosa and Bennett, 2018): "official statistics provided by Eurostat for this product category are too broad since they present aggregated data for semiconductor devices and LEDs apart from PV modules." To avoid these differences while reflecting the reality of a world market dominated by China and Taiwan, 67% of the global PV production according to (JRC, 2015), we have adopted the following approach:

- Keep Eurostat COMEXT and PRODCOM data to characterise the intra-EU trade and manufacturing.
- Disregard employment associated with manufacturing of inverters. The corresponding COMEXT code is too broad to relate to the PV marker of inverters. (Solar Power Europe, 2017) quantifies it to contribute to support only around 2% of the PV related employment.

The current status of the PV industry seems to be far from stable, as depicted in (Ossenbrink *et al.*, 2015). Therefore, a foresight exercise assuming prevalence of the current status quo is a conservative approach. Both (Ossenbrink *et al.*, 2015) and (Solar Power Europe, 2017) depict future technology pathways that could allow the European competitive manufacturing to increase their activity. As such, the results we present, being calibrated to the current known status quo, are conservative in this regard.

As for the wind case, the investment waves required to reach 2030 and 2050 energy and climate policy targets drive the evolution. From current figures close to 110 000 jobs, we expect that the realization of the EUCO3232.5 scenario would lead to an increase of up to almost 260 000 FTE by 2050.

Figure **29** shows the expected distribution of these European figures across countries. Germany will peak at more than 70 000 jobs by 2050, followed by IT, UK and PL growing over 10 000 jobs.

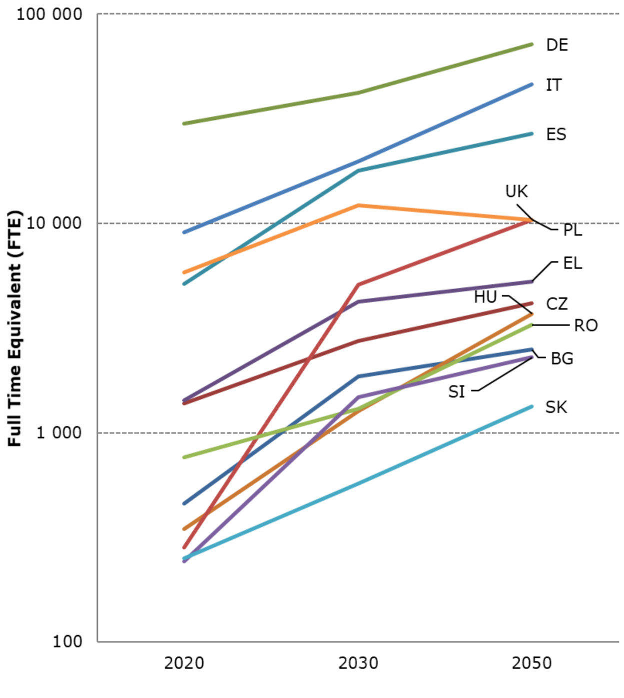


Figure 29. Total solar related employment expected evolution for the coal region's countries (considering all regions in the country).[47]

[47] Please note that the figure is given in logarithmic scale to increase clarity.

EL, CZ, RO, HU and BG will grow relevant figures over 2 000, while SK and SI are expected to experience more modest development.

Dedicated figures for each coal region are included in the corresponding region profile (Annex 10).

5.1.1.3 Bioenergy

We consider bioenergy sourced from different sectors: agriculture, forestry, biogas and municipal solid waste. For the purpose of this assessment, we have considered the following sectorial assumptions:

- Municipal solid waste production will stay stable in the future, i.e. no additional jobs for this sector.
- Forestry sector will source equivalent amounts of energy as in 2015, following the spirit of not reducing the CO_2 levels sunk in the forest.

Under these constraints, the increased biomass consumption foreseen in the EUCO3232.5 scenario is distributed among agriculture (including Short Rotation Forestry) and biogas production. Assuming the biomass increase is given as foreseen by the EUCO3232.5, its distribution across sectors does not have a remarkable impact on the resulting total jobs.

The employment has been assessed as follows:

- The increase in biomass primary energy consumption foreseen by EUCO3232.5 is distributed for each country according to the existing national potentials.
- The obtained primary energy demand is translated to required investment using the corresponding commodity costs for each sector as shown in (Pablo Ruiz *et al.*, 2015)
- The required investment is translated to jobs through the sectorial job intensity, as given in (EurObserv'ER, 2017). The calculation method is calibrated to 2015 resulting jobs.
- The resulting total national jobs are translated to plausible ranges of local employment using the distributors described in section 4.1.2.

The method implies that the trade of biomass such as biofuels and pellets stays as in 2015.

On the total employment evolution associated to the EUCO3232.5 for the coal region hosting countries, the forestry sector will maintain its size. Agriculture and biogas production are assumed to provide the required increasing amount for bioenergy. Figure 30 shows the distribution of employment by country. Germany will increase from more than 110 000 jobs up to more than 195 000. UK, IT, ES and PL will reach around 50 000 jobs by 2050. SK, CZ and RO will have more than 10 000 biomass related jobs by 2050. HU, EL and BG will have a more modest growth, not surpassing 10 000 FTEs.

Wind and solar technologies are more difficult to geographically position as they may be installed in a given region, but maintained by a company based on a different one. For biomass related technology there is a stronger link to the used land. Typically, the jobs are created attached to the land use.

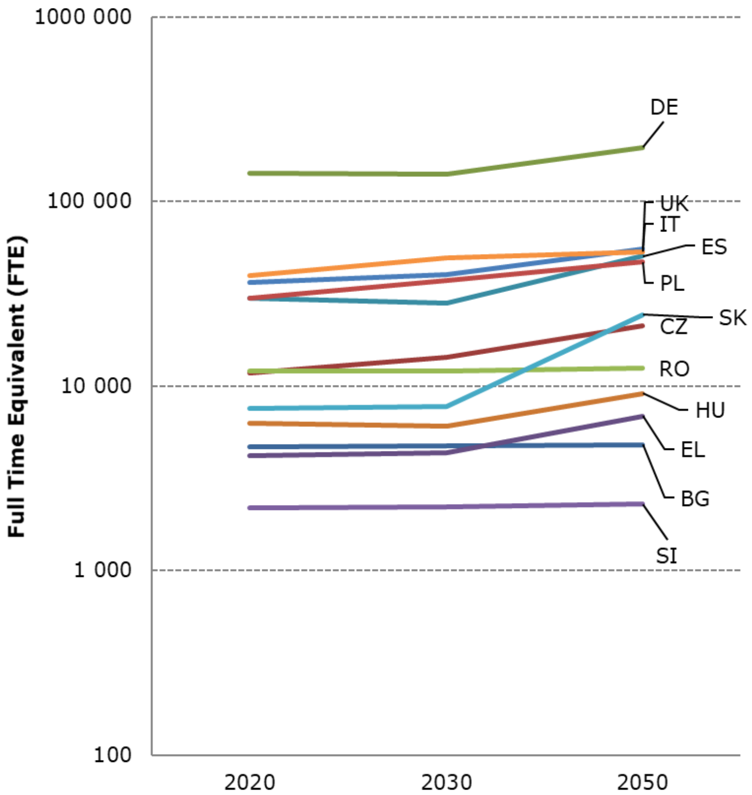


Figure 30. Total biomass production employment for the coal region's countries (considering all regions in the country).[48]

Dedicated corresponding figures for each coal region are included in the corresponding region profile (Annex 2).

5.1.1.4 Geothermal

Geothermal energy is not depicted as a key technology in the EUCO3232.5 scenario. Only DE, HU and IT develop some capacity from 2020 to 2050, while there is a remarkable development foreseen in DE for 2050. Geothermal is one of the most local sources. While some regions may have resources, the very neighbouring may not. Also the energy available has to be used close to the source, to minimize pumping consumption. Therefore the corresponding employment will have one of the most localized natures of all the analysed in this work.

To evaluate the employment development associated we applied the following approach:

- Distributed capacity installation across coal regions, driven by the weight of the local resource available over the total national available;
- Calibrated 2015 employment figures to the output of (EurObserv'ER, 2017), while ensuring the activity distribution as in (Fragkos and Paroussos, 2018);
- Distributed the corresponding nationally induced employment across regions driven by the capacity weights.

Following this evaluation, and derived from EUCO3232.5 scenario, only DE, HU and IT are expected to develop employment evolution from 2020 to 2050. The increase shown in 2050 is mostly driven by remarkable capacity installations foreseen for 2050 in DE.

From all the coal regions, Brandenburg (DE40), Dresden (DED2), Dusseldorf (DEA1), Észak-Magyarország (HU31), Koln (DEA2), Leipzig (DED5), Munster (DEA3), Saarland (DEC0) and Sachsen-Anhalt (DEE0) show employment evolution. The most remarkable

[48] Please note that the figure is given in logarithmic scale to increase clarity.

one expected to happen by 2050 in DE regions and to a lesser extent, in HU31. DE40 could reach 4 000 employments following our estimations derived from EUCO3232.5.

5.1.1.5 Energy Efficiency

Referring to the BAU scenario as described in 2.7, an estimation of the employment effects associated to the deployment of building renovation can be derived on a yearly basis. To do this, we disaggregated the investment costs (i.e. CAPEX) between "equipment" (including the building components, systems and construction materials) and "construction" (i.e. the workforce of the construction companies and installation jobs). The business profit of 10%, the overhead rate of 15% and the Value Added Tax (VAT) rate (applied by each Member State for the renovation of private dwellings[49]) were deduced from the total investment cost, which was then divided by the average national labour cost for these work areas, as estimated in the Euro Observer methodology report[50]. To do this, we assumed that the employment of the construction sector can be mainly covered by the regional and national workforce, while the jobs of the equipment one affect a wider area (continental, at least). Thus for this sector, we used an EU weighted average of labour cost (EUR 53 000/FTE), based on the current production of insulation materials, windows and heating/cooling systems within Europe[51].

Table 15. Yearly full-time equivalent employments (FTE) in the equipment and construction sectors, under the BAU scenario.

NUTS 2	Employment [thousands of FTE per year]	
	Equipment	Construction
BG34	0.8	3.9
BG41	1.6	7.5
CZ04	0.8	1.2
CZ08	1.0	1.5
DE40	4.7	2.9
DEA1	9.5	5.9
DEA2	8.5	5.3
DEA3	5.1	3.2
DEC0	2.4	1.5
DED2	2.6	1.6
DED5	1.6	1.0
DEE0	4.0	2.5
EL53	0.2	0.3
EL65	0.5	0.6
ES12	1.4	1.1
ES21	2.6	1.9

[49] https://ec.europa.eu/taxation_customs/sites/taxation/files/resources/documents/taxation/vat/how_vat_works/rates/vat_rates_en.pdf
[50] https://publications.ecn.nl/ECN-E--17-076
[51] https://ec.europa.eu/eurostat/web/prodcom/data/database

Table continued. Yearly full-time equivalent employments (FTE) in the equipment and construction sectors, under the BAU scenario.

NUTS 2	Employment [thousands of FTE per year]	
	Equipment	Construction
ES24	1.9	1.4
ES41	4.2	3.1
ES42	3.8	2.8
HU31	2.5	6.3
ITG2	0.9	0.6
PL21	1.8	3.6
PL22	2.4	4.6
PL41	0.9	1.7
PL51	1.7	3.3
PL71	2.2	4.3
PL81	1.7	3.3
RO41	1.2	5.2
RO42	1.0	4.4
SI03	0.8	1.1
SK02	1.7	2.9
UKC2	1.8	1.0
UKE2	1.0	0.5
UKE3	1.6	0.9
UKE4	2.6	1.5
UKF1	2.6	1.5
UKG2	2.0	1.1
UKL1	2.3	1.3
UKL2	1.3	0.8
UKM7	2.6	1.4
UKM8	3.1	1.7
UKM9	0.6	0.3

5.1.2 Regional foresight and transition groups

Previous sections have quantified the employment evolution that can be derived from the technology deployment as foreseen in EUCO3232.5 scenario. The details of these regional deployments are given in the corresponding regional fact sheets. In this section the implications of all the technology trends are systemically analysed, in relation to the coal related jobs quantified for the coal regions in (Alves Dias *et al.*, 2018)

First, each region is classified according its current, mid and long-term potential employment status. The classification is stablished thought the following indicators:

- Current status: ratio of potential RES-related jobs over registered coal related jobs as in (Alves Dias *et al.*, 2018). It informs on the relative size of decarbonizing and coal sectors, therefore on the magnitude of potential impact of transitioning from the coal sector.
- Mid-term status: ratio of RES-related jobs increase from 2020 to 2030, over coal related jobs as estimated in (Alves Dias *et al.*, 2018). Considering the 2020-2030 additional jobs provides insight on the retaliation potential of the decarbonizing employment.
- Long-term status: ratio of RES-related jobs increase from 2020 to 2050, over coal related jobs as in (Alves Dias *et al.*, 2018). Heading for a decarbonized energy system, the additionally created jobs over the previously coal-related existing ones provides a measure of the potential final impact of decarbonization.

Table 16 provides the corresponding values for each ratio and for each region. The colour code highlights the difference status of each region. Red brings forward those regions and time frames where RES-related employment potential is under 50% of the existing coal related jobs. Yellow marks the range from half to equal coal to decarbonized employment potential. Finally, green shows where existing decarbonized employment potentials surpasses current coal related registered employment.

Table 16. Current, mid and long term regional potential employment ratios.

	2020	2030	2050		2020	2030	2050
BG34	47%	11%	17%	**PL41**	179%	70%	157%
BG41	758%	124%	183%	**RO41**	59%	3%	8%
CZ08	34%	5%	11%	**RO42**	138%	8%	20%
CZ04	35%	11%	19%	**SK02**	3 272%	7%	2 921%
DEA3	183%	20%	91%	**SI03**	198%	93%	173%
DEA2	717%	35%	277%	**ES24**	633%	313%	648%
DEA1	652%	52%	247%	**ES12**	182%	36%	81%
DEC0	144%	10%	51%	**ES41**	1 808%	785%	1 707%
DE40	753%	98%	520%	**ES42**	5 126%	2 203%	4568%
DED2	300%	27%	153%	**ES21**	-	-	-
DEE0	2 297%	334%	1 572%	**UKC2**	690%	45%	185%
DED5	414%	39%	200%	**UKE3**	16 451%	2 097%	3 676%
EL53	18%	5%	12%	**UKE4**	9 265%	1 356%	2 280%
EL65	253%	96%	212%	**UKE2**	379%	52%	117%
HU31	431%	3%	45%	**UKF1**	409%	26%	63%
ITG2	988%	454%	1 115%	**UKM8**	5 588%	160%	894%
PL22	13%	3%	6%	**UKM7**	2 462%	332%	755%
PL21	139%	26%	57%	**UKM9**	6 572%	410%	3 224%
PL81	133%	33%	74%	**UKG2**	2 054%	156%	366%
PL71	102%	16%	36%	**UKL2**	947%	54%	318%
PL51	388%	84%	188%	**UKL1**	2 345%	147%	769%

From Table 16 the following groups of regions can be stablished:

- **Regions with High Decarbonizing Employment Potential (HDEP).** BG41, DEA2, DEA1, DE40, DED2, DEE0, DED5, EL65, ITG2, PL51, PL41, SK02, SI03, ES24, ES12, ES41, ES42, UKC2, UKE3, UKE4, UKE2, UKF1, UKM8, UKM7, UKM9, UKG2, UKL2 and UKL1.
  Regions where currently potential RES-employment sectors are of comparable size to the coal-related. Future decarbonisation scenario will entail clearly surpassing existing coal related jobs. Support to fully deploy the identified potential may be needed in these regions.
- **Slow Decarbonizing Employment Potential (SDEP) regions**. DEA3, DEC0, HU31, PL21, PL81, PL71 and RO42.
  These regions can potentially develop decarbonizing employment sectors to retaliate the coal related ones. The pace derived from EUCO3232.5 scenario can generate transitionary imbalances. Support to accelerate deployment may be needed in these regions.
- **Regions with restricted decarbonizing employment potential (RDEP).** BG34, CZ08, CZ04, EL53, PL22 and RO41.
  These regions under the EUCO3232.5 scenario do not deploy decarbonized employment to a comparable level of existing coal related levels. Support may be needed to mobilise untapped existing potential or to promote alternative options.

The full detail of the evolution depicted by these indicators is further analysed from Figure 31 to Figure 68, presenting the regional transition employment foresight for each region. For our results, the calibration year is 2015. Results for 2020 also refer to estimations.

The foresight transition for the Yugoiztochen region falls in the RDEP group. In 2020 the decarbonizing employment potential, mainly associated with Energy Efficiency, results close to half of the current coal related jobs. The decarbonisation of the energy system will not cover the estimated 12 000 current coal jobs with the 2 200 potential jobs by 2050.

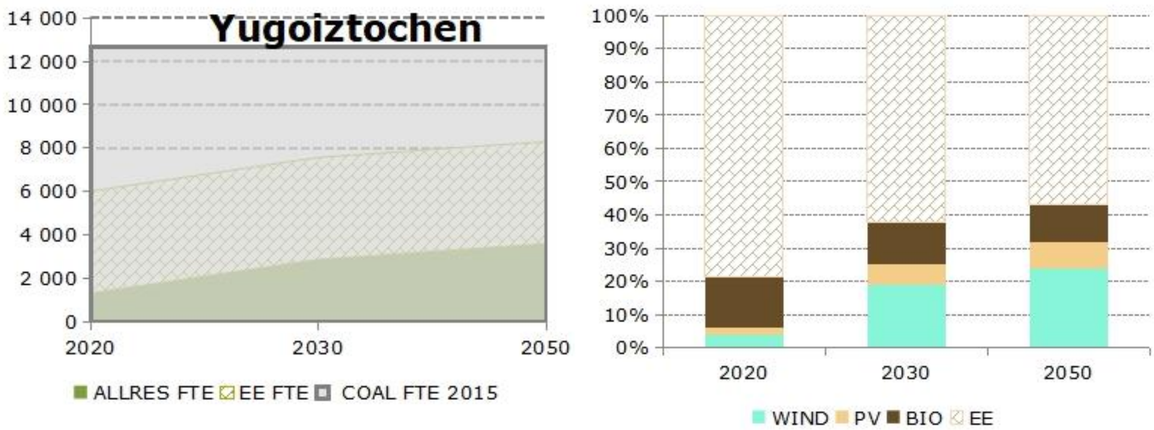


Figure 31. Current coal-related employment over transition foresight for BG34 (left). Sectorial contribution to decarbonizing employment (right)

The expected HDEP decarbonisation path for Yugozapaden starts from a favourable potential employment point. This is due to a building refurnishing potential remarkably bigger than the coal related employment. The increased weight of RES related jobs especially associated with wind and biomass resources, leads to a clearly net positive balance by 2030 and even more by 2050.

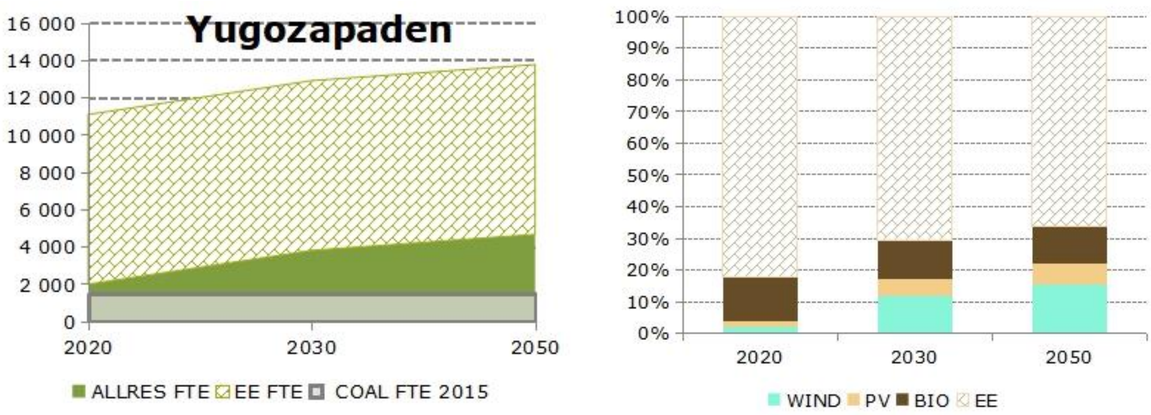


Figure 32. Current coal-related employment over transition foresight for BG41 (left). Sectorial contribution to decarbonizing employment (right)

The decarbonizing employment potential for Severozápad (RDEP) derived from EUCO3232.5 will likely not suffice to even out coal related employment which is quantified as close to 10 000 FTE. Main decarbonizing employment potential for the regions is associated with Energy Efficiency and Biomass sectors.

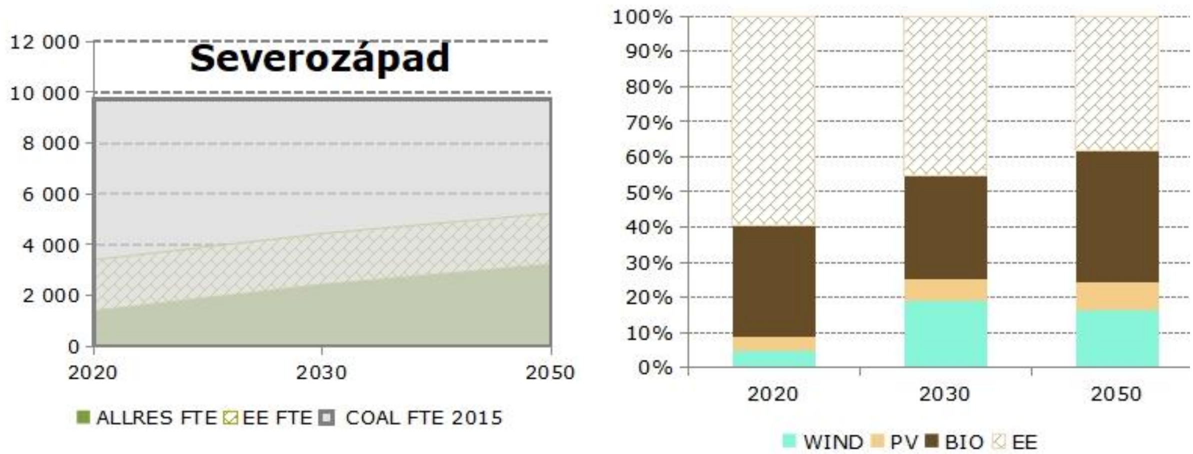
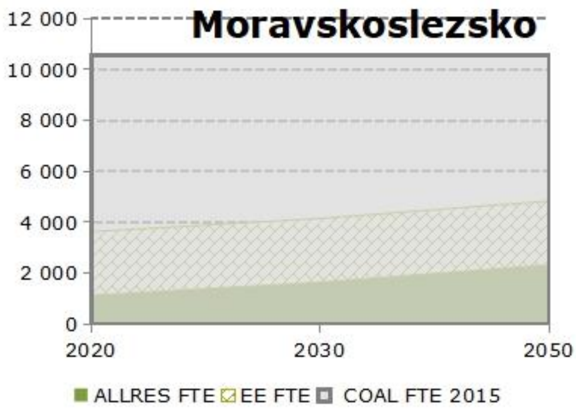


Figure 33. Current coal-related employment over transition foresight for CZ04 (left). Sectorial contribution to decarbonizing employment (right)

Moravskoslezsko is a case of a RDEP region. Starting from a remarkable coal related employment level of over 10 000 jobs, its decarbonizing employment growth is not foreseen to be able to cover the size of the coal related employment estimations. Support may be needed to mobilise employment potential over that foreseen as a result of the EUCO3232.5 scenario.



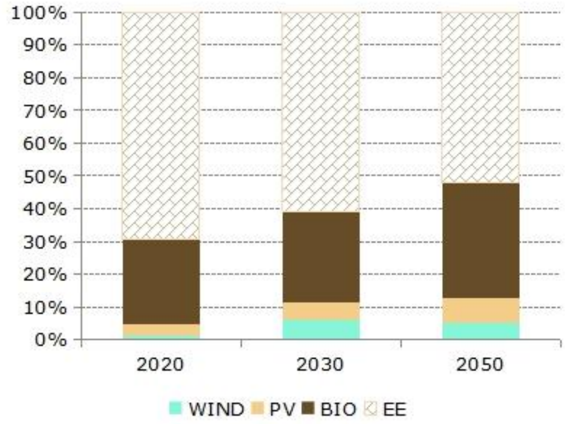
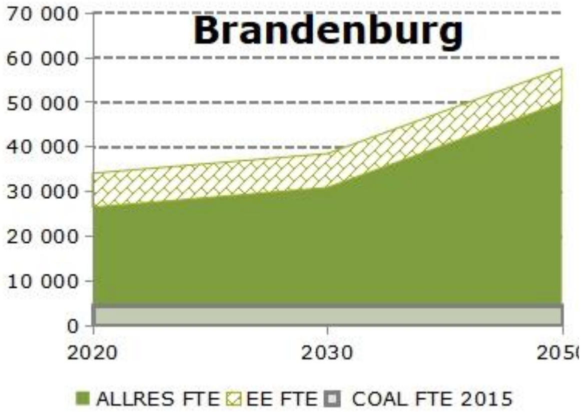


Figure 34. Current coal-related employment over transition foresight for CZ08 (left). Sectorial contribution to decarbonizing employment (right)

Brandenburg is a case of HDEP region. The relevant coal employment of over 4 000 FTE is by far surpassed by the potential by 2020, driven mostly by remarkable wind industry activity in the region. The leading role of wind will be exacerbated as decarbonisation progresses, potentially providing up to 24 000 FTE by 2050.



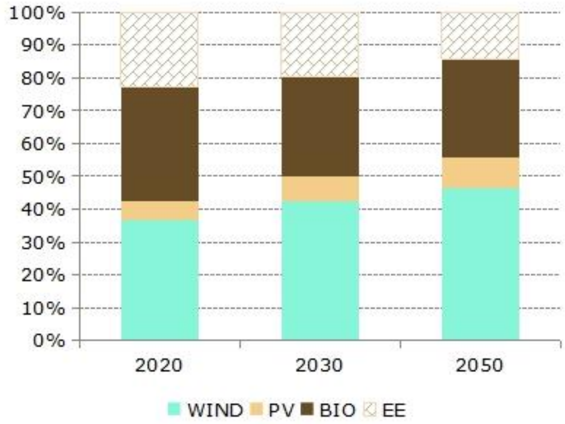


Figure 35. Current coal-related employment over transition foresight for DE40 (left). Sectorial contribution to decarbonizing employment (right)

For Düsseldorf, the relevant number of coal related jobs are also in a 1:6 ratio with the almost 28 000 decarbonizing potential in 2020. An additional 13 000 FTE could be mobilized as decarbonisation progresses. Considering the high current decarbonizing-to-coal employment potential ratio, the region could be labelled as HDEP region. However, this additional decarbonizing employment potential will not cover the coal related jobs.

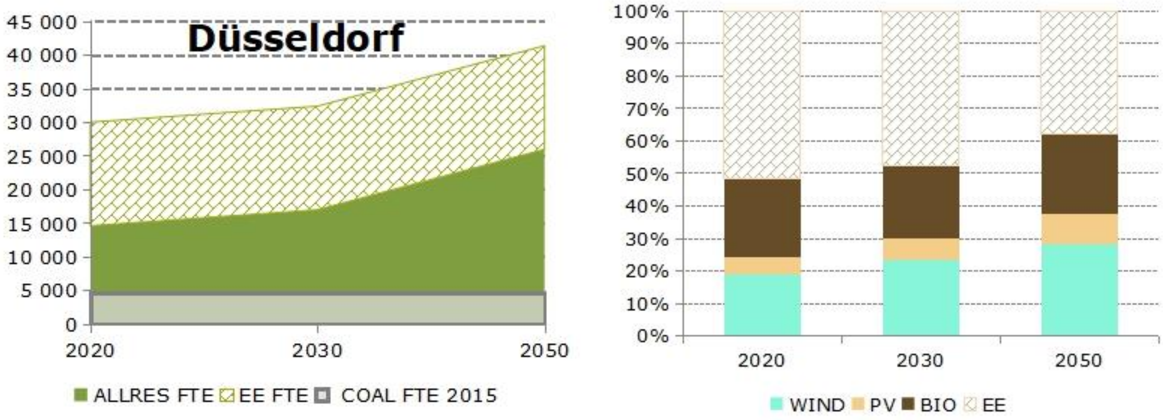


Figure 36. Current coal-related employment over transition foresight for DEA1 (left). Sectorial contribution to decarbonizing employment (right)

Köln region shows a clear HDEP profile. If the decarbonisation employment potential is realized fully by 2020, the replacement ratio could reach 1:6. This is mainly driven by the relevant potential in the biomass sector, well complemented by building refurnishing and wind sectors. Decarbonisation from 2030 onwards will mobilise additional existing potential.

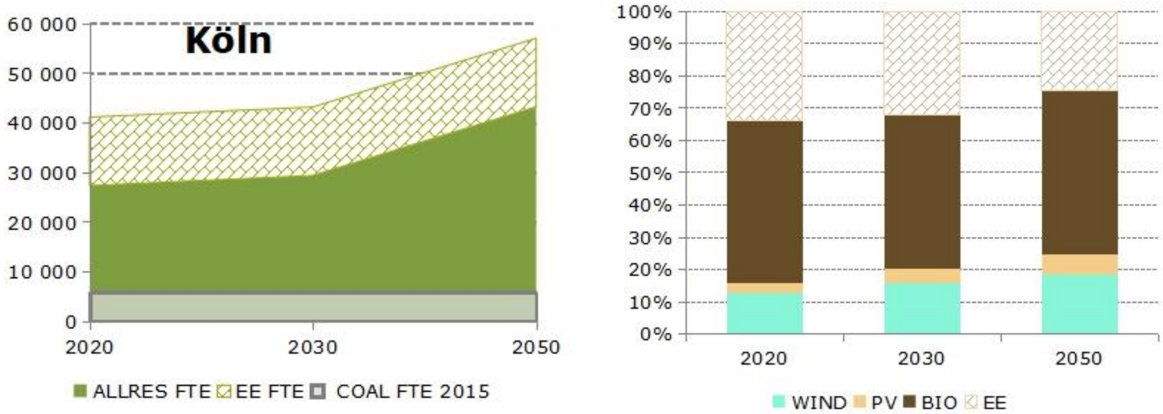


Figure 37. Current coal-related employment over transition foresight for DEA2 (left). Sectorial contribution to decarbonizing employment (right)

Münster HDEP region has a significant share of wind resource that if deployed could reach similar levels as the nearly 10 000 coal related jobs. The equivalent additional decarbonizing employment brought by the energy efficiency sector can ensure contained social impact toward decarbonisation.

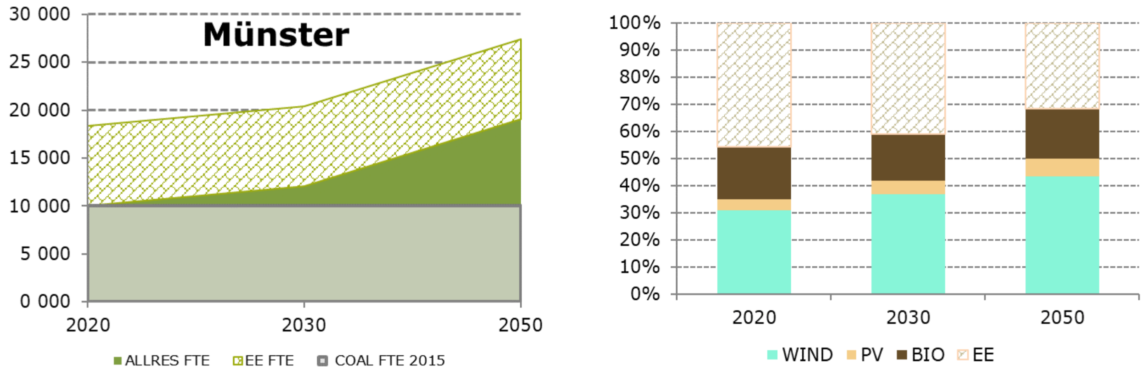


Figure 38. Current coal-related employment over transition foresight for DEA3 (left). Sectorial contribution to decarbonizing employment (right)

Saarland results in a SDEP region. Existing potential by 2020 could account for around 4 000 coal related jobs. Additionally induced decarbonizing employment by 2030 may not cover the coal related jobs by 2030. The region has a remarkable building refurnishing employment potential and relevant potential linked with biomass and wind technologies.

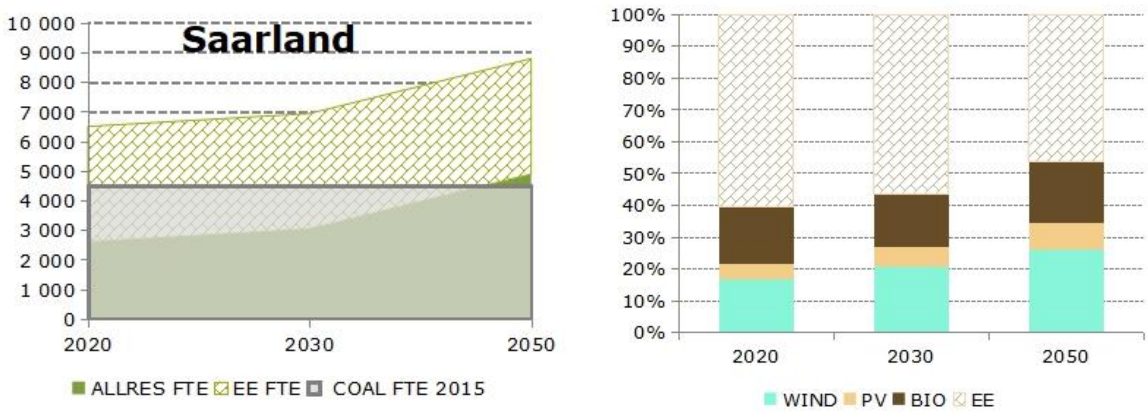
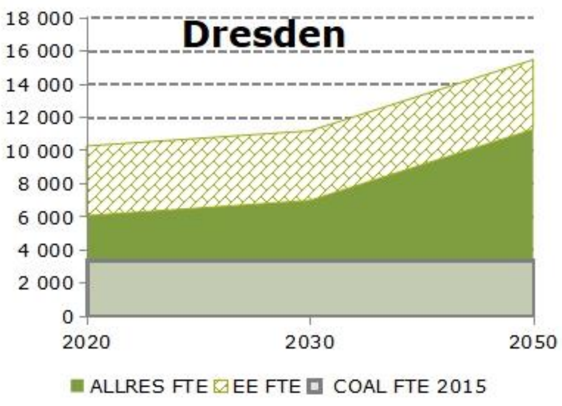


Figure 39. Current coal-related employment over transition foresight for DEC0 (left). Sectorial contribution to decarbonizing employment (right)

Dresden is grouped as a HDEP region. It has a relevant decarbonizing employment potential that, if deployed, it could provide 5 times the coal related employment. Accelerated decarbonisation could easily provide retaliation for coal related employment by 2030.



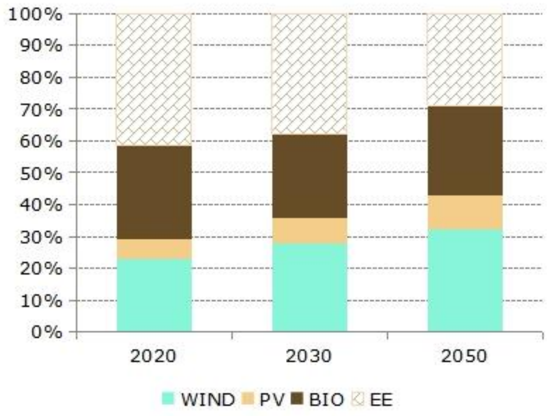
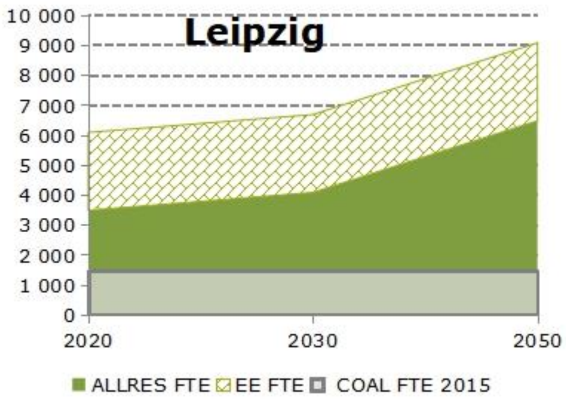


Figure 40. Current coal-related employment over transition foresight for DED2 (left). Sectorial contribution to decarbonizing employment (right)

Very favourable transition conditions appear for Leipzig that can be classified as a very decarbonisation-ready HDEP region. Although additional jobs reachable by 2030 may not surpass the existing coal related employment, the total decarbonizing employment potential by 2020 is almost 4 times that of coal. By 2050, the total decarbonizing related employment potential will reach 6 times the coal related.



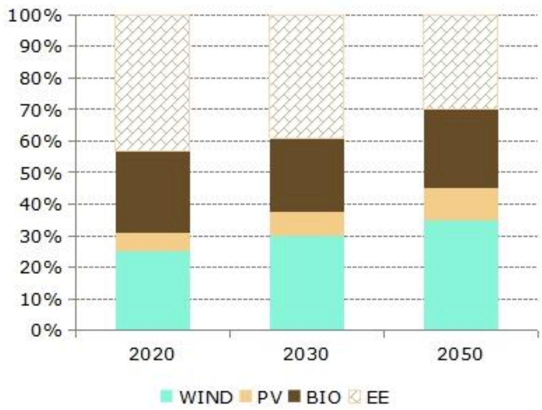


Figure 41. Current coal-related employment over transition foresight for DED5 (left). Sectorial contribution to decarbonizing employment (right)

Saxony-Anhalt region clearly holds decarbonizing potential to ensure smooth transition for its 1 000 coal related jobs. Mainly wind-driven, decarbonizing employment potential can provide the required resilience for a smooth transition in the region, backed up by also remarkable building refurnishing options.

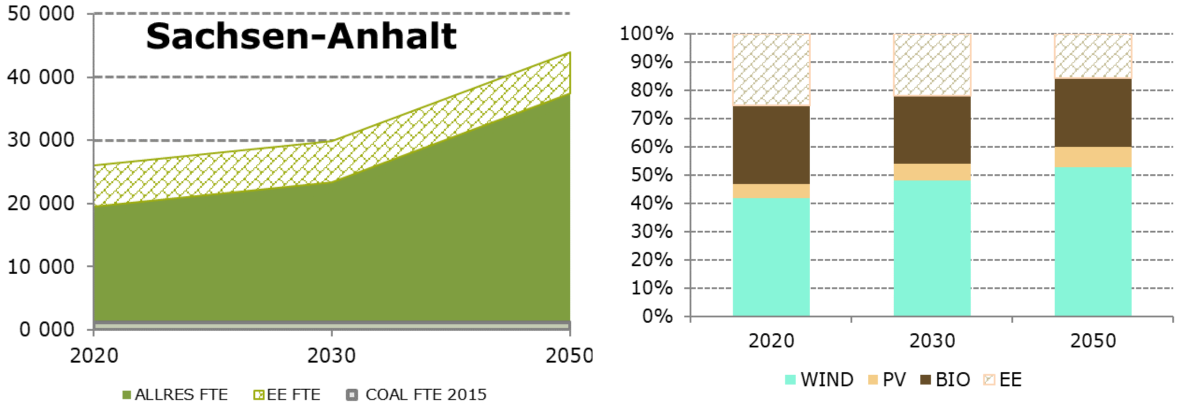


Figure 42. Current coal-related employment over transition foresight for DEE0 (left). Sectorial contribution to decarbonizing employment (right)

Dytiki Makedonia can be classified as a RDEP. The remarkable coal related jobs of almost 6 000 FTE that surpasses the decarbonizing employment potentially mobilized within the EUCO3232.5 scenario. The biomass related jobs will cover most of the near 2 000 FTE potential employment by 2050.

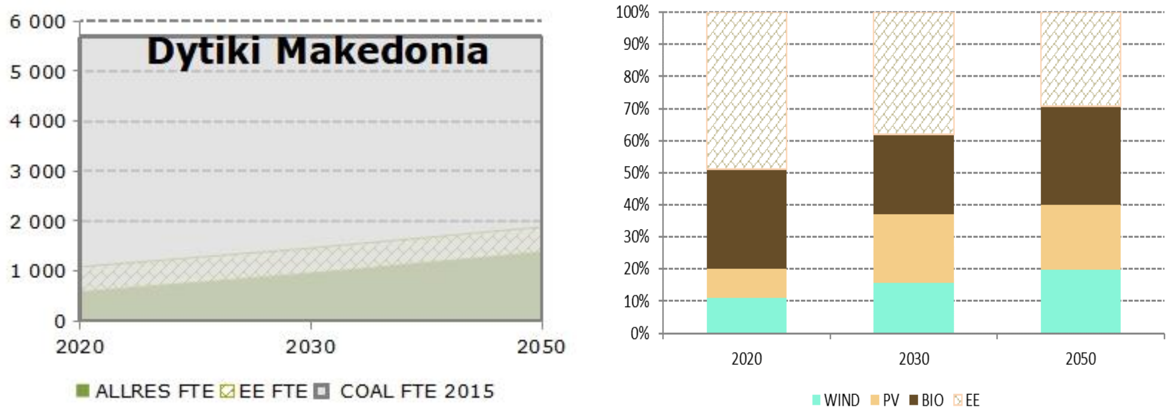


Figure 43. Current coal-related employment over transition foresight for EL53 (left). Sectorial contribution to decarbonizing employment (right)

Driven by a remarkable biomass related and building refurnishing potential, Peloponnisos appears as a HDEP region. A significant development of wind sector will turn out in a total of almost 4 000 FTE of decarbonazing employment potential to be compared with the nearly 1 000 coal related FTEs.

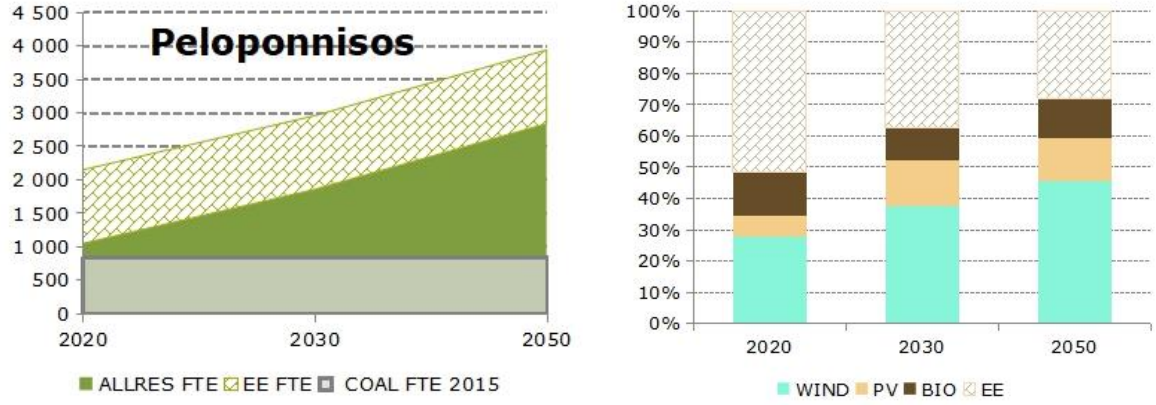


Figure 44. Current coal-related employment over transition foresight for EL65 (left). Sectorial contribution to decarbonizing employment (right)

Principado de Asturias remarkable energy efficiency, biomass and future wind potential can lead to 2 times the coal related employment by 2030 for this HDEP region.

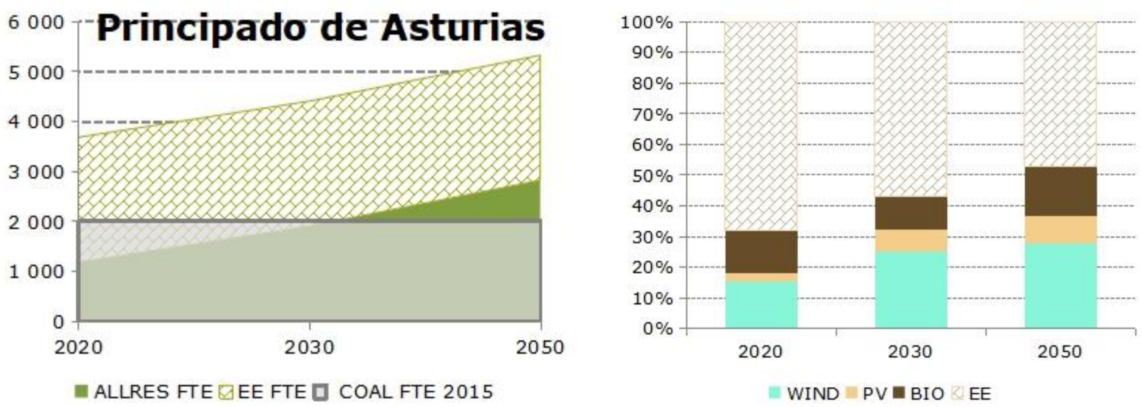


Figure 45. Current coal-related employment over transition foresight for ES12 (left). Sectorial contribution to decarbonizing employment (right)

Due to its heritage, País Vasco has been considered a coal region, although there are no significant levels of coal related employment in the region. Nevertheless, a potential bag of almost 8 000 FTE by 2020 can provide social buffering for this HDEP region.

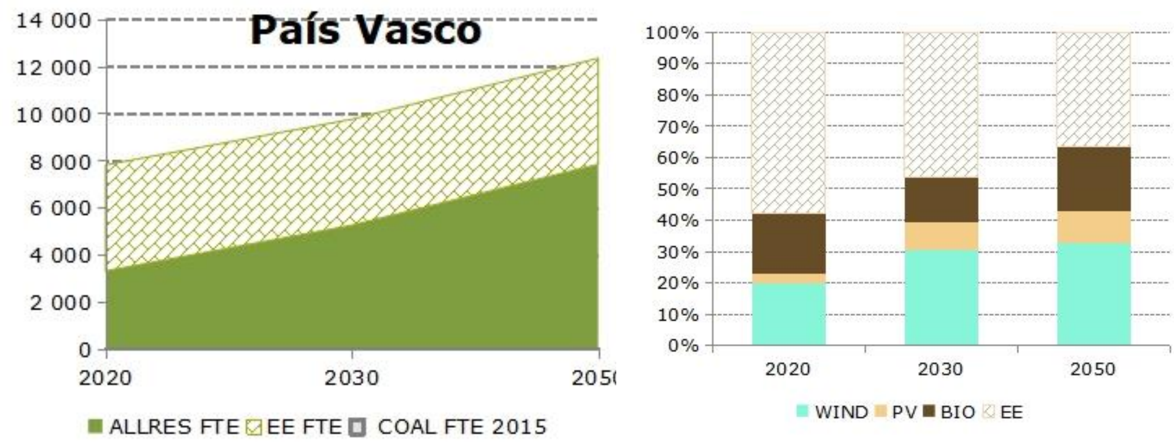


Figure 46. Current coal-related employment over transition foresight for ES21 (left). Sectorial contribution to decarbonizing employment (right)

The remarkable wind related potential of Aragón drives in obtaining a ratio of decarbonizing to coal related employment of potentially over 9, classifying the region as a HDEP.

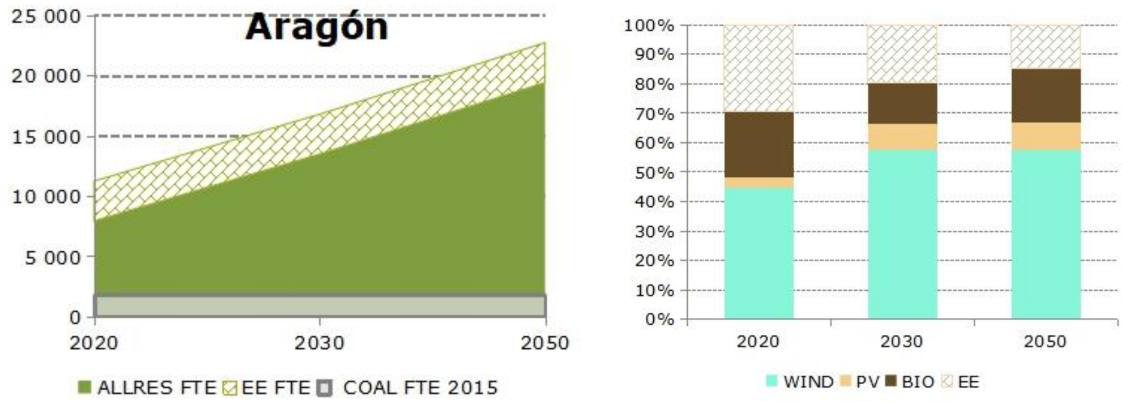


Figure 47. Current coal-related employment over transition foresight for ES24 (left). Sectorial contribution to decarbonizing employment (right)

Castilla y León is classified as HDEP region with nearly 1 000 coal related jobs. The regional employment potential driven by wind could reach the coal related ones, if realized at least to its 2020 prospective. We find significant additional employment potential associated with the development of both building refurnishing and PV sectors in the region.

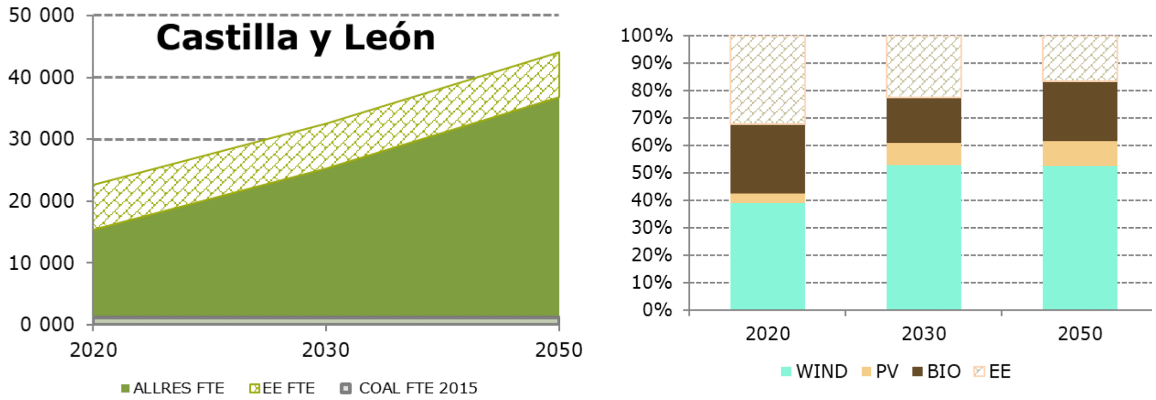


Figure 48. Current coal-related employment over transition foresight for ES41 (left). Sectorial contribution to decarbonizing employment (right)

Castila La Mancha is a HDEP region, with a 1:50 ratio of coal related jobs and the decarbonizing potential in the region by 2020. A remarkable wind related employment potential can provide almost 6 000 FTE by 2020. This can be further backed up by energy efficiency related employment creation and a blooming PV sector.

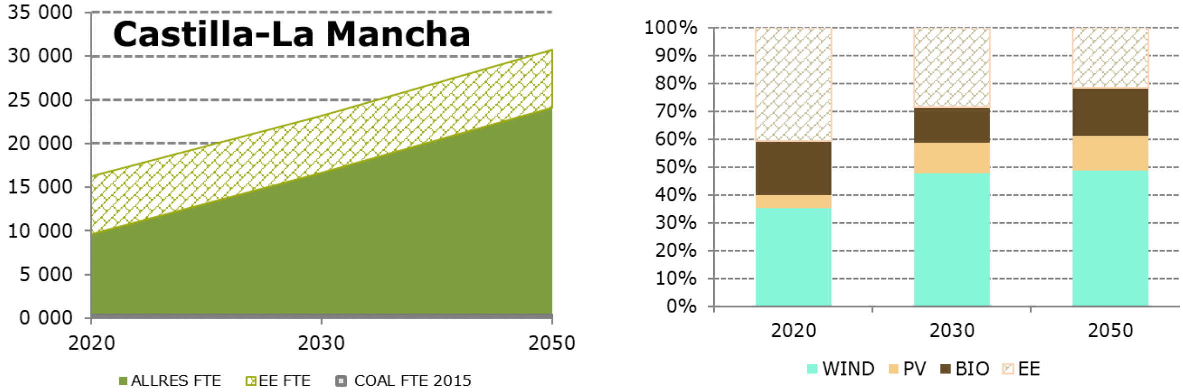
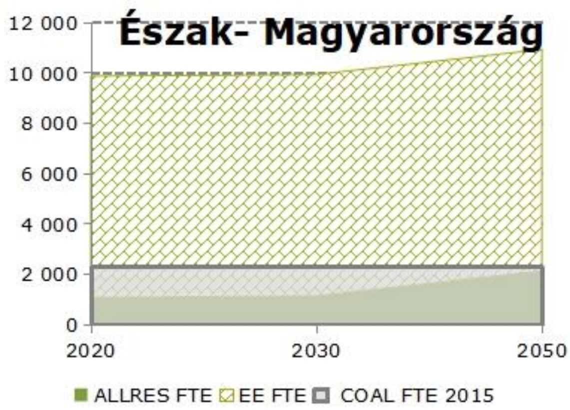


Figure 49. Current coal-related employment over transition foresight for ES42 (left). Sectorial contribution to decarbonizing employment (right)

Észak-Magyarország can be classified as a HDEP region due to its very significant energy efficiency related employment potential estimated in the region. Ensuring the mobilization of this sector will be key for a smooth regional transition. Renewable related potential alone will almost be equal the size of the coal related employment by 2050, mainly driven by biomass related employment.



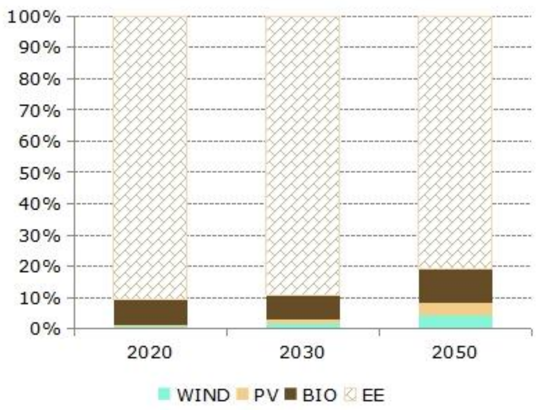
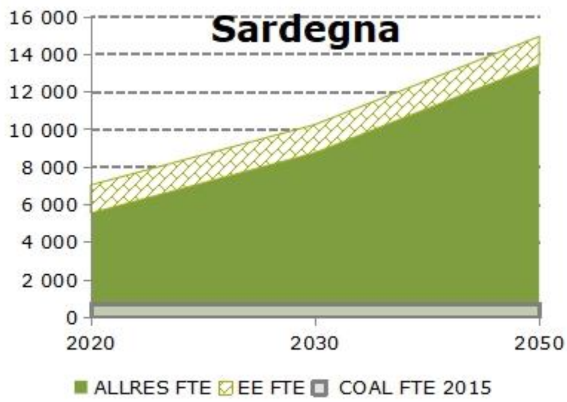


Figure 50. Current coal-related employment over transition foresight for HU31 (left). Sectorial contribution to decarbonizing employment (right)

Driven by a significant wind, biomass and energy efficiency related employment potential, Sardegna is classified as a HDEP region. By ensuring reasonable deployment of the available potential already in 2020, the region could reach a 21:1 ratio on decarbonizing potential to coal related employment by 2050.



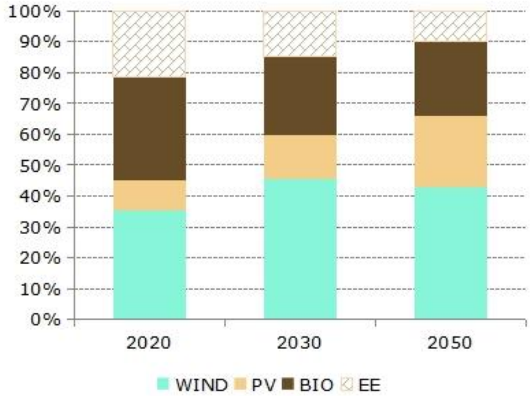
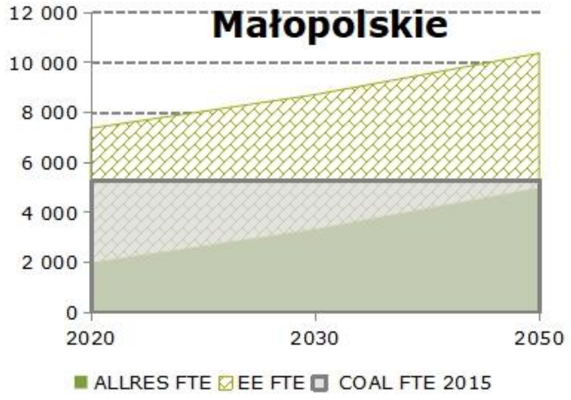


Figure 51. Current coal-related employment over transition foresight for ITG2 (left). Sectorial contribution to decarbonizing employment (right)

In 2020, Małopolskie shows a ratio of decarbonizing potential to coal employment of 1:38. If fully realized, it could enable the region's transition. Nevertheless the additional employment foreseen to be mobilized by 2030 will not suffice to match the size of the current coal sector. As a result, the region is classified in the SDEP cluster. However, there is a clear margin for improvement and holding significant potential, mainly in the building refurnishing sector.



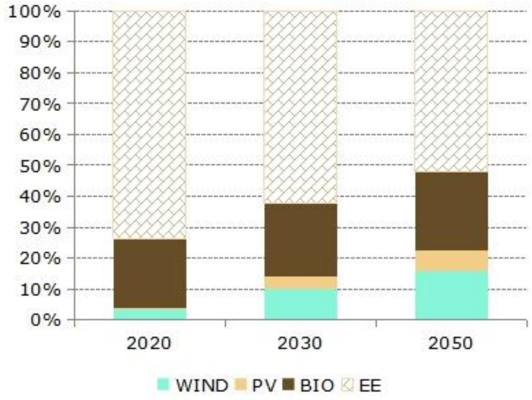
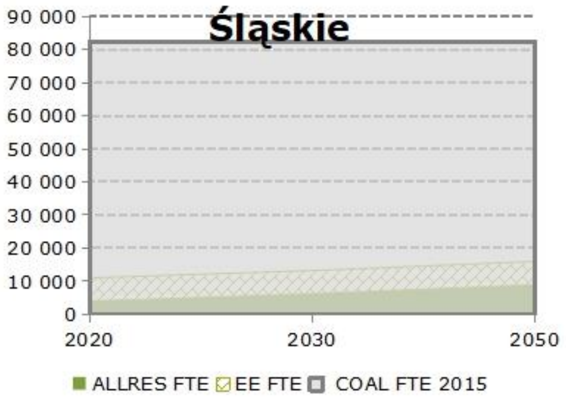


Figure 52. Current coal-related employment over transition foresight for PL21 (left). Sectorial contribution to decarbonizing employment (right)

Śląskie is the region which has by far the biggest number of coal related employment, with more than 80 000 FTE. The significant identified decarbonizing employment potential associated with the EUCO3232.5 starts from more than 10 000 FTE by 2020 and peaks over 15 000 by 2050. The additional potential required to be mobilized marks the region in the class of RDEP.



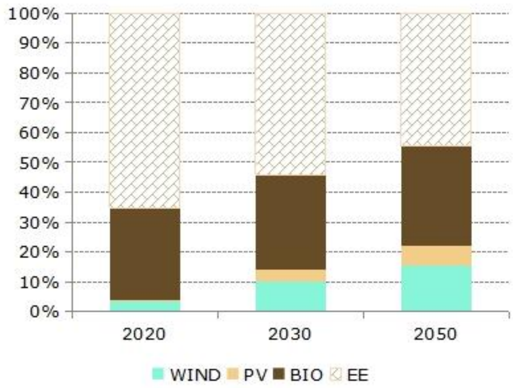


Figure 53. Current coal-related employment over transition foresight for PL22 (left). Sectorial contribution to decarbonizing employment (right)

Wielkopolskie, with a contained number of coal related jobs, building refurnishing and increasing wind potential, can have a smooth transition. Support may be needed to ensure the realization of existing potential of this HDEP region.

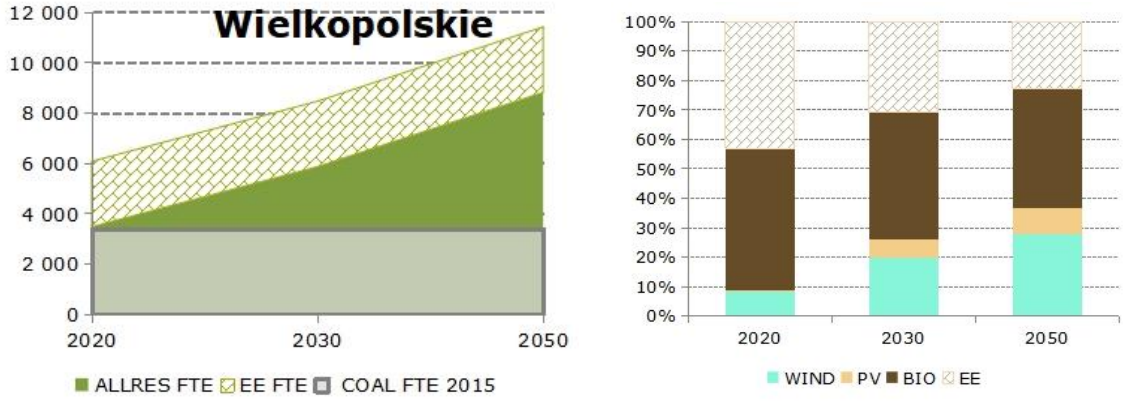


Figure 54. Current coal-related employment over transition foresight for PL41 (left). Sectorial contribution to decarbonizing employment (right)

Dolnośląskie appears as the more resilient coal region in Poland, due to a contained number of nearly 2 000 coal related jobs. In this case, the region's transition could be facilitaed by the potential employment related to energy efficiency by 2020 alone. Therefore, the region can be classified as HDEP.

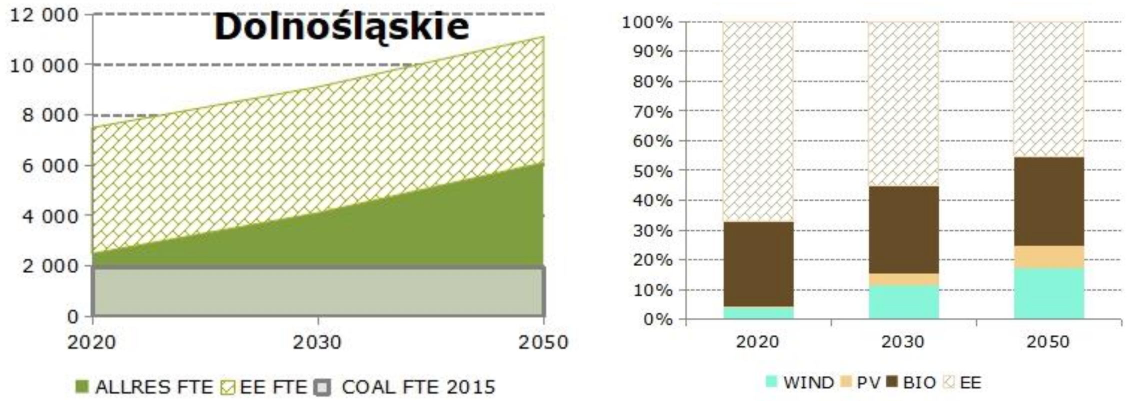


Figure 55. Current coal-related employment over transition foresight for PL51 (left). Sectorial contribution to decarbonizing employment (right)

Łódzkie begins the decarbonization pathway with remarkable potential in the building refurnishing sector. The expected additional employment potential to be mobilized -mainly in relation with the wind sector- does not reach the number of the coal related FTEs. Full mobilization of the existing potential and supplementary options may be needed for this SDEP region.

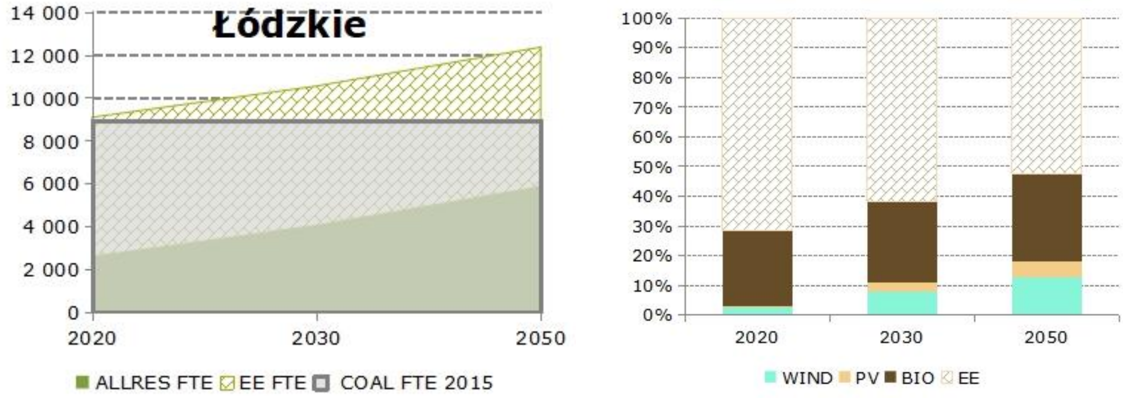


Figure 56. Current coal-related employment over transition foresight for PL71 (left). Sectorial contribution to decarbonizing employment (right)

Lubelskie is classified as a SDEP region with significant weight of the coal related jobs. Building refurnishing and future wind related employment potential is foreseen to add up to almost 12 000 FTE by 2050, double the almost 6 000 coal related FTEs. Faster mobilization of the existing potential may be needed to fully retaliate the coal related employment.

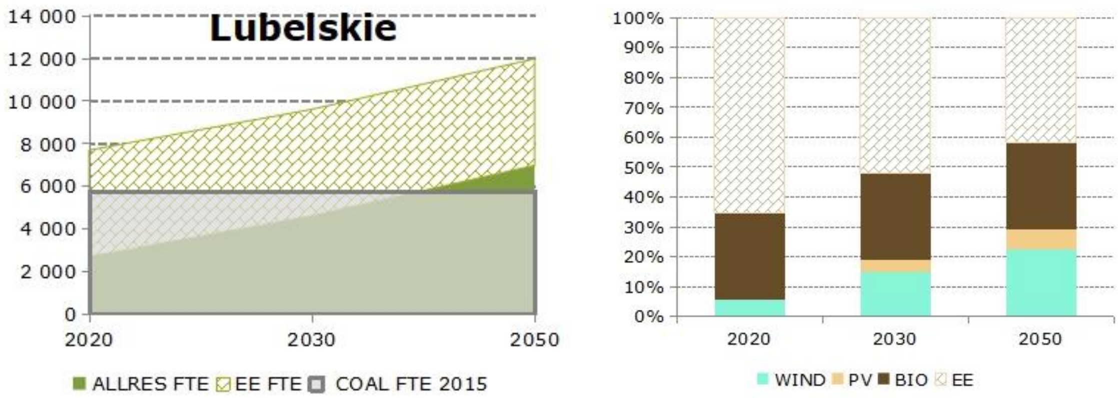


Figure 57. Current coal-related employment over transition foresight for PL81 (left). Sectorial contribution to decarbonizing employment (right)

Sud-Vest Oltenia can be classified as a RDEP region. The plausible employment potential to be catalized by the EUCO3232.5 scenario will be difficult to reach the high number of coal related jobs. While there is notable energy efficiency related employment potential, further alternatives or higher implementation of national capacity in the region may be required.

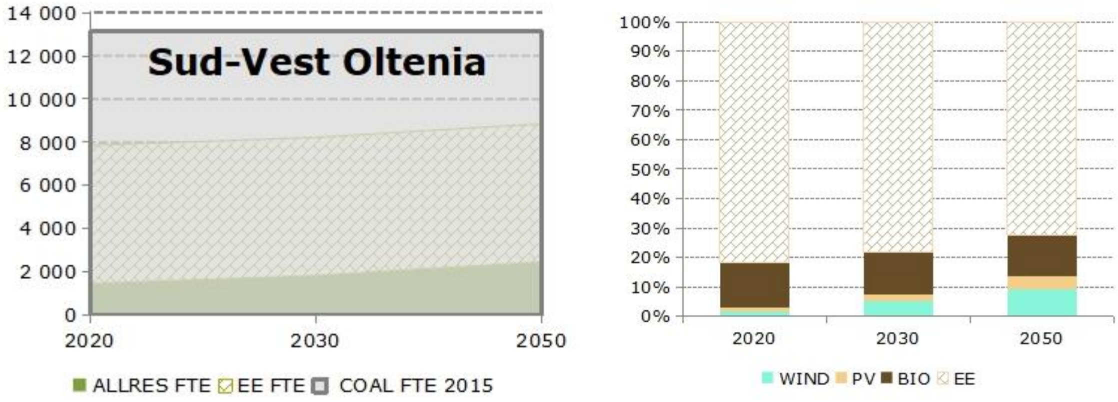


Figure 58. Current coal-related employment over transition foresight for RO41 (left). Sectorial contribution to decarbonizing employment (right)

With a coal sector half that of Sud-Vest Oltenia, Vest can be classified as a SDEP region. Additional decarbonizing jobs by 2030 may not reach the number of the coal related. However, decarbonizing potential employment can still be 1.5 times the coal related FTEs.

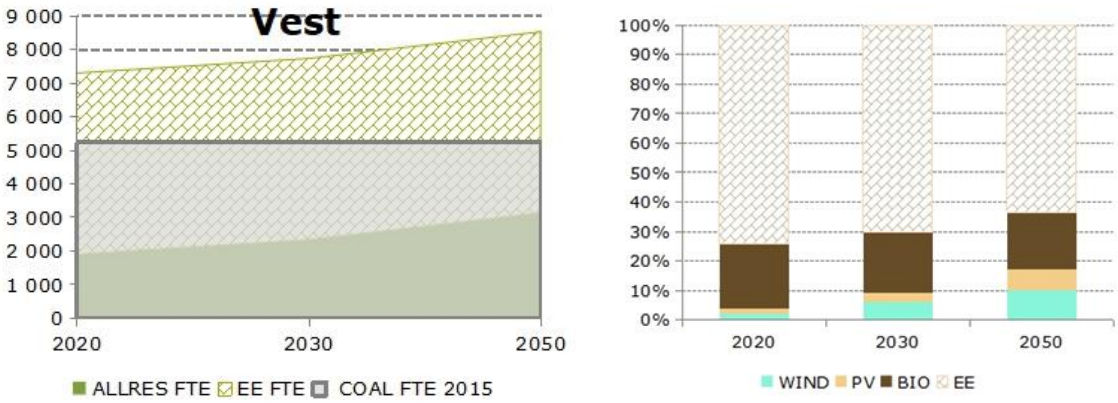


Figure 59. Current coal-related employment over transition foresight for RO42 (left). Sectorial contribution to decarbonizing employment (right)

Západné Slovensko shows a vast potential in energy efficiency and biomass. This accounts for almost 25 times the coal related employment reaching 60 times by 2050 if fully realised.

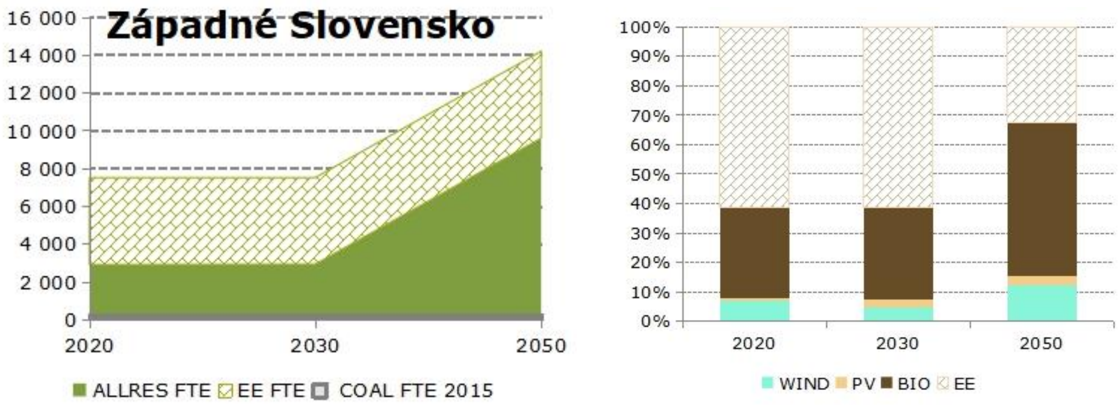


Figure 60. Current coal-related employment over transition foresight for SK02 (left). Sectorial contribution to decarbonizing employment (right)

Vzhodna Slovenija's transition can be facilitated if fully mobilizing the identified energy efficiency and biomass potential. A remarkable increase of solar related employment bring the region closer to a HDEP status.

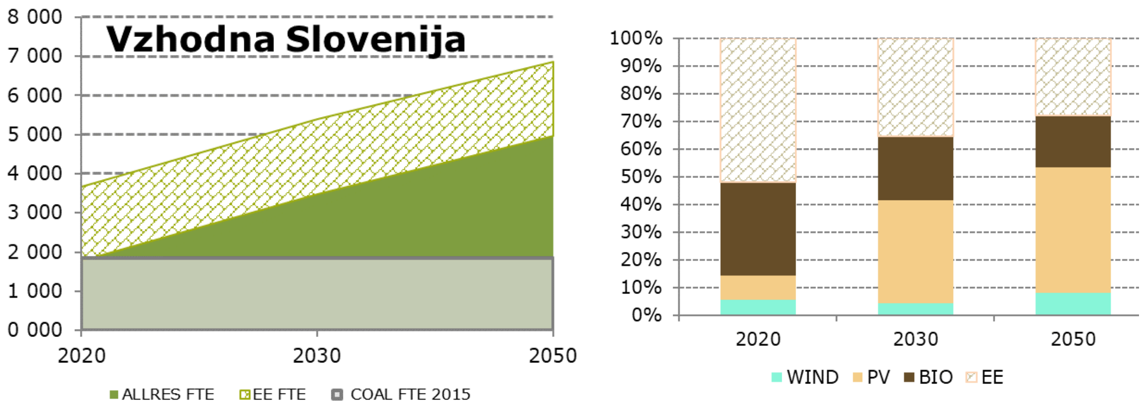


Figure 61. Current coal-related employment over transition foresight for SI03 (left). Sectorial contribution to decarbonizing employment (right)

Northumberland and Tyne and Wear is grouped within the HDEP regions. The renewable related potential employment in the region by 2020, mostly from wind and biomass, is three times that of the coal related jobs. Backed up by a remarkable potential in the energy efficiency sector, the ratio of decarbonizing potential employment to that coal related is estimated to be over 7:1 by 2030.

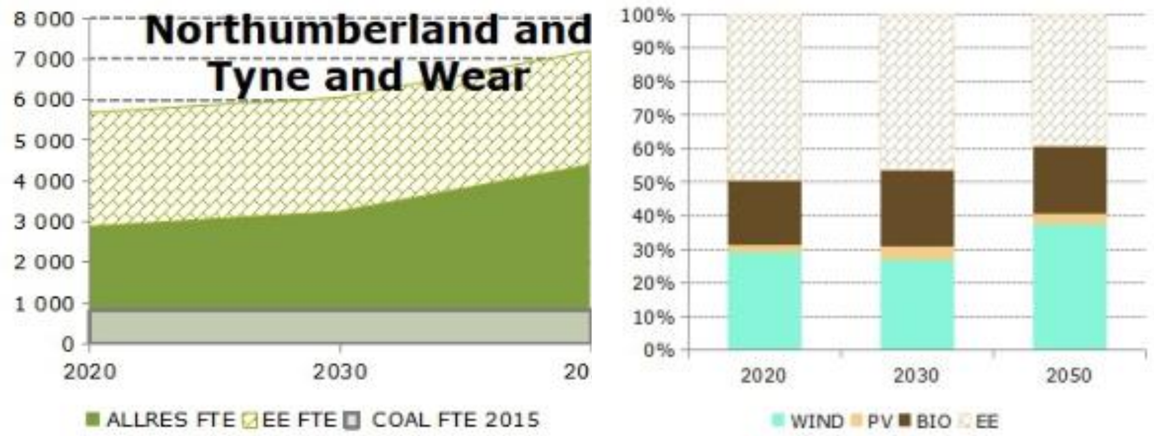


Figure 62. Current coal-related employment over transition foresight for UKC2 (left). Sectorial contribution to decarbonizing employment (right)

North Yorkshire is one of the regions in the UK with relatively higher coal related employment figures. Nevertheless, it is still classified as a HDEP region. Its decarbonizing potential FTEs over the coal related jobs by 2020 in the biomass, energy efficiency and wind sectors results in a ratio of 3:1 by 2020 that could reach almost 5:1 by 2050 under the EUCO3232.5 scenario.

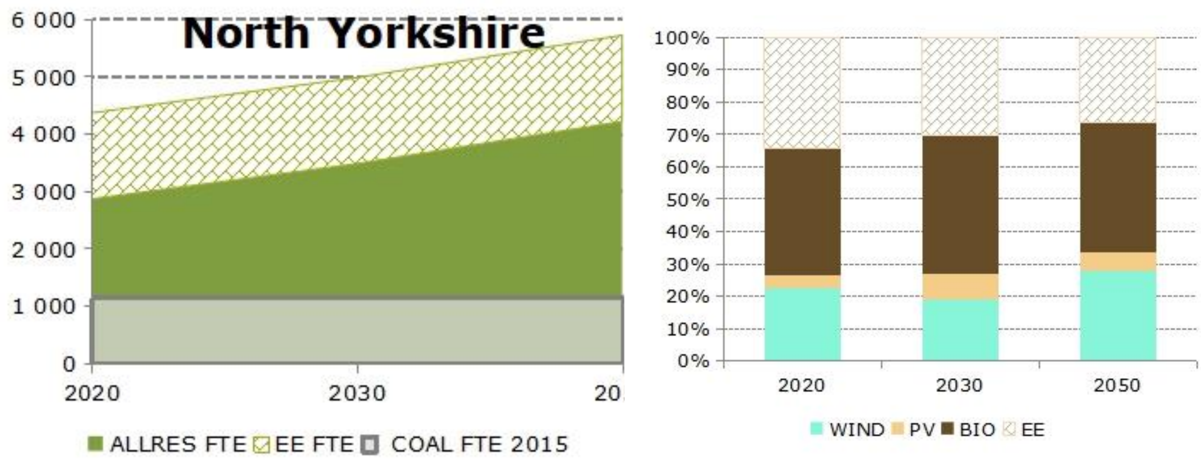
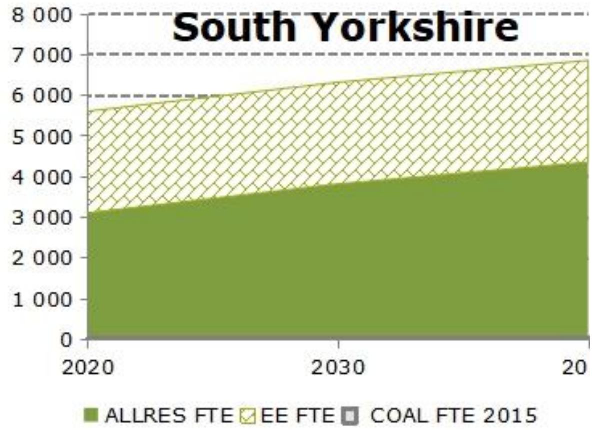


Figure 63. Current coal-related employment over transition foresight for UKE2 (left). Sectorial contribution to decarbonizing employment (right)

Coal related employment level at South Yorkshire is not comparable to its decarbonizing labour potential, classifying it as a HDEP region. The potential mostly achieved in the building refurnishing and in the biomass sectors results 160 times the coal related FTEs.



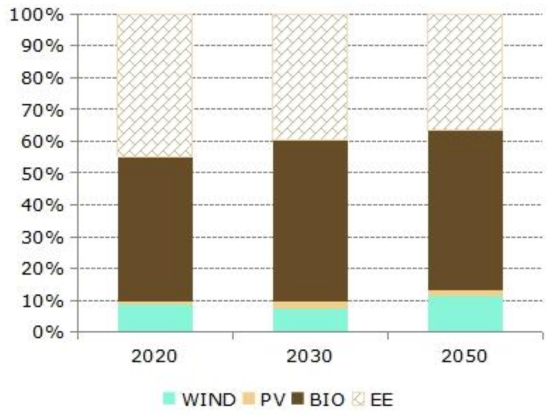
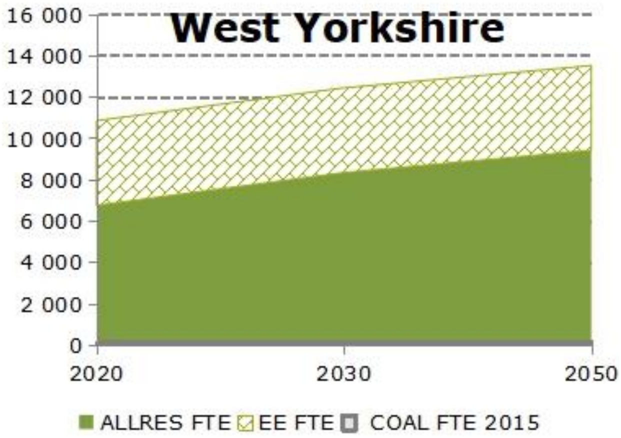


Figure 64. Current coal-related employment over transition foresight for UKE3 (left). Sectorial contribution to decarbonizing employment (right)

Similar to the case of South Yorkshire (UKE3), West Yorkshire is classified as a HDEP region. The coal related employment exposure of the region is insignificant compared to its relevant energy efficiency and biomass employment potentials even by 2020.



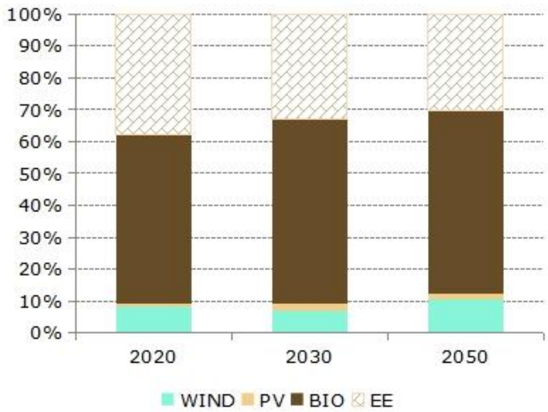


Figure 65. Current coal-related employment over transition foresight for UKE4 (left). Sectorial contribution to decarbonizing employment (right)

In Derbyshire and Nottinghamshire, we estimate a very significant employment potential in the buildings refurnishing sector. This being three times the level of coal related employement categorizes the region as a HDEP. The ratio can be over 1:4 by 2030 if futher biomass and wind potentials are realized.

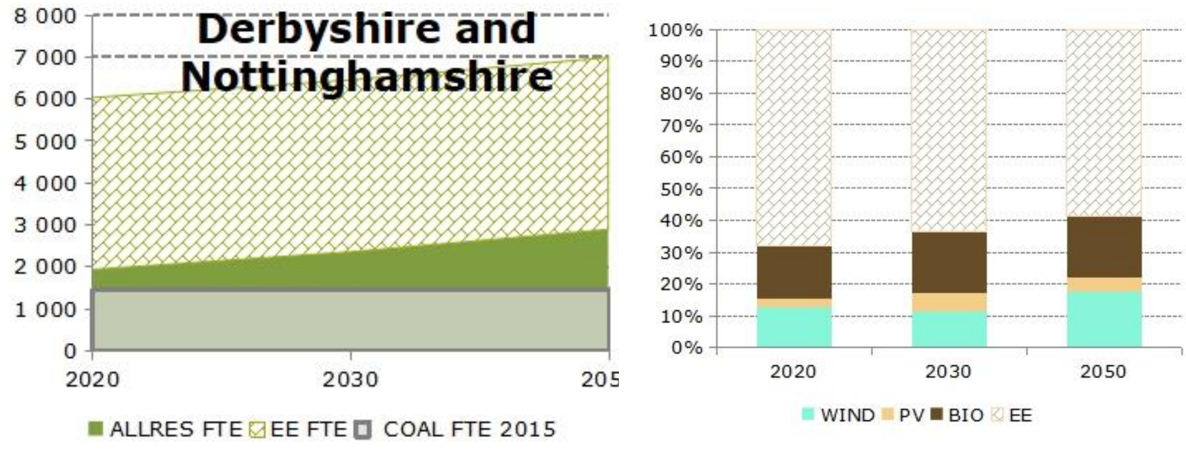


Figure 66. Current coal-related employment over transition foresight for UKF1 (left). Sectorial contribution to decarbonizing employment (right)

For Shropshire and Staffordshire the renewable related potential by 2020 alone translates to more than 10 times the regional coal related employment. Total decarbonizing potential by 2030 can count for more than 20 times the coal related FTEs.

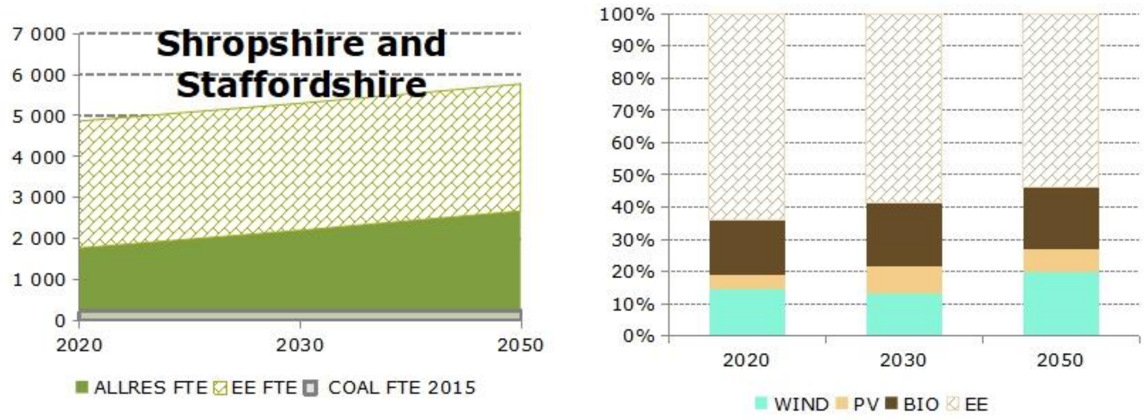
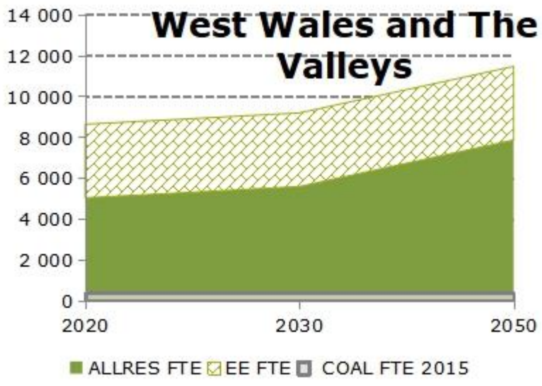


Figure 67. Current coal-related employment over transition foresight for UKG2 (left). Sectorial contribution to decarbonizing employment (right)

In West Wales and The Valleys, decarbonization of the employment driven by wind and energy efficiency potential growth only, can ensure the retaliation of coal related employment even by 2020.



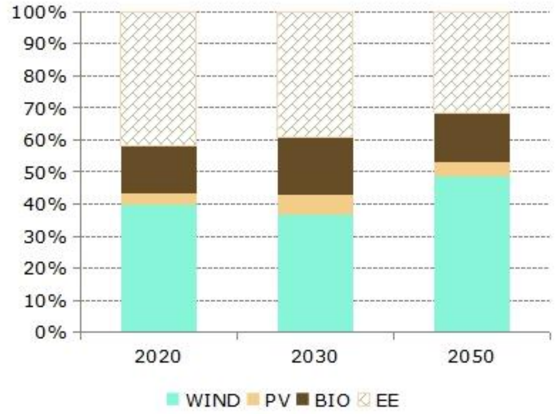
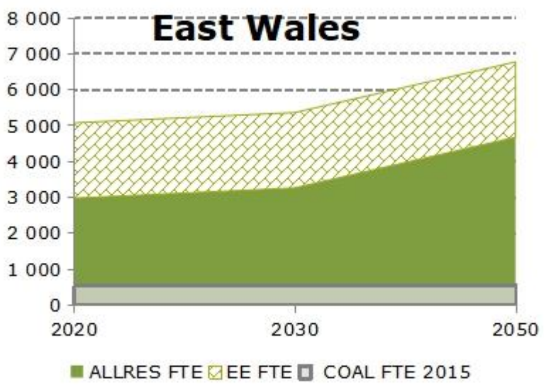


Figure 68. Current coal-related employment over transition foresight for UKL1 (left). Sectorial contribution to decarbonizing employment (right)

East Wales' is a HDEP region as wind alone could provide almost 4 times the coal related employment by 2020.



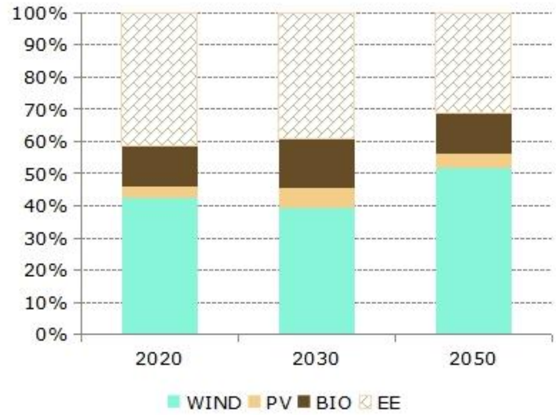


Figure 69. Current coal-related employment over transition foresight for UKL2 (left). Sectorial contribution to decarbonizing employment (right)

Driven by a significant wind related activity, Eastern Scotland does not face a major decarbonizing challengue. Also strong energy efficiency and biomass employment potentials can lead to a 27:1 employment ratio with coal sector by 2030 if the climate targets of EUCO3232.5 would be realized by then.

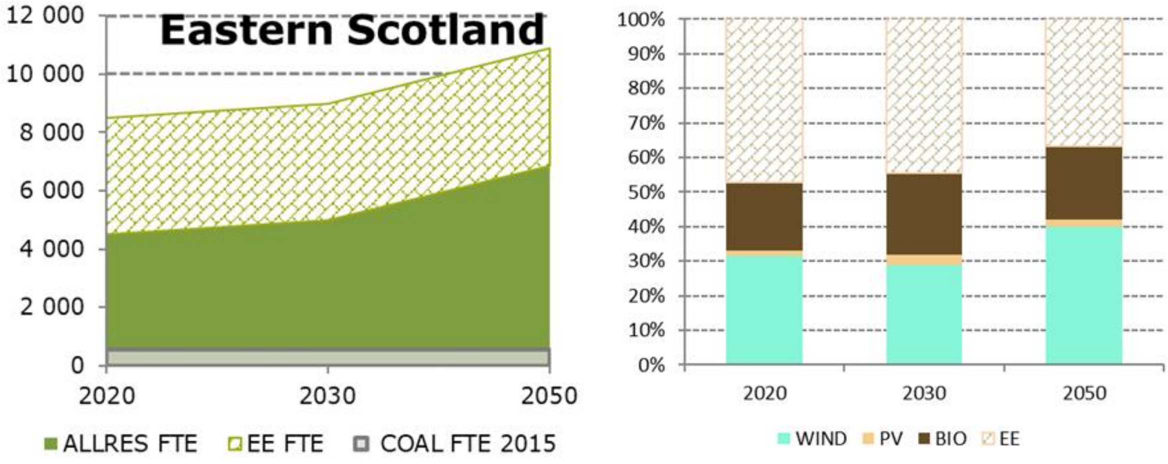


Figure 70. Current coal-related employment over transition foresight for EUKM7 (left). Sectorial contribution to decarbonizing employment (right)

West Central Scotland can be categorized as a HDEP counting with a remarkable building refurnishing potential complemented by the wind and biomass sectors. Already in 2020 the ratio of potential employment to coal related could reach 50:1.

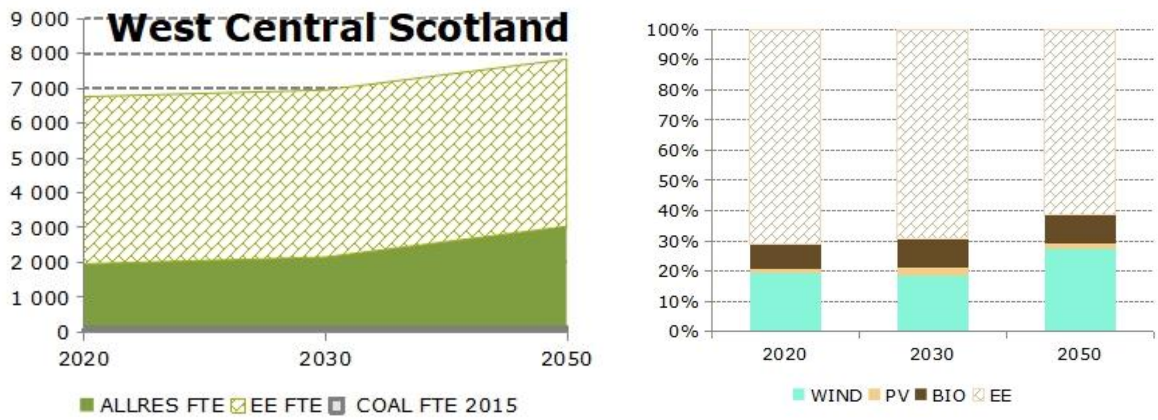


Figure 71. Current coal-related employment over transition foresight for UKM8 (left). Sectorial contribution to decarbonizing employment (right)

Southern Scotland is grouped as a HDEP region as wind related activity alone can provide almost 5 000 jobs compared to the 121 coal related by 2020. Futher potential lies in the biomass and energy efficiency sectors.

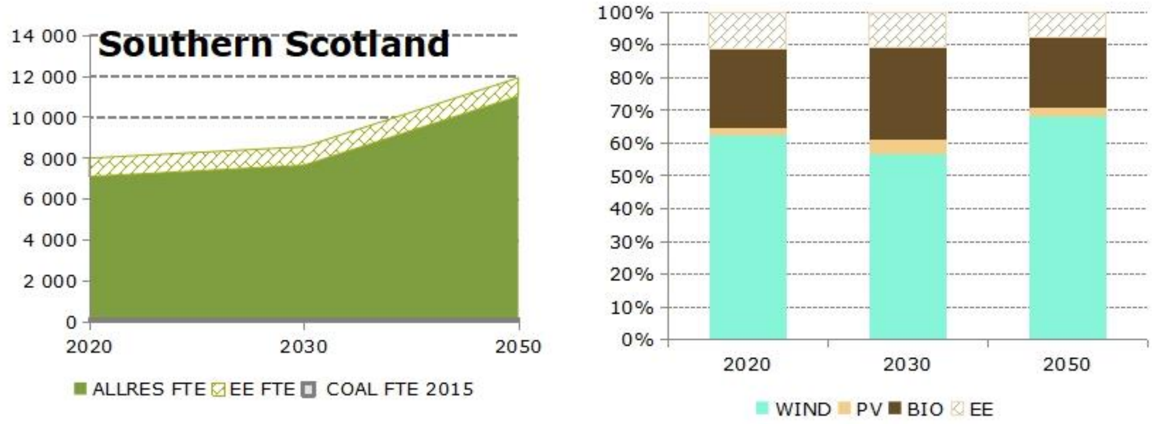


Figure 72. Current coal-related employment over transition foresight for EUKM9 (left). Sectorial contribution to decarbonizing employment (right)

6 Summary of key findings

- According to our estimations, there is a range of potential for clean energy technologies deployment, energy efficiency and jobs creation in the coal regions.
- We find that the technical potential of clean energy technologies shows significant variability across the investigated coal regions. However, in total, we estimate a technical potential of 1 516 GW in the coal regions alone. This would be enough to satisfy more than half of the technology deployment projection required to achieve an ambitious target of carbon neutrality by 2050.
- Toward 2030, we find that the EUCO3232.5 scenario projected capacity deployment, our estimations starting point, will translate to regional investments ranging from EUR 5 million for Západné Slovensko (SK02) to EUR 3.17 billion for Castilla y León (ES41), totalling EUR 38 billion for all coal regions. By 2050, these range from almost EUR 50 million for Yugozapaden (BG41) to EUR 3.52 billion for Wielkopolskie (PL41), reaching EUR 43 billion in total for all coal regions.
- In absolute numbers, we find that by 2030, up to almost 315 000 jobs can be created in total by deploying clean energy production technologies as projected in EUCO3232.5, reaching more than 460 000 by 2050.

Regarding the potential resilience of coal regions toward their transition from coal mining activities in terms of jobs, we cluster the regions finding:

- Regions that have a High Decarbonizing Employment Potential (HDEP). Jobs plausibly derived by 2030 from the regional impact of EUCO3232.5 scenario could account for at least 90% of current coal related jobs, reaching 100% by 2050. These regions include Aragon (ES24), Brandenburg (DE40), Castilla-La Mancha (ES42), Castilla y Leon (ES41), Derbyshire and Nottinghamshire (UKF1), Dolnoslaskie (PL51), Dresden (DED2), Dusseldorf (DEA1), East Wales (UKL2), Eastern Scotland (UKM7), Koln (DEA2), Leipzig (DED5), North Yorkshire (UKE2), Northumberland and Tyne and Wear (UKC2), Peloponnisos (EL65), Principado de Asturias (ES12), Sardegna (ITG2), Saxony-Anhalt (DEE0), Shropshire and Staffordshire (UKG2), South Yorkshire (UKE3), Southern Scotland (UKM9), Vzhodna Slovenija (Sl03), West Central Scotland (UKM8), West Yorkshire (UKE4), West Wales and The Valleys (UKL1), Wielkopolskie (PL41), Yugozapaden (BG41) and Západné Slovensko (SK02).
- Regions that have significant decarbonisation potential, but by 2030 job retaliation is below 90% and only fully realized by 2050. These regions show Slow Decarbonizing Employment Potential (SDEP) and include Észak-Magyarország (HU31), Lodzkie (PL71), Lubelskie (PL81), Małopolskie (PL21), Munster (DEA3), Saarland (DEC0) and Vest (RO42).
- Regions that show Restricted Decarbonizing Employment Potential (RDEP). That implies that the foreseen EUCO3232.5 derived regional employment potential may not suffice to even out coal related jobs for these regions. These regions include Dytiki Makedonia (EL53), Moravskoslezsko (CZ08), Severozápad (CZ04), Silesia (PL22), Sud-Vest Oltenia (RO41), and Yugoiztochen (BG34).

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List of abbreviations

BAT	Best Available Techniques
BOS	Balance Of System
CAPEX	Capital Expenditure
CCR	Carbon Capture Ready
CCUS	Carbon Capture, Utilisation and Storage
CHP	Combined Heat and Power
CRiT	Coal Regions in Transition
EBA	European Battery Alliance
EC	European Commission
EGS	Enhanced Geothermal Systems
EPBD	Energy Performance of Buildings Directive
ETES	Electric Thermal Storage
ETIP	Energy Technology and Innovation Platform
EU	European Union
FTE	Full Time Equivalents
FOM	Fixed Operation and Maintenance
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GW	Gigawatt
GWh	Gigawatt hours
HDD	Heating Degree Days
HHH	High Hub Height
HQ	Head Quarters
IEA	International Energy Agency
IED	Industrial Emissions Directive
IRENA	International Renewable Energy Agency
IT	Information Technology
JRC	Joint Research Centre
LCoE	Levelised cost of Electricity
LSP	Low Specific Power
MFH	Multi-Family Houses
MWh	Megawatt hours
NREL	National Renewable Energy Laboratory
NUTS	Nomenclature of territorial units for statistics (from the French version Nomenclature des Unités territoriales statistiques)
NZEB	Nearly Zero-Energy Buildings
OEM	Original Equipment Manufacturer

OP	Open pit or opencast mine
OPEX	Operational Expenditure
PC	Pulverised Coal
PCI	Projects of Common Interest
PV	Photovoltaic
RES	Renewable Energy Systems
SET	Strategic Energy Technology
SFH	Single Family Houses
UG	Underground mine
VAT	Value Added Tax
ZEP	European Platform for Zero Emissions Plants

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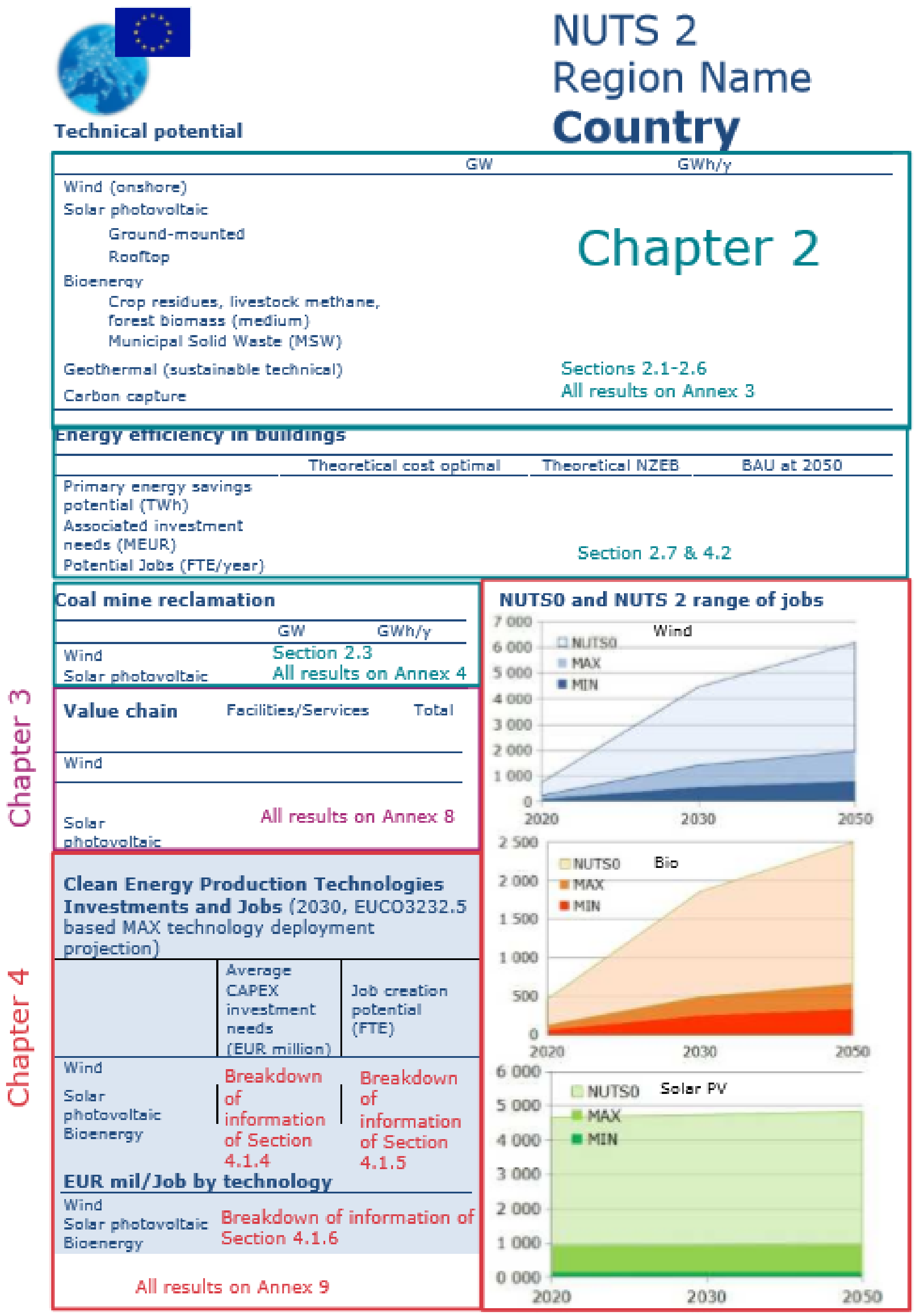
1. European Coal Regions in Transition (CRiT) by 2016 NUTS 2 classification

	NUTS 2 Code	Region	Country
1	BG34	Yugoiztochen	Bulgaria
2	BG41	Yugozapaden	Bulgaria
3	CZ08	Moravskoslezsko	Czech Republic
4	CZ04	Severozápad	Czech Republic
5	DEA3	Münster	Germany
6	DEA2	Köln	Germany
7	DEA1	Düsseldorf	Germany
8	DEC0	Saarland	Germany
9	DE40	Brandenburg	Germany
10	DED2	Dresden	Germany
11	DEE0	Sachsen-Anhalt	Germany
12	DED5	Leipzig	Germany
13	EL53	Dytiki Makedonia	Greece
14	EL65	Peloponnisos	Greece
15	HU31	Észak- Magyarország	Hungary
16	ITG2	Sardegna	Italy
17	PL22	Śląskie	Poland
18	PL21	Małopolskie	Poland
19	PL81	Lubelskie	Poland
20	PL71	Łódzkie	Poland
21	PL51	Dolnośląskie	Poland
22	PL41	Wielkopolskie	Poland
23	RO41	Sud-Vest Oltenia	Romania
24	RO42	Vest	Romania
25	SK02	Západné Slovensko	Slovakia
26	Sl03	Vzhodna Slovenija	Slovenia
27	ES24	Aragón	Spain
28	ES12	Principado de Asturias	Spain
29	ES41	Castilla y León	Spain
30	ES42	Castilla-La Mancha	Spain
31	ES21	País Vasco	Spain
32	UKC2	Northumberland and Tyne and Wear	United Kingdom
33	UKE3	South Yorkshire	United Kingdom
34	UKE4	West Yorkshire	United Kingdom
35	UKE2	North Yorkshire	United Kingdom
36	UKF1	Derbyshire and Nottinghamshire	United Kingdom
37	UKM8	West Central Scotland	United Kingdom
38	UKM7	Eastern Scotland	United Kingdom
39	UKM9	Southern Scotland	United Kingdom
40	UKG2	Shropshire and Staffordshire	United Kingdom
41	UKL2	East Wales	United Kingdom
42	UKL1	West Wales and The Valleys	United Kingdom

2. Regional fact sheets

Factsheet guide: data and corresponding chapters and annexes.



BG34 Yugoiztochen **Bulgaria**

Technical potential

	GW (power)	GWh/y
Wind (onshore)	7.11	14 012
Solar photovoltaic (PV)		
Ground-mounted	18.22	23 991
Rooftop	2.16	2 842
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.45	11 852 (primary)
Municipal Solid Waste (MSW)	0.04	2 728 (primary)
Geothermal (sustainable technical)	0.09	732
Carbon capture	3.96	29 456

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	3.35	4.67	1.80
Associated investment needs (MEUR)	5 819	10 472	3 666
Potential Jobs (FTE/year)			4 700

Coal mine reclamation

	GW	GWh/y
Wind	0.12	136.4
Solar PV	0.21	268.3

Value chain	Facilities/Services	Total
Wind	No factories in region; 1 (bearings) in close-by regions (RO31)	0
Solar PV	1 (components); 3 sellers; 5 installers	9

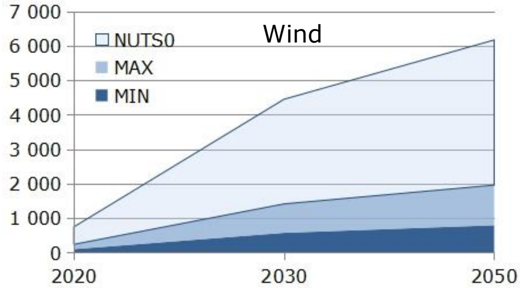
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

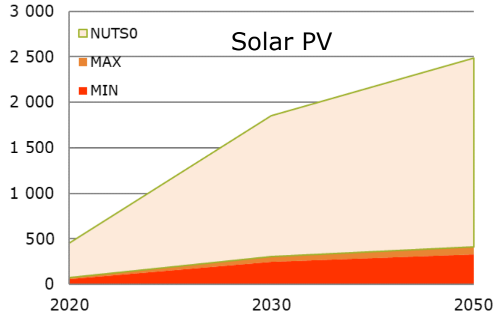
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	468.06	1 409
Solar PV	21.4	309
Bioenergy	39	932

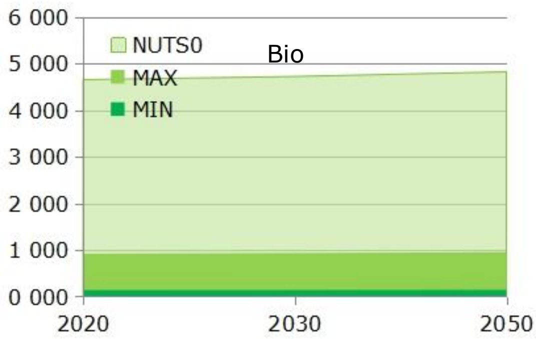
EUR mil/Job ratio

Wind, 0.57
Solar PV, 0.07
Bioenergy, 0.04

NUTS0 and NUTS 2 range of jobs







BG41 Yugozapaden **Bulgaria**

Technical potential

	GW (power)	GWh/y
Wind (onshore)	3.15	6 217
Solar photovoltaic (PV)		
Ground-mounted	5.96	759
Rooftop	2.51	3 195
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.27	7 194 (primary)
Municipal solid waste (MSW)	0.09	5 781 (primary)
Geothermal (sustainable technical)	0.10	773
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	8.35	11.45	4.45
Associated investment needs (MEUR)	11 461	20 161	7 115
Potential Jobs (FTE/year)			9 100

Coal mine reclamation

	GW	GWh/y
Wind	0.05	46.5
Solar PV	0.09	114.2

Value chain

	Facilities/Services	Total
Wind	No factories in region; 1 (bearings) in close-by regions (RO31)	0
Solar PV	2 (components); 3 (panels); 8 (sellers); 22 installers; 3 (services)	38

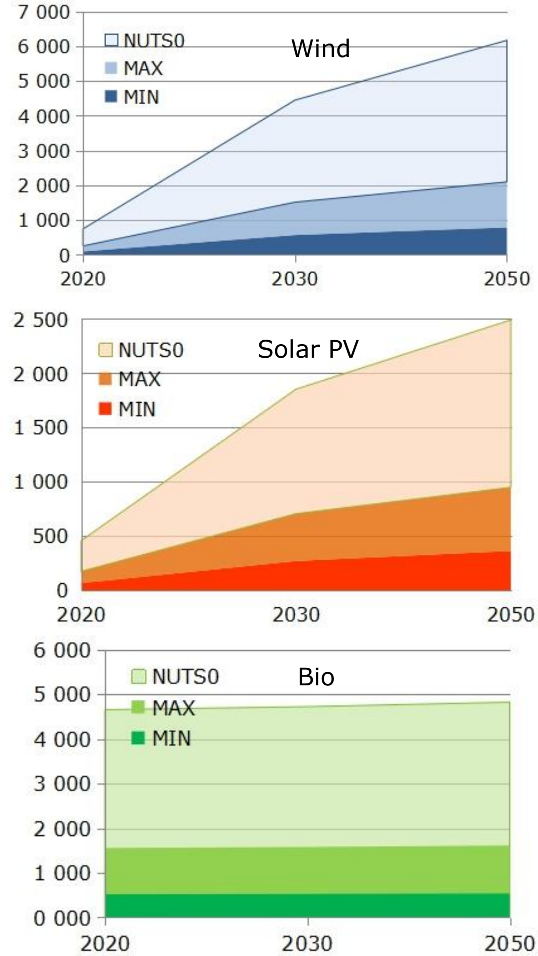
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

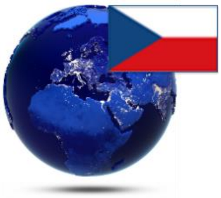
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	501.83	1 511
Solar PV	43.58	210
Bioenergy	66	1578

EUR mil/Job ratio

Wind, 0.57
Solar PV, 0.09
Bio, 0.04

NUTS0 and NUTS 2 range of jobs





CZ04
Severozápad
Czech Republic

Technical potential

	GW (power)	GWh/y
Wind (onshore)	4.45	8 764
Solar photovoltaic (PV)		
Ground-mounted	6.00	23 991
Rooftop	2.51	2 842
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.19	4 598 (primary)
Municipal solid waste (MSW)	0.03	2 037 (primary)
Geothermal (sustainable technical)	0.04	358
Carbon capture	1.01	7 535

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	8.31	12.05	4.58
Associated investment needs (MEUR)	5 321	8 579	3 128
Potential Jobs (FTE/year)			2 000

Coal mine reclamation

	GW	GWh/y
Wind	0.18	215.5
Solar PV	0.33	327.6

Value chain

	Facilities	Total
Wind	No factories in region; 3 (gearbox, nacelle assembly, blades) in close-by regions (CZ03, CZ05, DE40)	0
Solar PV	1 (seller); 15 (installer); 1 (services)	17

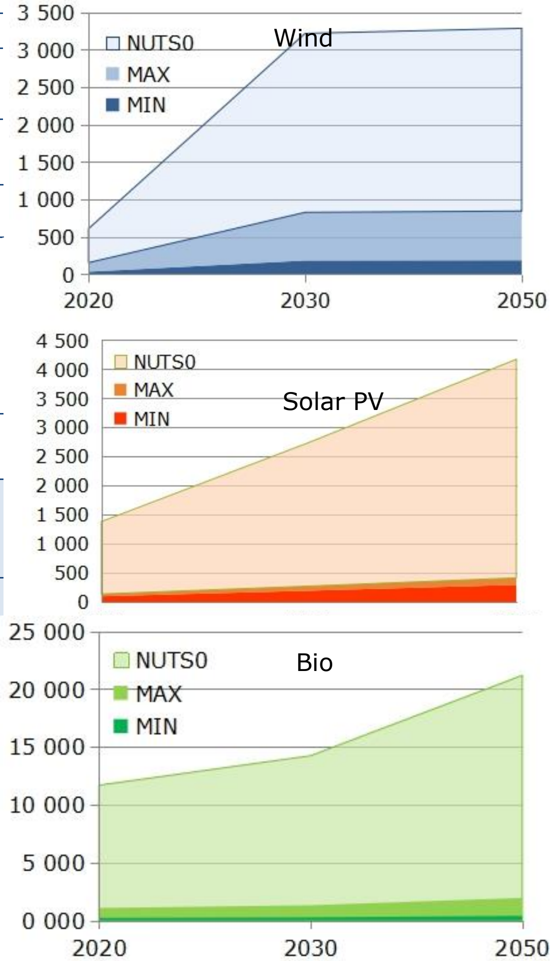
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	795.40	828
Solar PV	62.95	194
Bioenergy	88.40	1305

EUR mil/Job ratio

Wind, 1.29
Solar PV, 0.26
Bio, 0.07

NUTS0 NUTS 2 range of jobs



CZ08 Moravskoslezsko **Czech Republic**

Technical potential

	GW (power)	GWh/y
Wind (onshore)	4.06	8 813
Solar photovoltaic (PV)		
Ground-mounted	3.95	4 014
Rooftop	1.33	1 351
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.15	3 900 (primary)
Municipal solid waste (MSW)	0.03	2 134 (primary)
Geothermal (sustainable technical)	0.03	222
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	10.26	14.62	5.60
Associated investment needs (MEUR)	6 726	10 779	3 939
Potential Jobs (FTE/year)			2 500

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 2 (gearbox, nacelle assembly) in close-by regions (CZ03, CZ05)	0
Solar PV	1 (components); 20 (installers)	21

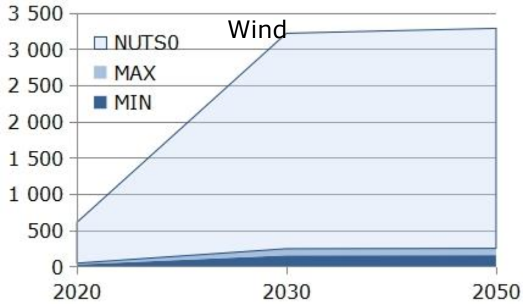
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

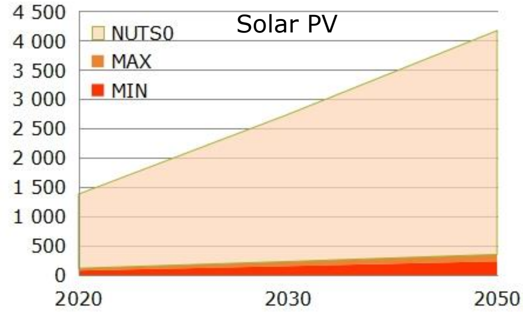
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	235.83	154
Solar PV	12.95	155
Bioenergy	77	322

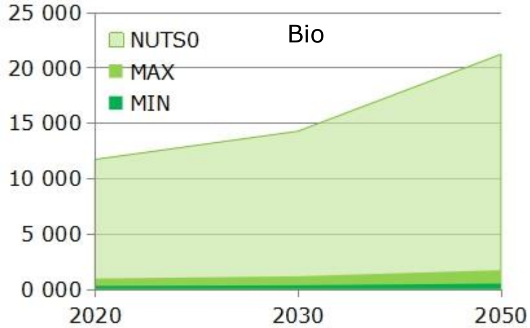
EUR mil/Job ratio

Wind, 1.43
Solar PV, 0.08
Bio, 0.07

NUTS0 and NUTS 2 range of jobs







DE40
Brandenburg
Germany

Technical potential

	GW (power)	GWh/y
Wind (onshore)	11.43	23 666
Solar photovoltaic (PV)		
Ground-mounted	20.59	20 617
Rooftop	4. 61	4 612
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	1.02	27 028 (primary)
Municipal solid waste (MSW)	0.01	9 172 (primary)
Geothermal (sustainable technical)	0.13	1 028
Carbon capture	0.94	7 029

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	19.52	26.72	10.40
Associated investment needs (MEUR)	39 945	51 302	20 531
Potential Jobs (FTE/year)			7 600

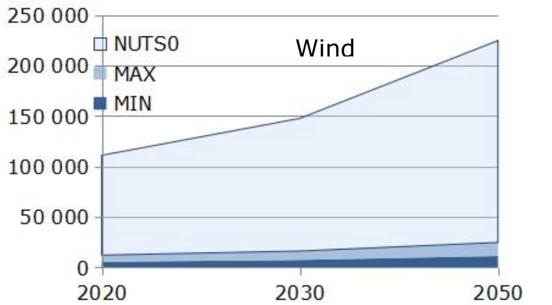
Coal mine reclamation

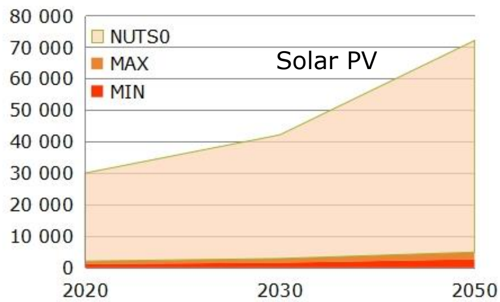
	GW	GWh/y
Wind	0.09	136.8
Solar PV	0.16	151.8

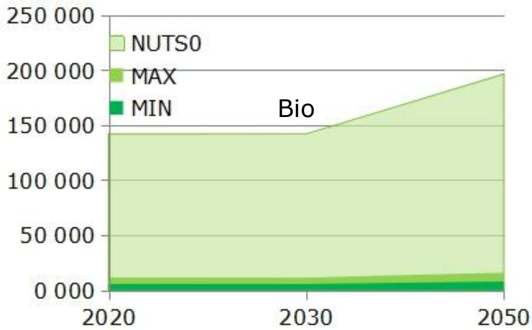
Value chain

	Facilities	Tota
Wind	2 in region (nacelle assembly, blades); 6 (nacelle assembly, blades, generators, foundations) in close-by regions (DE80, DEE0, PL42)	8
Solar PV	4 (materials); 6 (components); 6 (panels); 6 (sellers); 97 (installers); 1 (applications); 6 (services)	126

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	2 998.13	3 329
Solar PV	11.04	2 194
Bioenergy	724	5 744

EUR mil/Job ratio

Wind, 0.40
Solar PV, 0.03
Bio, 0.06

DEA1
Düsseldorf
Germany

Technical potential

	GW (power)	GWh/y
Wind (onshore)	0.95	2 005
Solar photovoltaic (PV)		
Ground-mounted	4. 98	4 904
Rooftop	4.81	4 735
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.10	2 625 (primary)
Municipal solid waste (MSW)	0.00	18 543 (primary)
Geothermal (sustainable technical)	0.02	154
Carbon capture	2.67	19 851

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	34.34	49.02	18.76
Associated investment needs (MEUR)	81 301	103 726	41 631
Potential Jobs			15 400

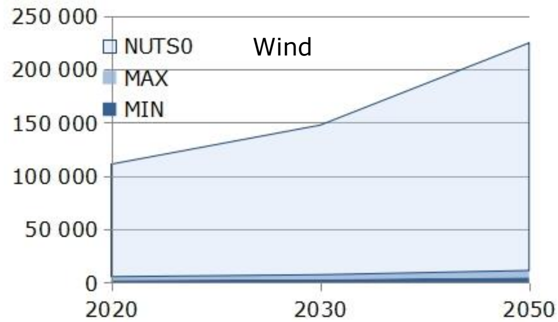
Coal mine reclamation

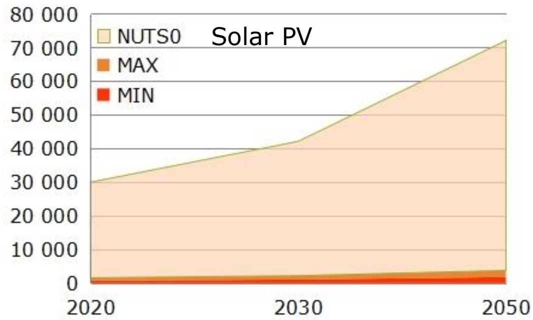
	GW	GWh/y
Wind	0.03	50.2
Solar PV	0.05	50.1

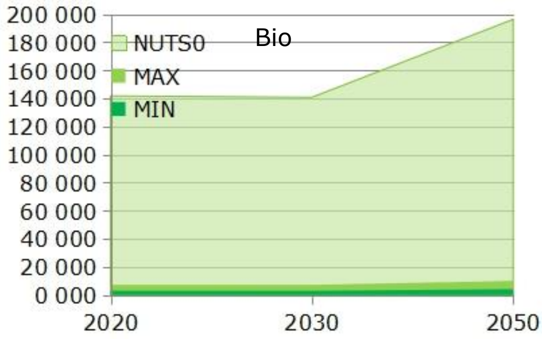
Value chain

	Facilities	Total
Wind	2 in region (generator, gearbox); 4 factories (nacelle assembly, gearbox) in close-by regions (DEA5, BE22, NL22)	
Solar PV	4 (prod. equip.); 5 (materials); 14 (components); 8 (panels); 24 (sellers); 131 (installers); 1 (applications); 8 (services)	195

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 381.25	3 243
Solar PV	144.37	1 956
Bioenergy	220.50	3 002

EUR mil/Job ratio

Wind, 0.62
Solar PV, 0.09
Bio, 0.03

DEA2 Köln
Germany

Technical potential

	GW (power)	GWh/y
Wind (onshore)	1.23	2 569
Solar photovoltaic (PV)		
Ground-mounted	6.69	66
Rooftop	4.34	4 279
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.18	4 742 (primary)
Municipal solid waste (MSW)	0.00	15 985 (primary)
Geothermal (sustainable technical)	0.02	180
Carbon capture	0.91	6 754

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	31.92	44.02	17.09
Associated investment needs (MEUR)	72 560	93 074	37 268
Potential Jobs (FTE/year)			13 800

Coal mine reclamation

	GW	GWh/y
Wind	0.06	89.6
Solar PV	0.11	108.8

Value chain

	Facilities	Total
Wind	No factories in region; 5 (nacelle assembly, gearbox, generator) in close-by regions (DEA1, DEA5, BE22)	0
Solar PV	5 (prod. equip.); 3 (materials); 8 (components); 3 (panels); 6 (sellers); 97 (installers); 1 (applications); 9 (services)	160

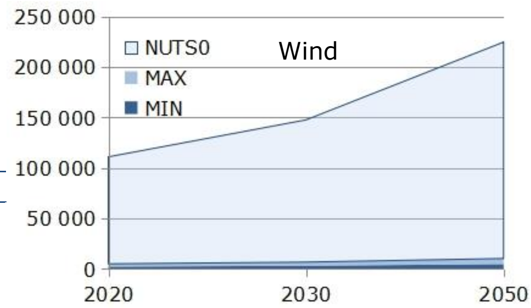
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

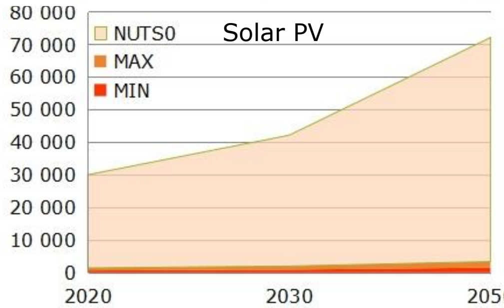
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 259.49	3 107
Solar PV	111.43	752
Bioenergy	454	3 781

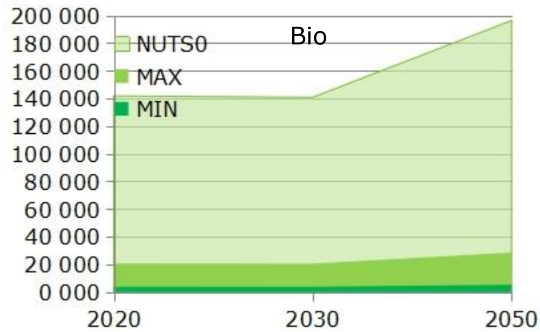
EUR mil/Job ratio

Wind, 0.48
Solar PV, 0.08
Bio, 0.02

NUTS0 and NUTS 2 range of jobs







DEA3 Münster
Germany

Technical potential

	GW (power)	GWh/y
Wind (onshore)	6.92	14 027
Solar photovoltaic (PV)		
Ground-mounted	9.46	9 181
Rooftop	3.00	2 909
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.29	7 572 (primary)
Municipal solid waste (MSW)	0.00	9 483 (primary)
Geothermal (sustainable technical)	0.03	245
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	19.20	26.06	10.18
Associated investment needs (MEUR)	43 632	56 108	22 442
Potential Jobs (FTE/year)			8 300

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 9 (generator, gearbox, blades, tower, foundry, nacelle assembly) in close-by regions (DEA1, DEA5, DE94, NL22)	0
Solar PV	5 (prod. equip.); 1 (materials); 4 (components); 4 (sellers); 91 (installers); 1 (applications; 4 (services)	110

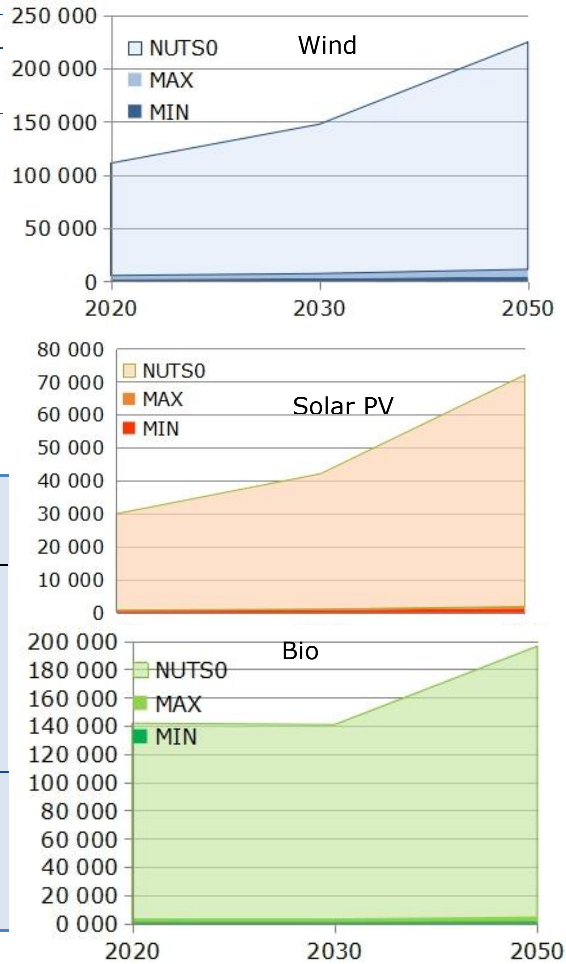
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 385.43	1 440
Solar PV	99.32	1 012
Bioenergy	1 287.00	919

EUR mil/Job ratio

Wind, 2.89
Solar PV, 0.12
Bio, 0.37

NUTS0 and NUTS 2 range of jobs



DEC0 Saarland
Germany

Technical potential

	GW	GWh/y
Wind (onshore)	0.10	200
Solar photovoltaic (PV)		
Ground-mounted	1.61	1 669
Rooftop	1.45	1 506
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.06	1 681 (primary)
Municipal solid waste (MSW)	0.00	3 564 (primary)
Geothermal (sustainable technical)	0.01	87
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	9.31	12.05	4.81
Associated investment needs (MEUR)	20 108	26 047	10 385
Potential Jobs (FTE/year)			3 900

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	1 in region (nacelle assembly); no factories in close-by regions	1
Solar PV	1 (prod. equip.); 1 (materials; 2 (components); 1 (sellers); 46 (installers); 1 (services)	52

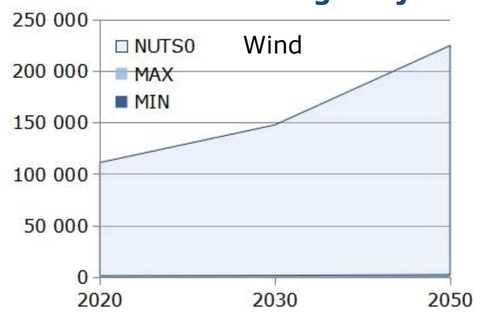
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

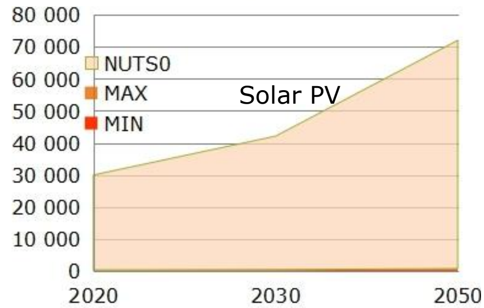
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	264.74	16 307
Solar PV	55.92	2 843
Bioenergy	72.70	386

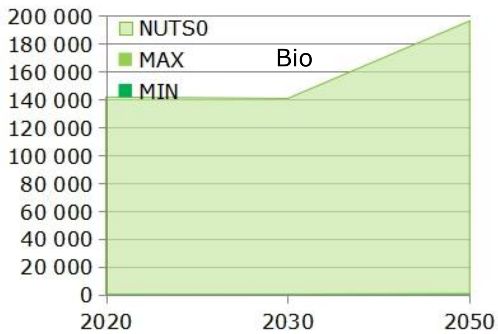
EUR mil/Job ratio

Wind, 0.04
Solar PV,016
Bio, 0.06

NUTS0 and NUTS 2 range of jobs







DED2 Dresden
Germany

Technical potential

	GW	GWh/y
Wind (onshore)	2.67	5 391
Solar photovoltaic (PV)		
Ground-mounted	6.92	6 969
Rooftop	2.37	2 381
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.24	6 306 (primary)
Municipal solid waste (MSW)	0.00	5 532 (primary)
Geothermal (sustainable technical)	0.03	263
Carbon capture	1.59	11 839

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	11.01	15.73	6.02
Associated investment needs (MEUR)	22 532	28 741	11 536
Potential Jobs (FTE/year)			4 200

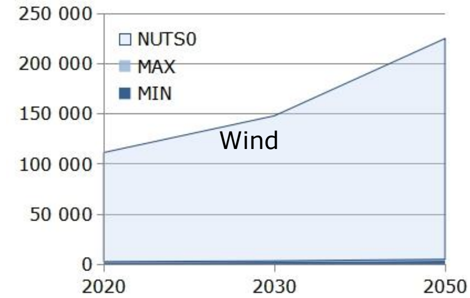
Coal mine reclamation

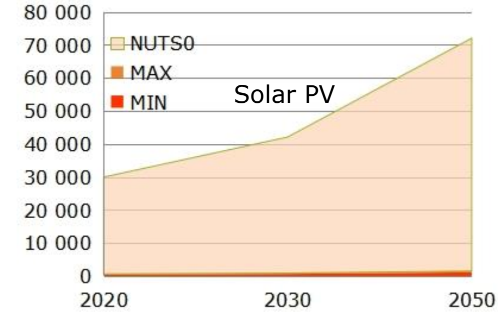
	GW	GWh/y
Wind	0.04	54.4
Solar PV	0.07	68.6

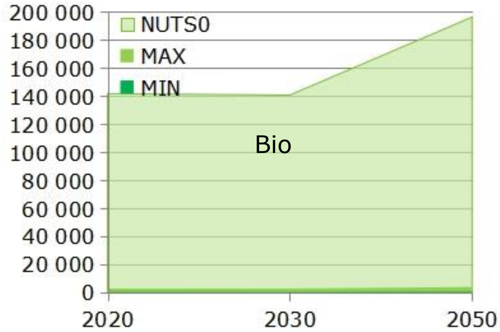
Value chain

	Facilities	Total
Wind	No factories in region; 3 factories (gearbox, blades, nacelle assembly) in close-by regions (CZ03, CZ05, DE40)	0
Solar PV	7 (prod. equip.); 2 (materials); 2 (components); 3 (panels); 2 (sellers); 67 (installers); 2 (applications); 5 (services)	90

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection**)**

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	567.07	2 128
Solar PV	45.16	889
Bioenergy	186	497

EUR mil/Job ratio

Wind, 0.43
Solar PV, 0.08
Bio, 0.06

DED5 Leipzig
Germany

Technical potential

	GW	GWh/y
Wind (onshore)	1.78	3 511
Solar photovoltaic (PV)		
Ground-mounted	4.43	4 572
Rooftop	1.40	1 441
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.12	3 123 (primary)
Municipal solid waste (MSW)	0.00	3 622 (primary)
Geothermal (sustainable technical)	0.01	104
Carbon capture	1.28	9 494

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	6.35	9.25	3.51
Associated investment needs (MEUR)	13 396	17 035	6 847
Potential Jobs (FTE/year)			2 600

Coal mine reclamation

	GW	GWh/y
Wind	0.01	18.0
Solar PV	0.02	22.5

Value chain

	Facilities	Total
Wind	No factories in region; 6 factories (generator, blades, nacelle assembly) in close-by regions (DE40, DEE0, DEG0, DE91)	0
Solar PV	3 (components); 2 (panels); 3 (sellers); 29 (installers); 1 (applications); 1 (services)	43

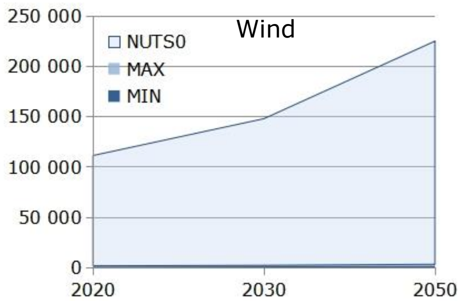
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

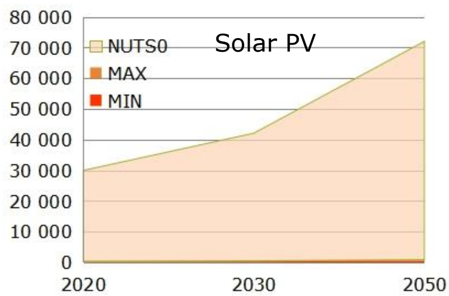
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	367.71	1 079
Solar PV	26.01	431
Bioenergy	97.40	338

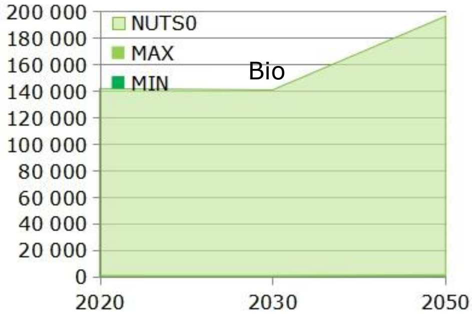
EUR mil/Job ratio

Wind, 0.59
Solar PV, 0.08
Bio, 0.06

NUTS0 and NUTS 2 range of jobs







DEE0 Sachsen-Anhalt **Germany**

Technical potential

	GW	GWh/y
Wind (onshore)	13.70	27 004
Solar photovoltaic (PV)		
Ground-mounting	24.25	24 451
Rooftop	4.08	4 111
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.63	16 602 (primary)
Municipal solid waste (MSW)	0.00	8 061 (primary)
Geothermal (sustainable technical)	0.09	736
Carbon capture	0.60	4 445

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	16.28	22.65	8.76
Associated investment needs (MEUR)	34 298	43 937	17 603
Potential Jobs (FTE/year)			6 500

Coal mine reclamation

	GW	GWh/y
Wind	0.03	46.2
Solar PV	0.06	54.2

Value chain

	Facilities	Total
Wind	2 in region (nacelle assembly, generator); 6 (blades, nacelle assembly) in close-by regions (DE40, DE93, DEG0, DE91)	2
Solar PV	1 (prod. equip.); 5 (materials); 4 (components); 3 (panels); 4 (sellers); 60 (installers); 4 (services)	81

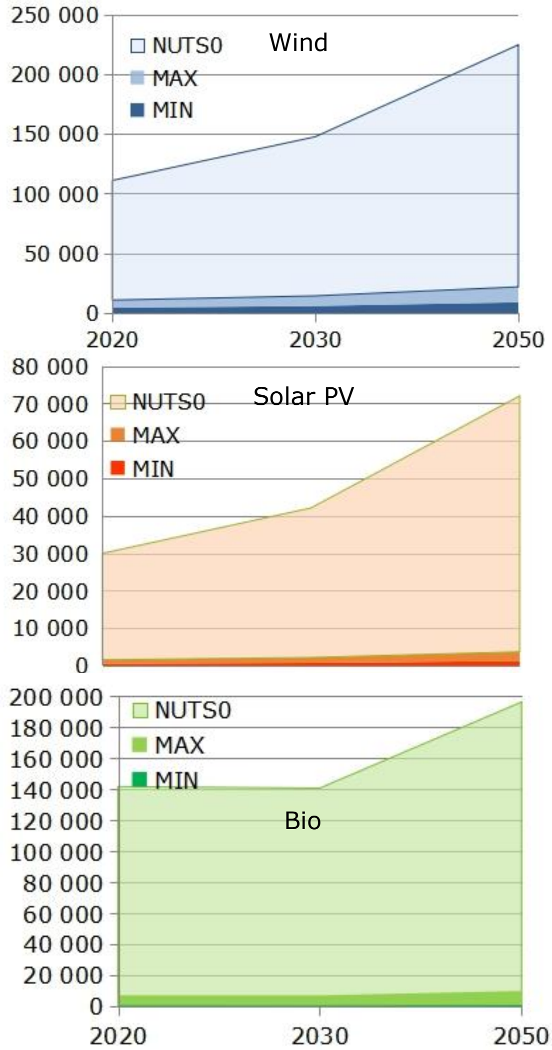
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	2 643.01	5 924
Solar PV	109.06	1 763
Bioenergy	450.90	652

EUR mil/Job ratio

Wind, 0.45
Solar PV, 0.08
Bio, 0.06

NUTS0 and NUTS 2 range of jobs



EL53 Dytiki Makedonia
Greece

Technical potential

	GW (power)	GWh/y
Wind (onshore)	5.58	12 262
Solar photovoltaic (PV)		
Ground-mounting	4.67	6 374
Rooftop	0.37	504
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.05	1 292 (primary)
Municipal solid waste (MSW)	0.02	899 (primary)
Geothermal (sustainable technical)	0.03	274
Carbon capture	0.80	5 979

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	1.37	1.37	0.62
Associated investment needs (MEUR)	2 475	2 475	1 114
Potential Jobs (FTE/year)			500

Coal mine reclamation

	GW	GWh/y
Wind	0.36	245.2
Solar PV	0.64	833.4

Value chain

	Facilities	Total
Wind	No factories in region; 1 (towers) in country (EL30)	0
Solar PV	4 (installers)	4

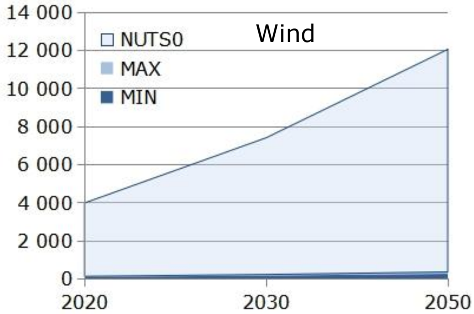
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

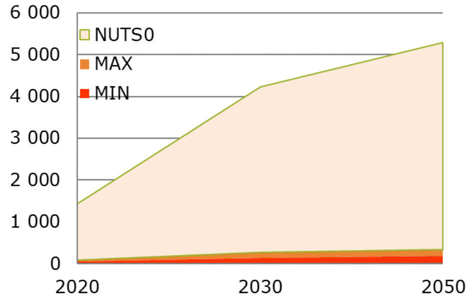
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	98.81	151
Solar PV	39.14	279
Bioenergy	33	28

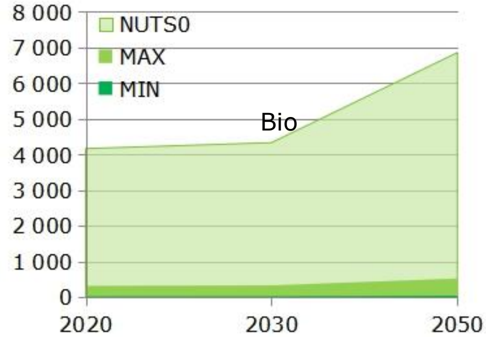
EUR mil/Job ratio

Wind, 1.11
Solar, 0.13
Bio, 0.10

NUTS0 and NUTS 2 range of jobs







EL65 Peloponnisos **Greece**

Technical potential

	GW (power)	GWh/y
Wind (onshore)	27.44	64 684
Solar photovoltaic (PV)		
Ground-mounting	1.01	1 533
Rooftop	0.65	994
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.05	1 190 (primary)
Municipal solid waste (MSW)	0.03	1 690 (primary)
Geothermal (sustainable technical)	0.08	651
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	1.76	1.76	0.79
Associated investment needs (MEUR)	5 006	5 023	2 257
Potential Jobs (FTE/year)			1 100

Coal mine reclamation

	GW	GWh/y
Wind	21.7	0.02
Solar PV	53.3	0.04

Value chain

	Facilities	Total
Wind	No factories in region; 1 factory (towers) in close-by region (EL30)	0
Solar PV	1 (components); 1 (sellers); 5 (installers)	7

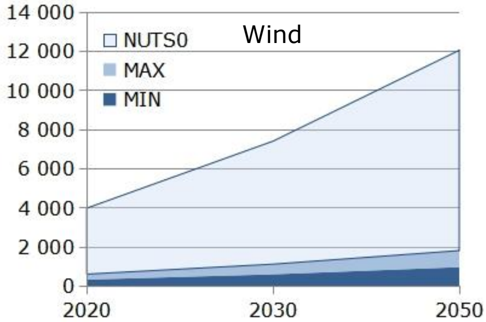
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

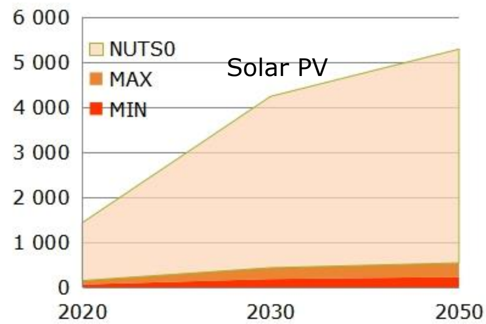
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	31.40	582
Solar PV	42.34	183
Bioenergy	522.62	47

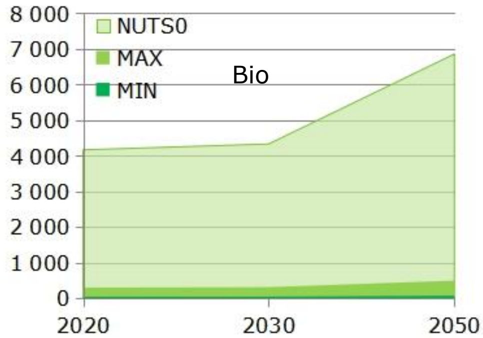
EUR mil/Job ratio

Wind, 0.92
Solar PV, 0.13
Bio, 0.10

NUTS0 and NUTS 2 range of jobs







ES12 Principado de Asturias **Spain**

Technical potential

	GW (power)	GWh/y
Wind	7.03	17 587
Solar photovoltaic (PV)		
Ground-mounting	2.46	2 808
Rooftop	0.86	979
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.10	2 513 (primary)
Municipal solid waste (MSW)	0.04	2 666 (primary)
Geothermal (sustainable technical)	0.05	425
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	4.46	5.13	2.16
Associated investment needs (MEUR)	11 999	11 924	5 383
Potential Jobs (FTE/year)			2 500

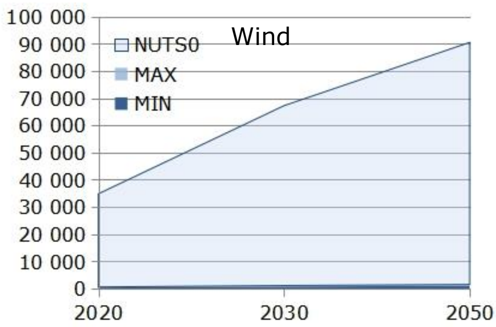
Coal mine reclamation

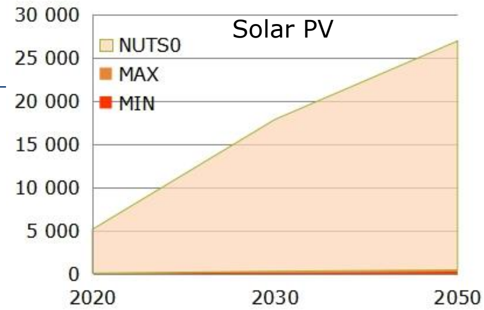
	GW	GWh/y
Wind	0.00	4.5
Solar PV	0.01	6.3

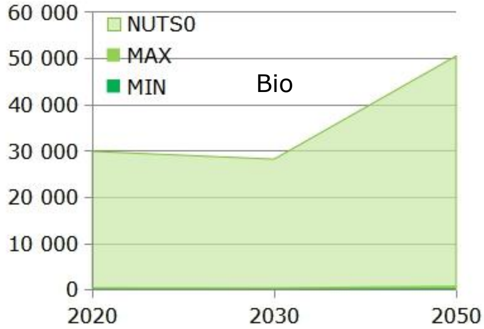
Value chain

	Facilities	Tota
Wind	1 in region (towers); 13 (nacelle assembly, gearboxes, generators, blades, towers) in close-by regions (ES41, ES11, ES13)	1
Solar PV	4 (components); 1 (panels); 2 (sellers); 17 (installers)	24

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	173.62	754
Solar PV	26.61	182
Bioenergy	46.70	134

EUR mil/Job ratio

Wind, 0.39
Solar PV, 0.11
Bio, 0.10

ES21 País Vasco
Spain

Technical potential

	GW	GWh/y
Wind (onshore)	3.15	7 068
Solar photovoltaic (PV)		
Ground-mounted	2.54	296
Rooftop	1.41	1 639
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.08	2 133 (primary)
Municipal solid waste (MSW)	0.04	5 342 (primary)
Geothermal (sustainable technical)	0.04	312
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	8.54	9.73	4.11
Associated investment needs (MEUR)	21 926	20 949	9 647
Potential Jobs (FTE/year)			4 500

Coal mine reclamation

	GW	GWh/y
Wind	Very small	0.7
Solar PV	Very small	1.9

Value chain

	Facilities	Total
Wind	4 in region (gearboxes, blades); 14 (gearboxes, generators, blades, towers) in close-by regions (ES41, ES22, ES13, ES12, ES24)	4
Solar PV	2 (prod. equip.); 8 (components); 3 (panels); 2 (sellers); 29 (installers); 2 (applications); 1 (services)	47

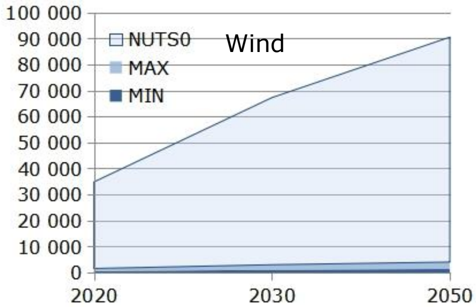
Clean Energy Production Technologies Investments and Jobs (2030, MAX technology deployment projection)

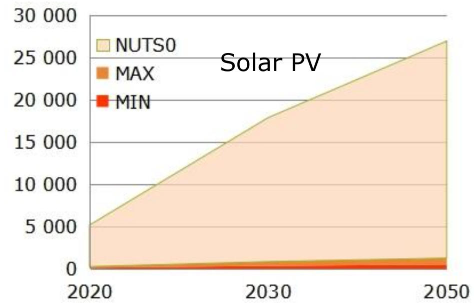
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	469.74	2 989
Solar PV	71.41	827
Bioenergy	139.20	700

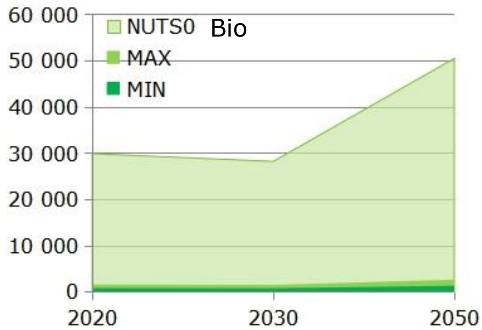
EUR mil/Job ratio

Wind, 0.36
Solar PV, 0.11
Bio, 0.07

NUTS0 and NUTS 2 range of jobs







ES24 Aragón
Spain

Technical potential

	GW (power)	GWh/y
Wind (onshore)	121.19	280 958
Solar photovoltaic (PV)		
Ground-mounted	25.31	39 439
Rooftop	1.31	2 041
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.59	15 319 (primary)
Municipal solid waste (MSW)	0.05	3 500 (primary)
Geothermal (sustainable technical)	0.26	2 114
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	6.65	7.69	3.23
Associated investment needs (MEUR)	16 176	16 373	7 324
Potential Jobs (FTE/year)			2 500

Coal mine reclamation

	GW	GWh/y
Wind	0.01	21.5
Solar PV	0.03	37.1

Value chain

	Facilities	Total
Wind	No factory in region; 23 (nacelle assembly, gearboxes, generators, blades, towers) in close-by regions (ES41, ES22, ES21, ES51, ES52)	0
Solar PV	3 (materials); 6 (components); 3 (panels); 6 (sellers); 29 (installers); 1 (applications); 4 (services)	52

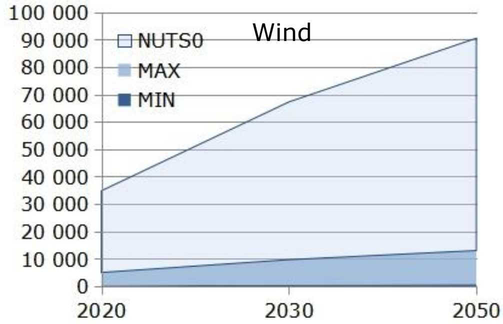
Clean Energy Production Technologies Investments and Jobs (2030, MAX technology deployment projection)

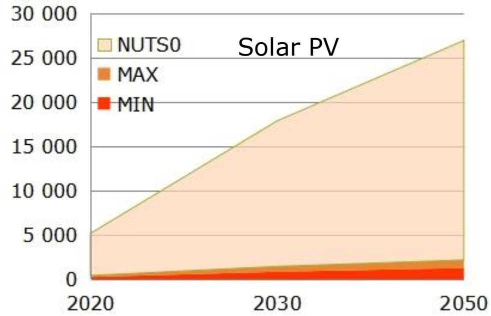
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 521.45	9 673
Solar PV	124.13	1 438
Bioenergy	228.60	1 040

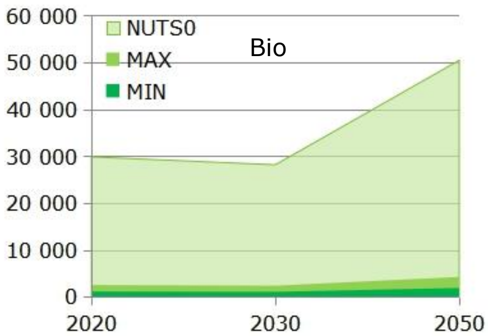
EUR mil/Job ratio

Wind, 0.56
Solar PV, 0.11
Bio, 0.10

NUTS0 and NUTS 2 range of jobs







ES41 Castilla y León
Spain

Technical potential

	GW (power)	GWh/y
Wind (onshore)	228.19	502 125
Solar photovoltaic (PV)		
Ground-mounted	79.89	120 727
Rooftop	3.52	5 312
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	1.31	34 444 (primary)
Municipal solid waste (MSW)	0.09	6 394 (primary)
Geothermal (sustainable technical)	0.50	4 032
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	15.88	18.48	7.73
Associated investment needs (MEUR)	34 143	35 375	15 641
Potential Jobs			7 300

Coal mine reclamation

	GW	GWh/y
Wind	0.02	24.0
Solar PV	0.04	66.5

Value chain

	Facilities	Total
Wind	6 in region (nacelle, gearbox, blades); 27 (nacelle assembly, gearboxes, generators, blades, towers, power converters) in close-by regions	6
Solar PV	1 (materials); 3 (components); 1 (panels); 51 (installers); 1 (services)	57

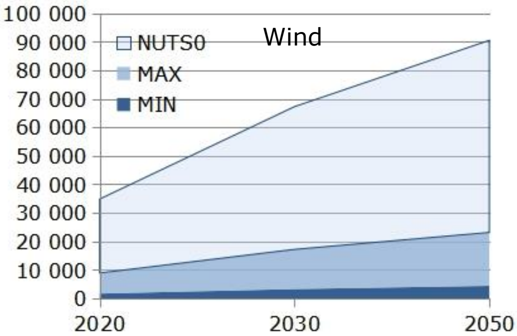
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

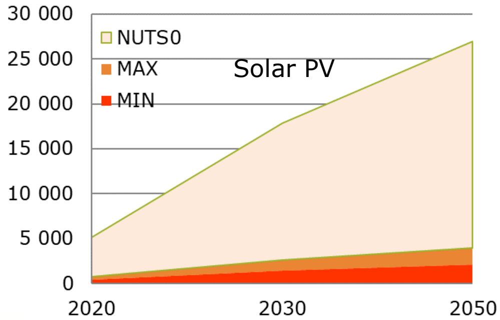
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	2 702.62	17 182
Solar PV	359.93	2 657
Bioenergy	525.60	1 540

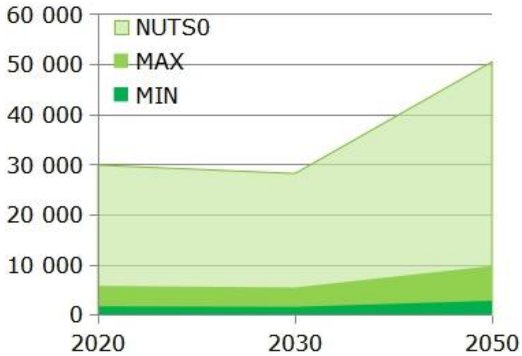
EUR mil/Job ratio

Wind, 0.54
Solar PV, 0.11
Bio, 0.10

NUTS0 and NUTS 2 range of jobs







ES42 Castilla-La Mancha
Spain

Technical potential

	GW (power)	GWh/y
Wind (onshore)	154.92	323 550
Solar photovoltaic (PV)		
Ground-mounted	64.70	105 178
Rooftop	2.86	4 645
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.72	18 947 (primary)
Municipal solid waste (MSW)	0.07	5 613 (primary)
Geothermal (sustainable technical)	0.40	3 176
Carbon capture	0.10	745

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	10.80	12.63	5.27
Associated investment needs (MEUR)	31 356	32 963	14 472
Potential Jobs (FTE/year)			6 600

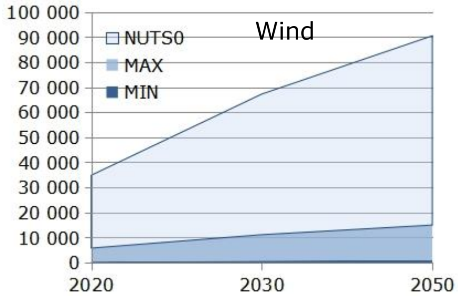
Coal mine reclamation

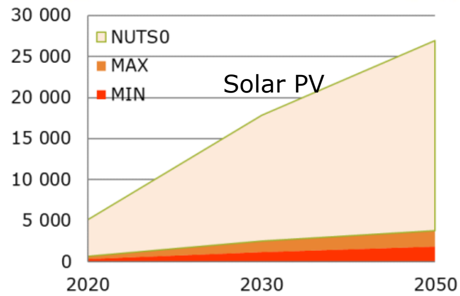
	GW	GWh/y
Wind	0.01	11.8
Solar PV	0.02	37.0

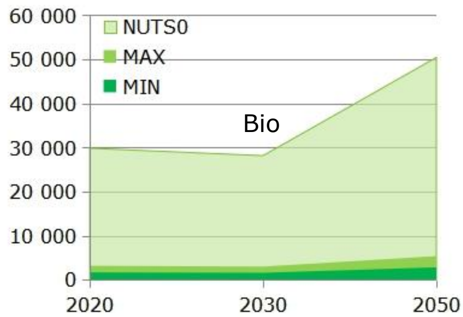
Value chain

	Facilities	Total
Wind	3 in region (nacelle assembly, blades); 13 (nacelle assembly, gearboxes, generators, blades, towers, power converters) in close-by regions (ES24, ES30, ES41, ES52, ES61)	3
Solar PV	7 (components); 1 (panels); 5 (sellers); 54 (installers); 1 (applications); 2 (services)	70

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 747.19	11 108
Solar PV	310.26	2 545
Bioenergy	290.00	1 566

EUR mil/Job ratio

Wind, 0.42
Solar PV, 0.10
Bio, 0.10

HU31 Észak-Magyarország
Hungary

Technical potential

	GW (power)	GWh/y
Wind (onshore)	0[52]	0
Solar photovoltaic (PV)		
Ground-mounting	10.13	11 837
Rooftop	1.83	2 141
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.27	7 291 (primary)
Municipal solid waste (MSW)	0.04	2 673 (primary)
Geothermal (sustainable technical)	0.10	807
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	5.61	7.13	2.87
Associated investment needs (MEUR)	25 253	30 498	12 544
Potential Jobs (FTE/year)			8 800

Coal mine reclamation

	GW	GWh/y
Wind	0.03	23.7
Solar PV	0.05	29.3

Value chain

	Facilities	Total
Wind	No factories in region; 3 factories (generators) in close-by regions (HU32, RO11, SK03)	0
Solar PV	1 (materials); 2 (components); 1 (panels); 4 (sellers); 11 (installers)	19

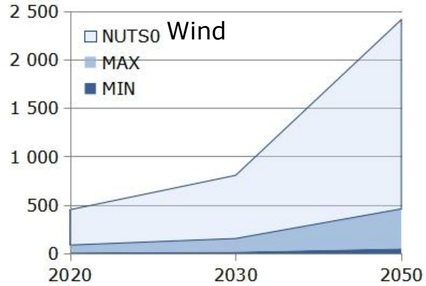
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

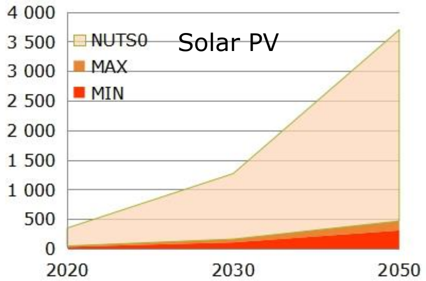
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	20.61	153
Solar PV	9.66	153
Bioenergy	39	411

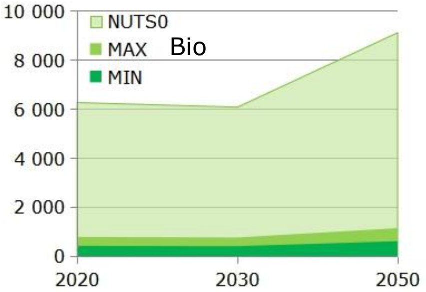
EUR mil/Job ratio

Wind, 1.57
Solar PV, 0.08
Bio, 0.05

NUTS0 and NUTS 2 range of jobs







[52] Assumed zero. Insignificant potential due to low capacity factors in the region.

ITG2 Sardegna
Italy

Technical potential

	GW (power)	GWh/y
Wind (onshore)	41.94	93 388
Solar photovoltaic (PV)		
Free standing	13.14	19 852
Rooftop	3.10	4 679
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.09	2 395 (primary)
Municipal Solid Waste (MSW)	0.03	4 638 (primary)
Geothermal (sustainable technical)	0.13	1 061
Carbon capture	0.34	2 532

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	8.63	10.05	4.20
Associated investment needs (MEUR)	5 471	9 500	3 368
Potential Jobs (FTE/year)			1 500

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 2 factories (blades, gearbox) in other parts of country (ITF4, ITH5)	0
Solar PV	3 (components); 2 (sellers); 57 (installers); 1 (services)	63

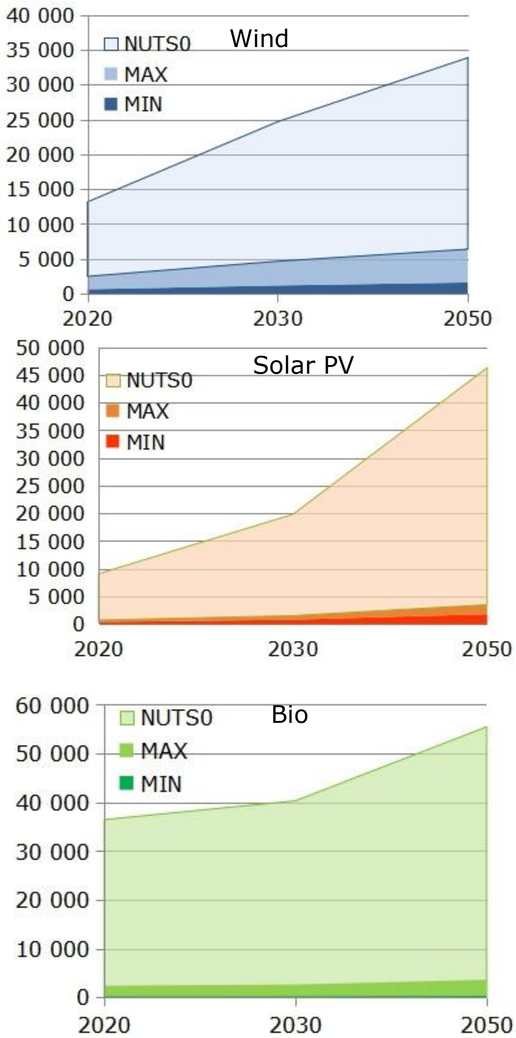
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection**)**

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 983.61	4 641
Solar PV	118.99	1 483
Bioenergy	243.20	199

EUR mil/Job ratio

Wind, 0.74
Solar PV, 0.10
Bio, 0.09

NUTS0 and NUTS 2 range of jobs



PL21 Małopolskie
Poland

Technical potential

	GW (power)	GWh/y
Wind (onshore)	1.23	2 512
Solar photovoltaic (PV)		
Ground-mounted	10.94	11 053
Rooftop	2.57	2 598
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.25	6 602 (primary)
Municipal solid waste (MSW)	0.05	5 330 (primary)
Geothermal (sustainable technical)	0.07	550
Carbon capture	0.29	2 144

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	8.09	10.94	4.28
Associated investment needs (MEUR)	13 104	20 367	7 531
Potential Jobs (FTE/year)			5 400

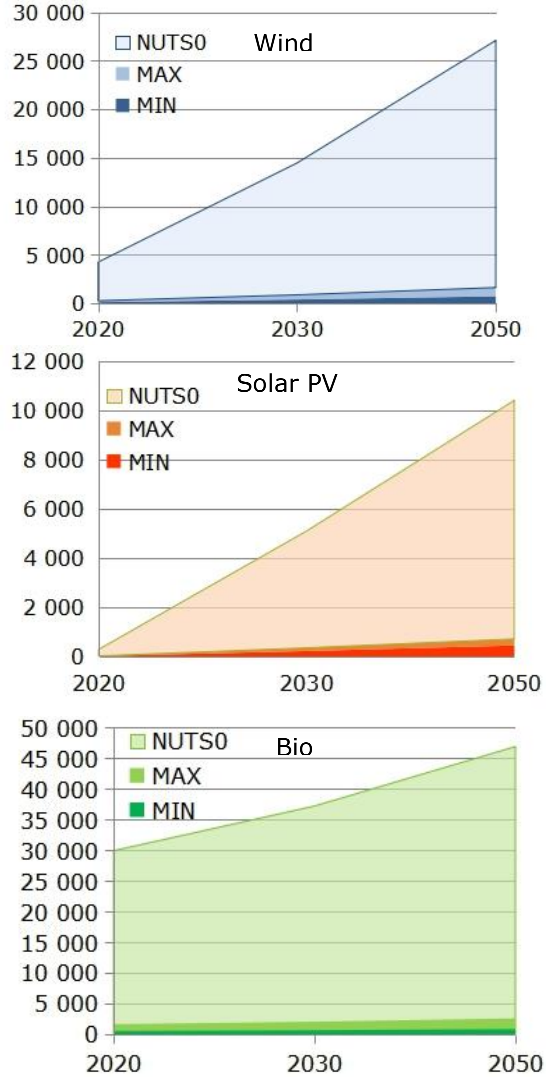
Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 3 (nacelle assembly, generators) in close-by regions (CZ05, HU32, SK03)	0
Solar PV	1 (prod. equip.); 1 (materials); 3 (components); 2 (panels); 4 (sellers); 38 (installers); 1 (services)	50

NUTS0 and NUTS 2 range of jobs



Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	536.30	862
Solar PV	10.67	348
Bioenergy	134	693

EUR mil/Job ratio

Wind, 1.08
Solar PV, 0.05
Bio, 0.06

PL22 Śląskie
Poland

Technical potential

	GW (power)	GWh/y
Wind (onshore)	0.30	627
Solar photovoltaic (PV)		
Ground-mounted	9.14	9 276
Rooftop	3.30	3 356
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.22	5 858 (primary)
Municipal solid waste (MSW)	0.10	7 252 (primary)
Geothermal (sustainable technical)	0.06	496
Carbon capture	2.07	15 376

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	11.05	14.39	5.72
Associated investment needs (MEUR)	16 987	25 860	9 640
Potential Jobs (FTE/year)			7 000

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 3 (nacelle assembly, generators) in close-by regions (CZ05, HU32, SK03)	0
Solar PV	7 (components); 3 (panels); 8 (sellers); 54 (installers)	72

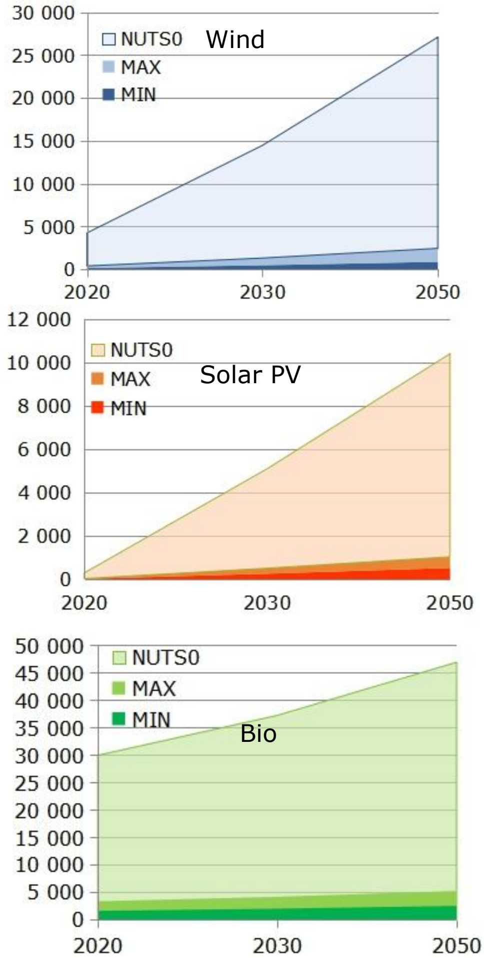
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	807.80	1 298
Solar PV	15.48	504
Bioenergy	268.20	1 993

EUR mil/Job ratio

Wind, 1.11
Solar PV, 0.05
Bio, 0.06

NUTS0 and NUTS 2 range of jobs



PL41 Wielkopolskie **Poland**

Technical potential

	GW (power)	GWh/y
Wind (onshore)	10.40	23 752
Solar photovoltaic (PV)		
Ground-mounted	31.25	31 796
Rooftop	2.75	2 794
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.65	16 827 (primary)
Municipal solid waste (MSW)	0.07	5 563 (primary)
Geothermal (sustainable technical)	0.15	1 207
Carbon capture	0.24	1 750

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	3.69	5.10	1.98
Associated investment needs (MEUR)	6 042	9 516	3 501
Potential Jobs (FTE/year)			2 600

Coal mine reclamation

	GW	GWh/y
Wind	0.15	565.5
Solar PV	0.28	293.5

Value chain

	Facilities	Total
Wind	No factories in region; 7 (nacelle assembly, blades, foundations) in close-by regions (PL42, CZ05, DE40, DE80)	0
Solar PV	2 (materials); 2 (components); 2 (sellers); 28 (installers)	34

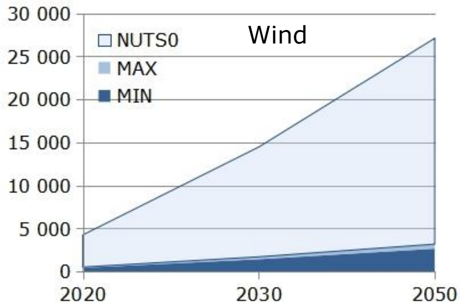
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

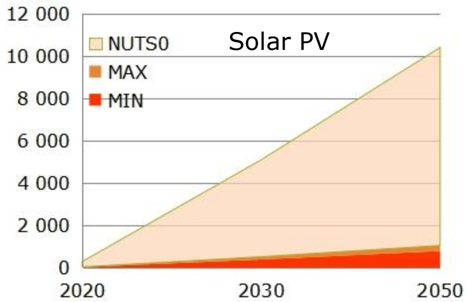
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 049.84	1 405
Solar PV	15.65	499
Bioenergy	235.30	2 294

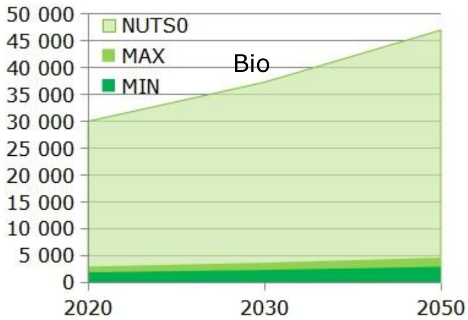
EUR mil/Job ratio

Wind, 1.26
Solar PV, 0.06
Bio, 0.06

NUTS0 and NUTS 2 range of jobs







PL51
Dolnośląskie
Poland

Technical potential

	GW (power)	GWh/y
Wind (onshore)	5.25	11 410
Solar photovoltaic (PV)		
Ground-mounted	18.69	19 106
Rooftop	2.55	261
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.46	12 231 (primary)
Municipal solid waste (MSW)	0.06	4 668 (primary)
Geothermal (sustainable technical)	0.09	751
Carbon capture	0.51	3 760

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	7.73	9.31	3.72
Associated investment needs (MEUR)	12 402	18 756	7 011
Potential Jobs (FTE/year)			5 000

Coal mine reclamation

	GW	GWh/y
Wind	0.03	53.3
Solar PV	0.07	72.5

Value chain

	Facilities	Total
Wind	No factories in region; 5 (nacelle assembly, blades, foundations) in close-by regions (PL42, CZ05, DE40)	0
Solar PV	2 (components); 1 (seller); 21 (installers)	24

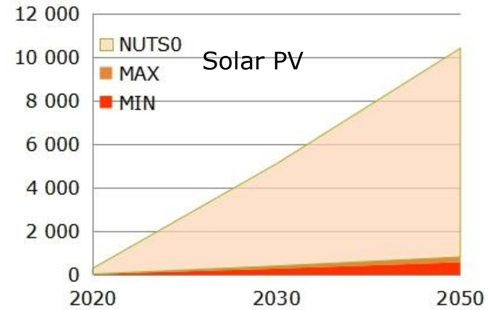
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

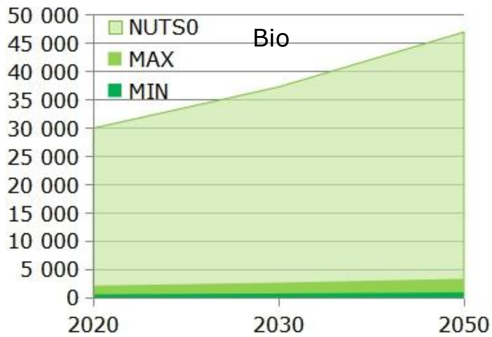
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	634.83	722
Solar PV	12.12	395
Bioenergy	171.90	753

EUR mil/Job ratio

Wind, 1.08
Solar PV, 0.06
Bio, 0.06

NUTS0 and NUTS 2 range of jobs





PL71 Łódzkie
Poland

Technical potential

	GW (power)	GWh/y
Wind (onshore)	5.67	12 261
Solar photovoltaic (PV)		
Ground-mounted	19.95	20 344
Rooftop	1.82	1 853
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.58	15 408 (primary)
Municipal solid waste (MSW)	0.05	3 988 (primary)
Geothermal (sustainable technical)	0.09	695
Carbon capture	0.34	2 494

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	9.62	12.78	5.04
Associated investment needs (MEUR)	15 800	24 327	9 029
Potential Jobs (FTE/year)			6 500

Coal mine reclamation

	GW	GWh/y
Wind	0.05	97.4
Solar PV	0.10	104.4

Value chain

	Facilities	Total
Wind	No factories in region; 1 factory (nacelle assembly) in close-by region (CZ05), 2 factories (foundation, blades) in other part of country (PL42)	0
Solar PV	1 (components); 2 (sellers); 23 (installers)	26

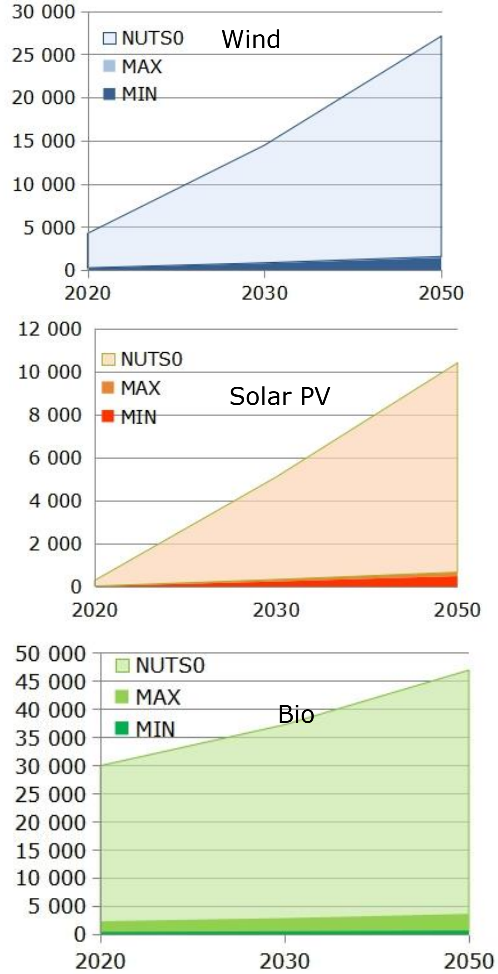
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	515.49	764
Solar PV	10.00	307
Bioenergy	186.00	543

EUR mil/Job ratio

Wind, 1.32
Solar PV, 0.07
Bio, 0.06

NUTS0 and NUTS 2 range of jobs



PL81 Lubelskie
Poland

Technical potential

	GW (power)	GWh/y
Wind (onshore)	12.16	28 592
Solar photovoltaic (PV)		
Ground-mounted	27.33	28 084
Rooftop	2.05	2 109
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.59	15 670 (primary)
Municipal solid waste (MSW)	0.05	3 412 (primary)
Geothermal	0.11	851
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	6.96	9.78	3.77
Associated investment needs (MEUR)	11 782	18 718	6 862
Potential Jobs (FTE/year)			5 000

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar (PV)	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 2 (foundation, blades) in other part of country (PL42)	0
Solar PV	1 (materials); 1 (components); 1 (sellers); 20 (installers); 1 (services)	24

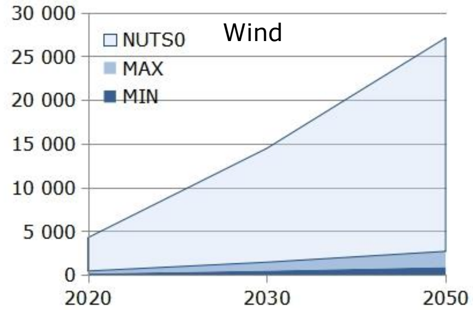
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

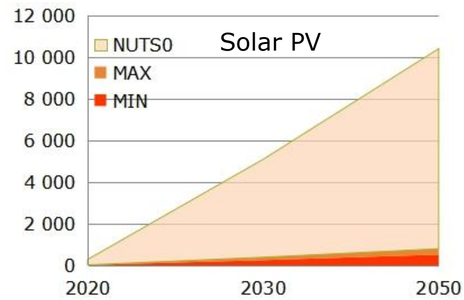
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	885.97	1 424
Solar PV	11.96	382
Bioenergy	178.60	347

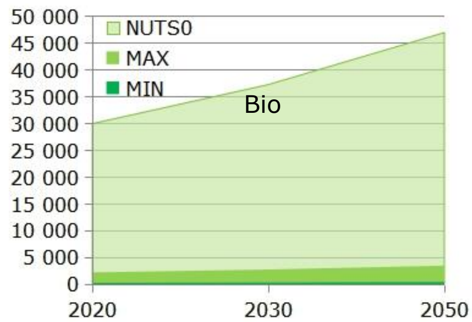
EUR mil/Job ratio

Wind, 1.40
Solar PV, 0.08
Bio, 0.06

NUTS0 and NUTS 2 range of jobs







RO41 Sud-Vest Oltenia
Romania

Technical potential

	GW	GWh/y
Wind (onshore)	11.21	22 104
Solar photovoltaic (PV)		
Ground-mounted	30.48	3 852
Rooftop	3.40	4 302
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.52	13 663 (primary)
Municipal solid waste (MSW)	0.06	2 844 (primary)
Geothermal (sustainable technical)	0.14	1 138
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	9.31	13.39	5.11
Associated investment needs (MEUR)	8 295	15 564	5 368
Potential Jobs (FTE/year)			6 400

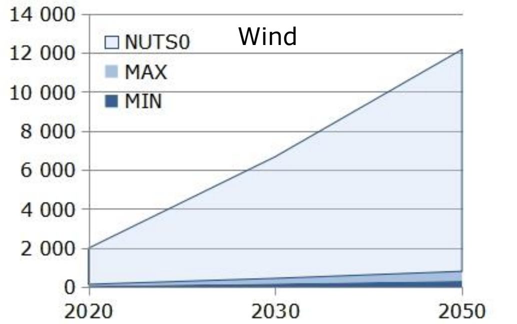
Coal mine reclamation

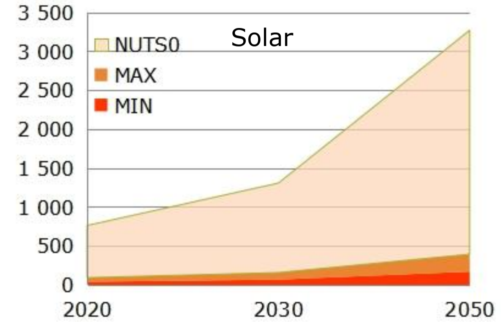
	GW	GWh/y
Wind	0.07	78.5
Solar PV	0.15	182.0

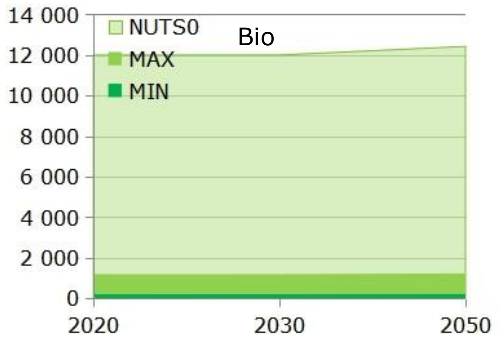
Value chain

	Facilities	Total
Wind	No factories in region; 2 (bearings, generators) in close-by regions (RO11, RO31)	0
Solar PV	4 (installers)	4

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	281.23	170
Solar PV	11.45	68
Bioenergy	54.80	205

EUR mil/Job ratio

Wind, 1.15
Solar PV, 010
Bio, 0.05

RO42 Vest
Romania

Technical potential

	GW	GWh/y
Wind (onshore)	8.83	17 397
Solar photovoltaic (PV)		
Ground-mounted	29.12	34 358
Rooftop	2.93	3 468
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.69	18 285 (primary)
Municipal solid waste (MSW)	0.05	2 541 (primary)
Geothermal (sustainable technical)	0.17	1 379
Carbon capture	0.11	819

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	9.17	12.76	4.94
Associated investment needs (MEUR)	7 211	12 977	4 542
Potential Jobs (FTE/year)			5 400

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No in region; 3 (bearings, generators) in close-by regions (RO11, RO31, HU32)	0
Solar PV	1 (seller); 21 (installer); 1 (applications)	23

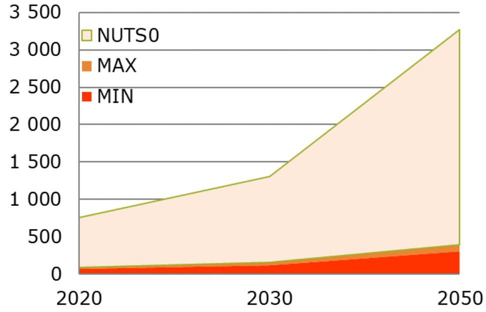
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

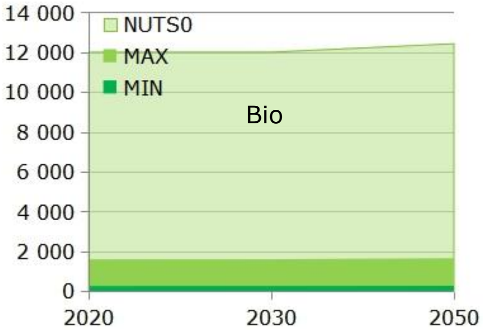
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	301.36	251
Solar PV	17.59	158
Bioenergy	73.60	260

EUR mil/Job ratio

Wind, 0.98
Solar PV, 0.10
Bio, 0.05

NUTS0 and NUTS 2 range of jobs





SK02 Západné Slovensko
Slovakia

Technical potential

	GW	GWh/y
Wind (onshore)	25.48	55 169
Solar photovoltaic (PV)		
Ground-mounted	2.80	3 272
Rooftop	1.34	1 541
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.37	9 803 (primary)
Municipal solid waste (MSW)	0.03	3 468 (primary)
Geothermal (sustainable technical)	0.04	358
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	11.63	12.30	5.38
Associated investment needs (MEUR)	16 376	17 304	7 578
Potential Jobs (FTE/year)			4 600

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 2 (generators) in close-by regions (SK03, HU32)	0
Solar PV	1 (prod. equip.); 2 (sellers); 31 (installers); 1 services	35

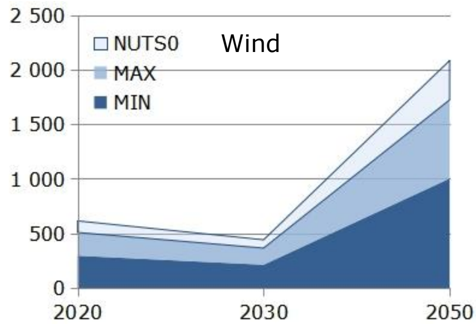
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

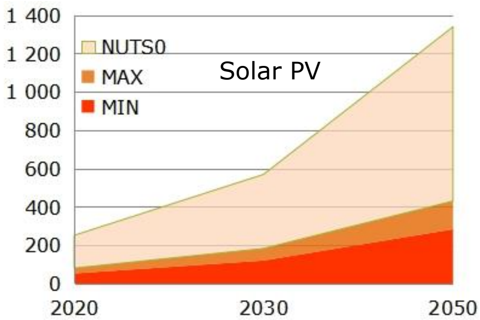
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	0	365
Solar PV	5.49	183
Bioenergy	64.30	594

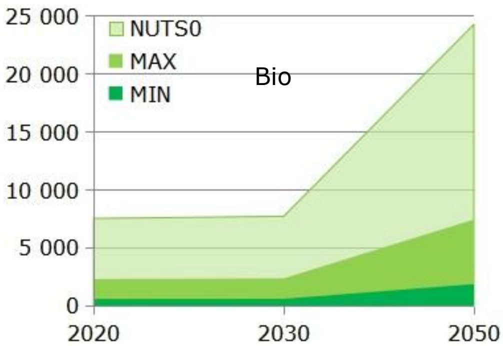
EUR mil/Job ratio

Wind, 0.82
Solar PV, 0.07
Bio, 0.05

NUTS0and NUTS 2 range of jobs







SI03 Vzhodna Slovenija
Slovenia

Technical potential

	GW	GWh/y
Wind (onshore)	1.90	3 742
Solar photovoltaic (PV)		
Ground-mounted	16.20	3 272
Rooftop	3.26	1 541
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.61	16 277 (primary)
Municipal Solid Waste (MSW)	0.03	2 747 (primary)
Geothermal (sustainable technical)	0.09	722
Carbon capture	0.11	789

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	4.78	7.12	2.68
Associated investment needs (MEUR)	4 758	9 276	3 158
Potential Jobs (FTE/year)			1 900

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factories in region; 1 (nacelle assembly) in close-by region (AT21)	0
Solar PV	1 (prod. equip.); 4 (components); 1 (panels); 2 (sellers); 17 (installers); 2 applications; 2 (services)	29

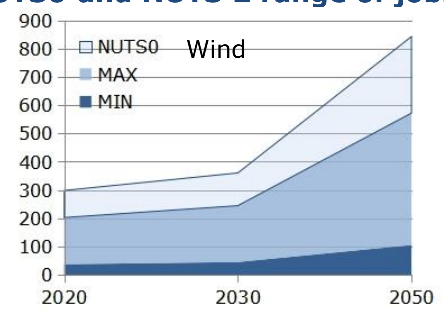
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

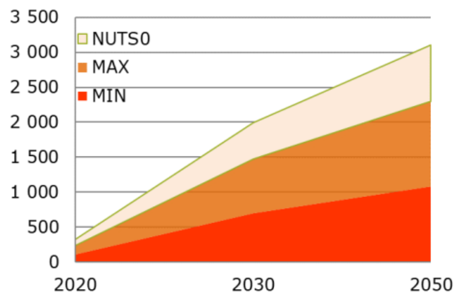
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	145.85	244
Solar PV	100.65	1 992
Bioenergy	59.80	236

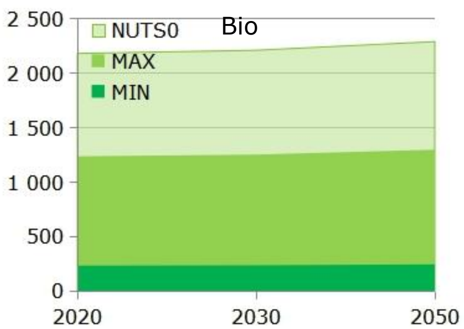
EUR mil/Job ratio

Wind, 0.82
Solar PV, 0.14
Bio, 0.05

NUTS0 and NUTS 2 range of jobs







UKC2 Northumberland and Tyne and Wear
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	6.52	21 786
Solar photovoltaic (PV)		
Ground-mounted	4.44	3 835
Rooftop	1.00	863
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.09	2 368 (primary)
Municipal solid waste (MSW)	0.04	4 041 (primary)
Geothermal (sustainable technical)	0.03	207
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	3.74	9.83	3.05
Associated investment needs (MEUR)	6 983	20 629	6 213
Potential Jobs			2 800

Coal mine reclamation

	GW	GWh/y
Wind	Very small	12.1
Solar PV	0.01	5.1

Value chain

	Facilities	Total
Wind	1 factory in region (blades); 3 (nacelle assembly, nacelle shell, gearbox) in close-by regions (UKC1, UKE1, UKE4)	1
Solar PV	1 (materials); 1 (components); 2 (panels); 53 (installers); 5 (services)	62

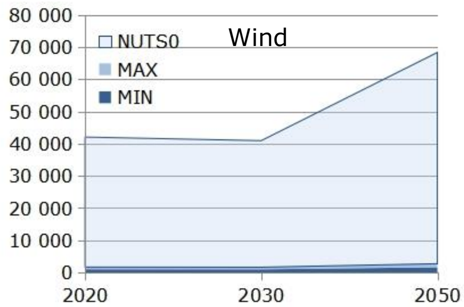
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

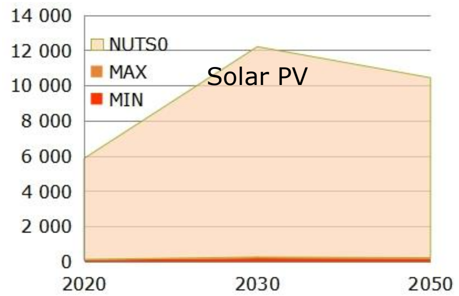
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	683.74	952
Solar PV	11.69	185
Bioenergy	144.70	189

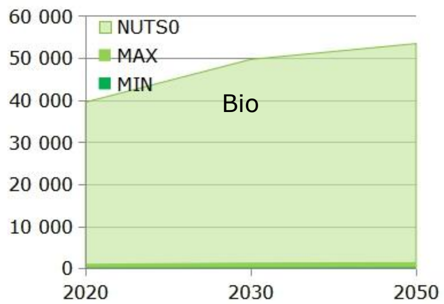
EUR mil/Job ratio

Wind, 1.32
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKE2 North Yorkshire
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	6.60	20 441
Solar photovoltaic (PV)		
Ground-mounted	8.76	7 737
Rooftop	0.65	576
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.18	4 529 (primary)
Municipal solid waste (MSW)	0.02	2 369 (primary)
Geothermal (sustainable technical)	0.03	245
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	1.95	5.30	1.63
Associated investment needs (MEUR)	3 691	11 281	3 369
Potential Jobs (FTE/year)			1 500

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factory in region; 4 (nacelle assembly, nacelle shell, gearbox, blades) in close-by regions (UKC1, UKE1, UKE4, UKC2)	0
Solar PV	2 (materials); 1 (components); 45 (installers); 1 (applications); 4 (services)	53

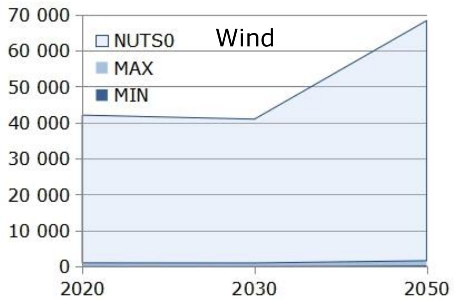
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

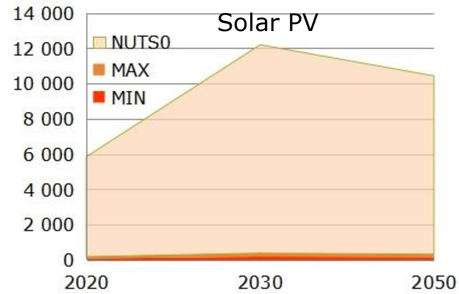
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	400.17	945
Solar PV	18.03	342
Bioenergy	225.80	960

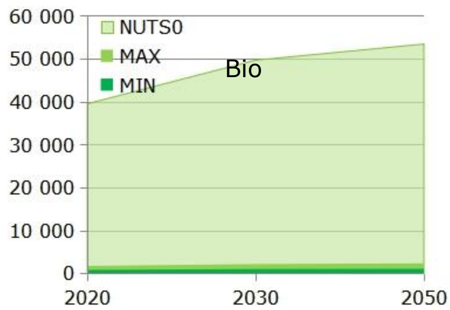
EUR mil/Job ratio

Wind, 1.20
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKE3 South Yorkshire
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	0.39	1 096
Solar photovoltaic (PV)		
Ground-mounted	1.44	1315
Rooftop	0.65	576
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.02	542 (primary)
Municipal solid waste (MSW)	0.04	3 958 (primary)
Geothermal (sustainable technical)	0.01	52
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	2.99	8.08	2.49
Associated investment needs (MEUR)	6 219	18 949	5 663
Potential Jobs (FTE/year)			2 500

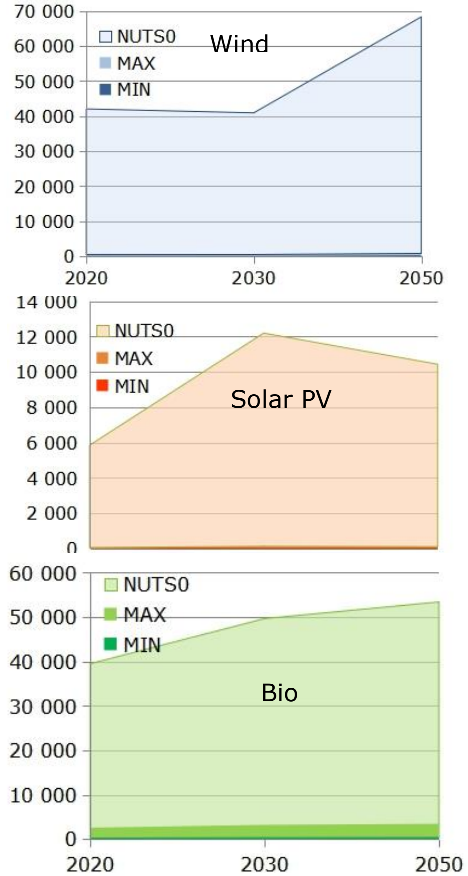
Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factory in region (blades); 3 (nacelle assembly, nacelle shell, gearbox, blades) in close-by regions (UKC1, UKE1, UKE4, UKC2)	0
Solar PV	1 (components); 3 (sellers); 52 (installers); 3 (applications); 2 services	61

NUTS0 and NUTS 2 range of jobs



Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	199.18	174
Solar PV	6.27	86
Bioenergy	338.40	424

EUR mil/Job ratio

Wind, 1.23
Solar PV, 0.08
Bio, 0.11

UKE4 West Yorkshire
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	0.24	681
Solar photovoltaic (PV)		
Ground-mounted	1.51	1 329
Rooftop	1.47	1 296
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.02	449 (primary)
Municipal solid waste (MSW)	0.06	6 504 (primary)
Geothermal (sustainable technical)	0.01	62
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	5.32	14.03	4.35
Associated investment needs (MEUR)	10 385	30 766	9 259
Potential Jobs (FTE/year)			4 100

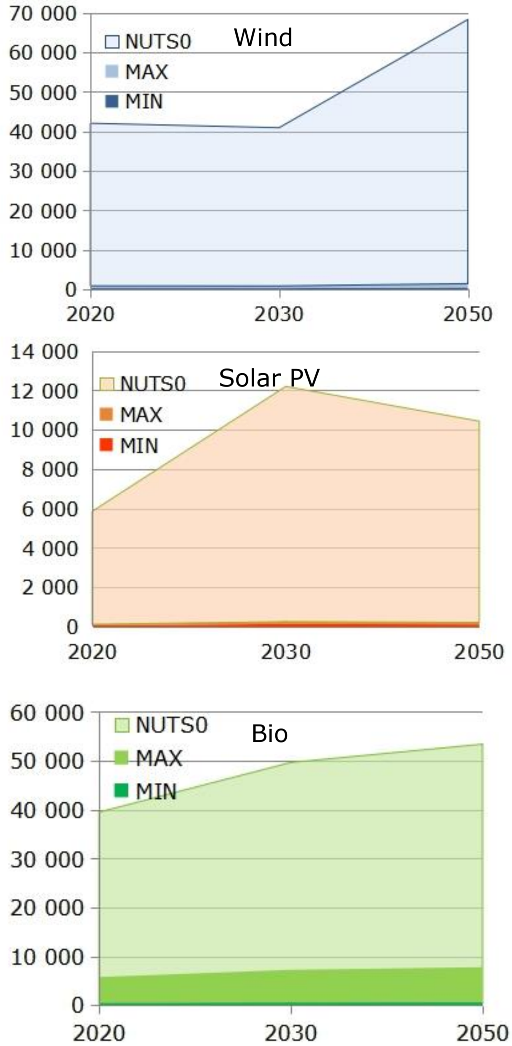
Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	1 factory in region (gearbox); 3 (nacelle assembly, nacelle shell, blades) in close-by regions (UKC1, UKE1, UKC2)	1
Solar PV	4 (components); 2 (panels); 4 (sellers); 79 (installers); 2 (applications); 5 (services)	96

NUTS0 and NUTS 2 range of jobs



Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	363.02	857
Solar PV	11.81	135
Bioenergy	762.80	502

EUR mil/Job ratio

Wind,0.59
Solar PV, 0.02
Bio, 0.11

UKF1 Derbyshire and Nottinghamshire
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	1.90	5 485
Solar photovoltaic (PV)		
Ground-mounted	5.73	5 263
Rooftop	1.60	1 472
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.08	2 090 (primary)
Municipal solid waste (MSW)	0.05	2 641 (primary)
Geothermal (sustainable technical)	0.02	158
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	4.77	13.14	4.03
Associated investment needs (MEUR)	9 742	30 269	9 003
Potential Jobs (FTE/year)			4 100

Coal mine reclamation

	GW	GWh/y
Wind	Very small	3.2
Solar PV	Very small	1.2

Value chain

	Facilities	Total
Wind	No factory in region; 2 factories (nacelle shell, gearbox) in close-by regions (UKE1, UKE4)	0
Solar PV	2 (materials); 1 (components); 1 (sellers); 79 (installers); 6 (applications); 2 (services)	91

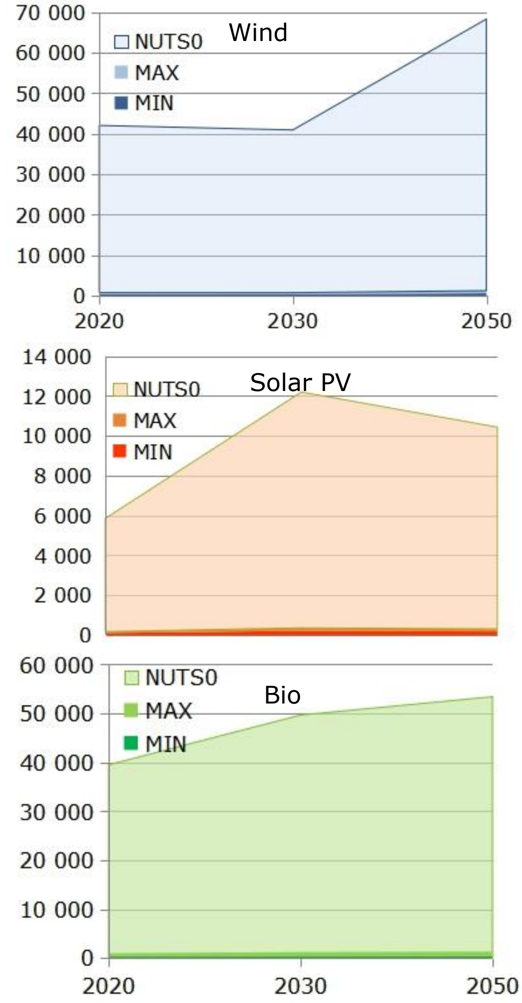
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	313.58	360
Solar PV	16.73	277
Bioenergy	130.30	282

EUR mil/Jobs ratio

Wind, 1.26
Solar PV, 0.03
Bio, 0.11

NUTS0 and NUTS 2 range of jobs



UKG2 Shropshire and Staffordshire
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	4.12	12 674
Solar photovoltaic (PV)		
Ground-mounted	8.77	8 052
Rooftop	1.47	1 353
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.09	2 296 (primary)
Municipal solid waste (MSW)	0.01	4 657 (primary)
Geothermal (sustainable technical)	0.02	179
Carbon capture	0	

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	3.68	10.20	3.12
Associated investment needs (MEUR)	5 197	15 681	4 698
Potential Jobs (FTE/year)			3 100

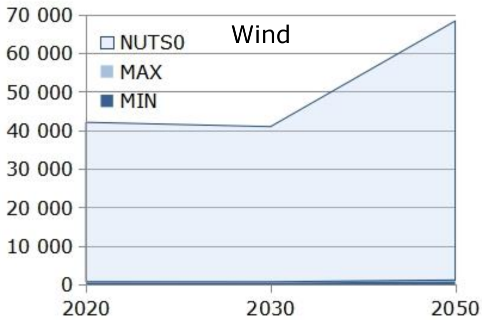
Coal mine reclamation

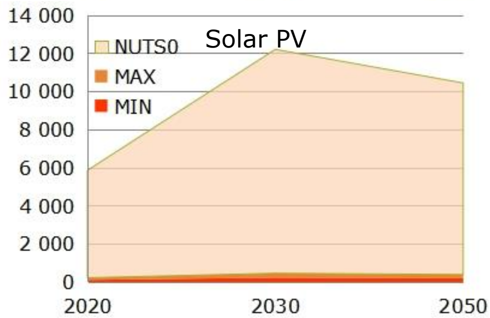
	GW	GWh/y
Wind	Very small	1.0
Solar PV	Very small	0.7

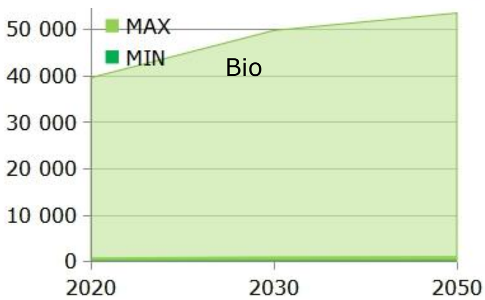
Value chain

	Facilities	Total
Wind	No factory in region; 3 (towers, nacelle shell, gearbox) in close-by regions (UKL2, UKE1, UKE4)	0
Solar PV	1 (materials); 2 (components); 1 (panels); 2 (sellers); 84 (installers); 3 (applications); 1 (services)	94

NUTS0 and NUTS 2 range of jobs







Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	290.91	480
Solar PV	21.11	327
Bioenergy	109.50	195

EUR mil/Job ratio

Wind, 1.17
Solar PV, 0.08
Bio, 0.04

UKL1 West Wales and The Valleys
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	21.70	76 631
Solar photovoltaic (PV)		
Ground-mounted	11.74	10 679
Rooftop	2.13	1 933
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.13	3 201 (primary)
Municipal solid waste (MSW)	0.03	5 407 (primary)
Geothermal (sustainable technical)	0.04	350
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	4.08	10.96	3.38
Associated investment needs (MEUR)	8 699	26 315	7 878
Potential Jobs (FTE/year)			3 600

Coal mine reclamation

	GW	GWh/y
Wind	0.01	24.5
Solar PV	0.02	14.4

Value chain

	Facilities	Total
Wind	No factory in region; 1 (towers) in close-by region (UKL2)	0
Solar PV	2 (prod. equip.); 3 (materials); 4 (components); 1 (panels); 2 (sellers); 118 (installers); 5 (applications); 6 (Services)	141

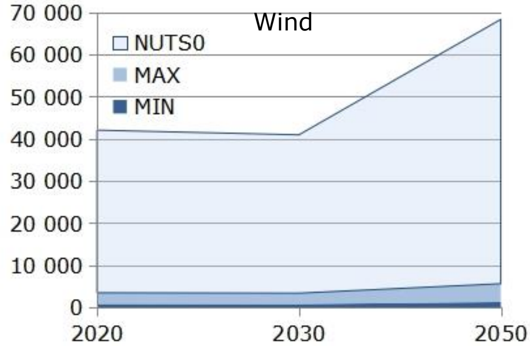
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

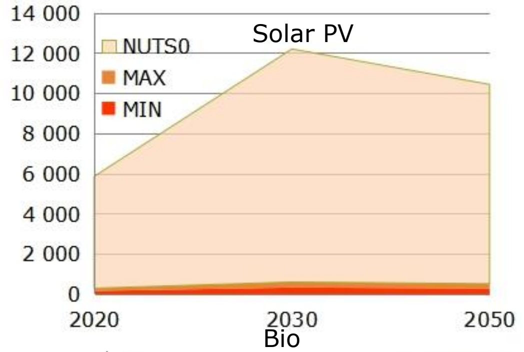
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 418.61	3 348
Solar photovoltaic	27.67	570
Bioenergy	172	945

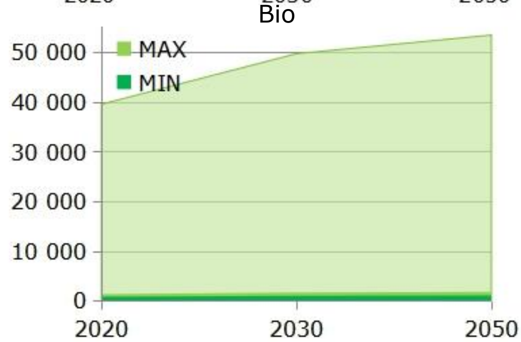
EUR mil/Job ratio

Wind, 0.74
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKL1 West Wales and The Valleys
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	21.70	76 631
Solar photovoltaic (PV)		
Ground-mounted	11.74	10 679
Rooftop	2.13	1 933
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.13	3 201 (primary)
Municipal solid waste (MSW)	0.03	5 407 (primary)
Geothermal (sustainable technical)	0.04	350
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	4.08	10.96	3.38
Associated investment needs (MEUR)	8 699	26 315	7 878
Potential Jobs (FTE/year)			3 600

Coal mine reclamation

	GW	GWh/y
Wind	0.01	24.5
Solar PV	0.02	14.4

Value chain

	Facilities	Total
Wind	No factory in region; 1 factory (towers) in close-by region (UKL2)	0
Solar PV	2 (prod. equip.); 3 (materials); 4 (components); 1 (panels); 2 (sellers); 118 (installers); 5 (applications); 6 (Services)	141

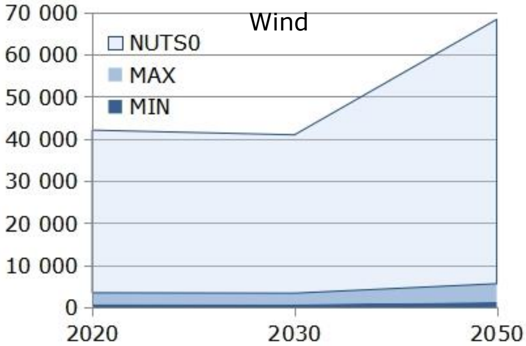
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

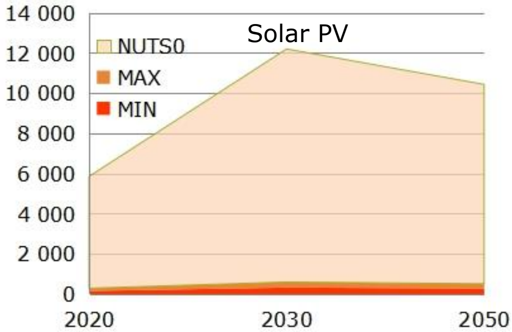
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 418.61	3 348
Solar photovoltaic	27.67	600
Bioenergy	172	945

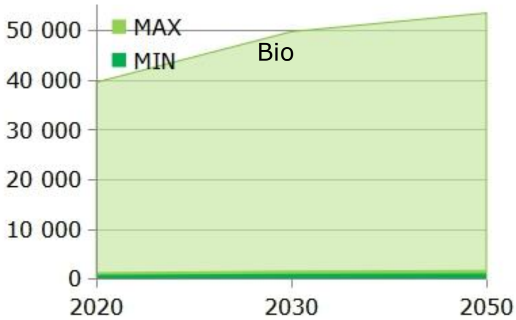
EUR mil/Job ratio

Wind, 0.74
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKM7 Eastern Scotland
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	19.11	56 213
Solar photovoltaic (PV)		
Ground-mounted	7.84	632
Rooftop	0.85	676
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.23	5 959 (primary)
Municipal solid waste (MSW)	0.01	4 012 (primary)
Geothermal (sustainable technical)	0.04	357
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	5.1	13.05	4.08
Associated investment needs (MEUR)	10 248	29 477	8 938
Potential Jobs (FTE/year)			4 000

Coal mine reclamation

	GW	GWh/y
Wind	Very small	8.0
Solar PV	0.01	4.6

Value chain

	Facilities	Total
Wind	1 factory in region (nacelle assembly); 3 (nacelle assembly, towers, blades) in close-by regions (UKM6, UKC1, UKC2)	1
Solar PV	1 (components); 63 (installers); 7 (services)	71

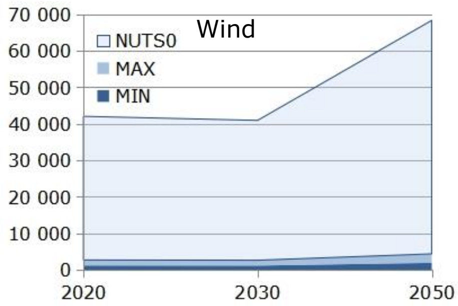
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

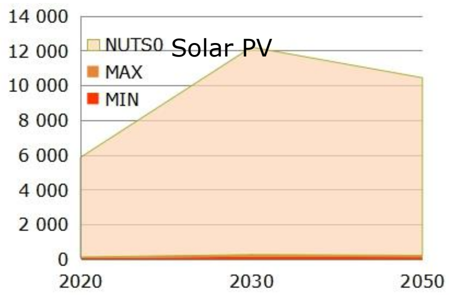
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	1 102.90	1 135
Solar PV	12.10	262
Bioenergy	925.50	3 329

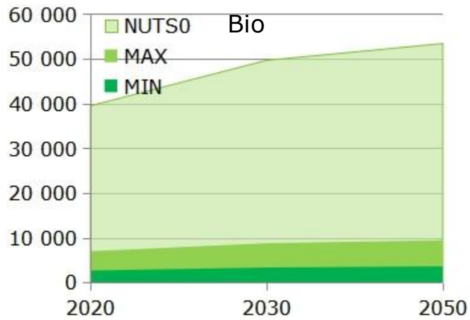
EUR mil/Job ratio

Wind, 0.82
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKM8 West Central Scotland
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	8.46	26 481
Solar photovoltaic (PV)		
Ground-mounted	0.85	676
Rooftop	0.88	697
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.01	304 (primary)
Municipal solid waste (MSW)	0.04	4 074 (primary)
Geothermal (sustainable technical)	0.01	60
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	6.36	15.98	5.03
Associated investment needs (MEUR)	12 439	35 136	10 704
Potential Jobs (FTE/year)			4 800

Coal mine reclamation

	GW	GWh/y
Wind	0.04	116.8
Solar PV	0.09	61.2

Value chain

	Facilities	Total
Wind	No factory in region; 4 (nacelle assembly, towers, blades) in close-by regions (UKC1, UKC2, UKM6, UKM7)	0
Solar PV	1 (prod. equip.); 1 (components); 30 (installers); 1 (applications); 7 (services)	40

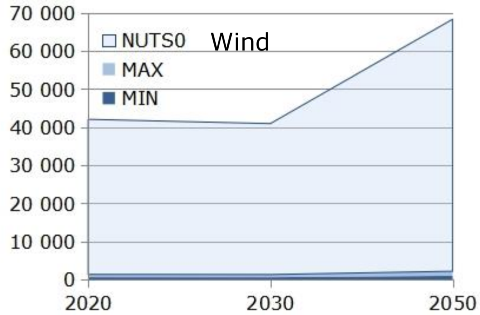
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

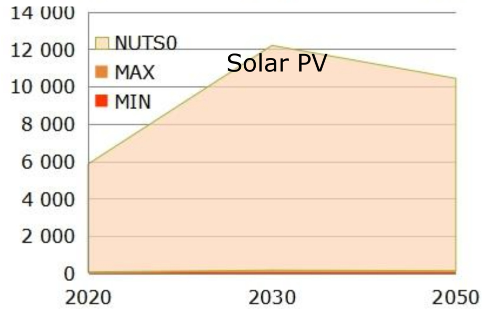
	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	543.26	573
Solar PV	8.07	175
Bioenergy	71	223

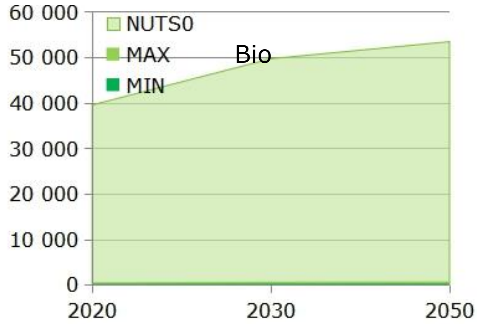
EUR mil/Job ratio

Wind, 1.03
Solar PV, 0.01
Bio, 0.11

NUTS0 and NUTS 2 range of jobs







UKM9 Southern Scotland
United Kingdom

Technical potential

	GW	GWh/y
Wind (onshore)	8.46	23 500
Solar photovoltaic (PV)		
Ground-mounted	9.47	7 846
Rooftop	0.63	52
Bioenergy		
Crop residues, livestock methane, forest biomass (medium)	0.20	5 094 (primary)
Municipal Solid Waste (MSW)	0.02	2 381 (primary)
Geothermal (sustainable technical)	0.06	480
Carbon capture	0	0

Energy efficiency in buildings

	Theoretical cost optimal	Theoretical NZEB	BAU at 2050
Primary energy savings potential (TWh)	1.20	3.18	0.99
Associated investment needs (MEUR)	2 244	6 646	2 000
Potential Jobs (FTE/year)			900

Coal mine reclamation

	GW	GWh/y
Wind	N/A	N/A
Solar PV	N/A	N/A

Value chain

	Facilities	Total
Wind	No factory in region; 4 (nacelle assembly, towers, blades) in close-by regions (UKC1, UKC2, UKM6, UKM7)	0
Solar PV	1 (components); 1 (sellers); 35 (installers) 2 (services)	39

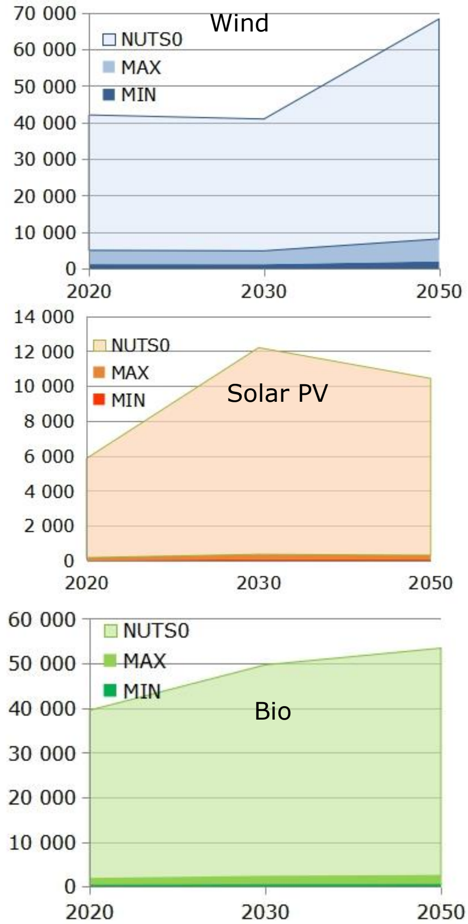
Clean Energy Production Technologies Investments and Jobs (2030, EUCO3232.5 based MAX technology deployment projection)

	Average CAPEX needs (EUR million)	Job creation potential (FTE)
Wind	2 053.73	4 847
Solar PV	16.95	253
Bioenergy	255.10	484

EUR mil/Job ratio

Wind, 0.98
Solar PV, 0.08
Bio, 0.11

NUTS0 and NUTS 2 range of jobs



3. Technical potential per region

Table 17. Estimated potential for onshore wind and solar energy in the coal regions.

Region (NUTS 2)	Onshore Wind		Solar PV				
			ground mounted		rooftop		
	Capacity (GW)	Production (GWh/year)	Capacity (GW)	Production (GWh/year)	Capacity (GW)	Production (GWh/year)	Buildings density (m^2)
BG34	7.1	14,012	18.22	23,991	2.16	2,842	9,827,000,320
BG41	3.2	6,217	5.96	759	2.51	3,195	10,592,000,000
CZ04	4.4	8,764	5.99	6,033	1.24	1,252	6,662,000,128
CZ08	4.1	8,813	3.95	4,014	1.33	1,351	4,558,000,128
DE40	11.4	23,666	20.59	20,617	4.61	4,612	22,175,000,576
DEA1	0.9	2,005	4.98	4,904	4.81	4,735	5,235,999,744
DEA2	1.2	2,569	6.69	66	4.34	4,279	7,023,000,064
DEA3	6.9	14,027	9.46	9,181	3.00	2,909	6,812,000,256
DEC0	0.1	200	1.61	1,669	1.45	1,506	2,520,000,000
DED2	2.7	5,391	6.92	6,969	2.37	2,381	6,883,999,744
DED5	1.8	3,511	4.43	4,572	1.40	1,441	3,580,000,000
DEE0	13.7	27,004	24.25	24,451	4.08	4,111	16,124,999,680
EL53	5.6	12,262	4.67	6,374	0.37	504	3,927,000,064
EL65	27.4	64,684	1.01	1,533	0.65	994	7,420,000,256
ES12	7	17,587	2.46	2,808	0.86	979	6,304,000,000
ES21	3.2	7,068	2.54	296	1.41	1,639	4,901,000,192
ES24	121.2	280,958	25.31	39,439	1.31	2,041	13,176,000,512
ES41	228.2	502,125	79.89	120,727	3.52	5,312	40,583,999,488
ES42	154.9	323,550	64.70	105,178	2.86	4,645	23,853,000,704
HU31	0	0	10.13	11,837	1.83	2,141	8,398,000,128
ITG2	41.9	93,388	13.14	19,852	3.10	4,679	16,625,000,448
PL21	1.2	2,512	10.94	11,053	2.57	2,598	13,249,999,872
PL22	0.3	627	9.14	9,276	3.30	3,356	11,034,000,384
PL41	10.4	23,752	31.25	31,796	2.75	2,794	24,523,999,232
PL51	5.2	11,410	18.69	19,106	2.55	261	14,099,999,744
PL71	5.7	12,261	19.95	20,344	1.82	1,853	16,138,000,384

Table continued: Estimated potential for onshore wind and solar energy in the coal regions.

Region (NUTS 2)	Onshore Wind		Solar PV				
			ground mounted		rooftop		
	Capacity (GW)	Production (GWh/year)	Capacity (GW)	Production (GWh/year)	Capacity (GW)	Production (GWh/year)	
PL81	12.2	28,592	27.33	28,084	2.05	2,109	16,138,000,384
RO41	11.2	22,104	30.48	3,852	3.40	4,302	20,241,000,448
RO42	8.8	17,397	29.12	34,358	2.94	3,468	16,261,999,616
SK02	25.5	55,169	2.84	3,272	1.34	1,541	15,416,999,936
SI03	1.9	3,742	16.17	18,543	3.26	374	10,444,000,256
UKC2	6.5	21,786	4.44	3,835	1.00	863	11,027,999,744
UKE2	6.6	20,441	8.76	7,737	0.65	576	4,104,000,000
UKE3	0.4	1,096	1.44	1,315	1.01	92	6,839,000,064
UKE4	0.2	681	1.51	1,329	1.47	1,296	1,448,999,936
UKF1	1.9	5,485	5.73	5,263	1.60	1,472	1,931,000,064
UKG2	4.1	12,674	8.77	8,052	1.47	1,353	4,476,000,256
UKL1	21.7	76,631	11.74	10,679	2.13	1,933	6,051,999,744
UKL2	14.3	47,200	6.71	685	1.19	1,079	10,899,000,320
UKM7	19.1	56,213	7.84	632	0.85	688	5,959,000,064
UKM8	8.5	26,481	0.85	676	0.88	697	6,953,999,872
UKM9	8.5	26,481	9.47	7,846	0.63	52	1,454,000,000

Table 18. Estimated potential for offshore wind in countries hosting the coal regions.

Country	Capacity (GW)	Production (GWh/year)
Bulgaria	0.45	1,314
Germany	27.84	106,525
Greece	0.03	65
Italy	5.36	12,550
Poland	12.31	48,695
Romania	8.77	27,411
Spain	0.79	2,121
United Kingdom	103.61	441,169
Total	**159.14**	**639,850**

Table 19. Estimated potential for bioenergy (crop residues, livestock methane, and municipal solid waste) in the coal regions.

Region NUTS 2	Bioenergy					
	Crop residues		Livestock Methane		Municipal Solid Waste	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*
BG34	0.40	0.12	0.03	0.01	0.14	0.04
BG41	0.02	0.01	0.01	0.00	0.29	0.09
CZ04	0.12	0.04	0.02	0.01	0.09	0.03
CZ08	0.08	0.02	0.02	0.01	0.10	0.03
DE40	0.92	0.28	0.13	0.05	0.04	0.01
DEA1	0.14	0.04	0.05	0.02	0.00	0.00
DEA2	0.17	0.05	0.04	0.01	0.00	0.00
DEA3	0.50	0.15	0.17	0.06	0.00	0.00
DEC0	0.04	0.01	0.01	0.00	0.00	0.00
DED2	0.30	0.09	0.05	0.02	0.00	0.00
DED5	0.25	0.08	0.03	0.01	0.00	0.00
DEE0	1.16	0.35	0.11	0.04	0.00	0.00
EL53	0.08	0.02	0.01	0.00	0.06	0.02
EL65	0.01	0.00	0.02	0.01	0.11	0.03
ES12	0.00	0.00	0.04	0.01	0.12	0.04
ES21	0.06	0.02	0.02	0.01	0.14	0.04
ES24	0.76	0.23	0.23	0.08	0.16	0.05
ES41	2.43	0.73	0.31	0.11	0.28	0.09
ES42	1.35	0.41	0.20	0.07	0.25	0.07
HU31	0.25	0.07	0.02	0.01	0.12	0.04
ITG2	0.08	0.02	0.08	0.03	0.11	0.03
PL21	0.22	0.06	0.04	0.02	0.15	0.05

*Note: Thermal Capacity represents the thermal input delivered by the biomass fuel (MWth/MW thermal).

Table continued. Estimated potential for bioenergy (crop residues, livestock methane, and municipal solid waste) in the coal regions.

Region NUTS 2	Bioenergy					
	Crop residues		Livestock Methane		Municipal Solid Waste	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*
PL22	0.20	0.06	0.04	0.01	0.32	0.10
PL41	1.06	0.32	0.29	0.10	0.25	0.07
PL51	0.78	0.23	0.04	0.01	0.20	0.06
PL71	0.46	0.14	0.10	0.04	0.18	0.05
PL81	0.63	0.19	0.07	0.03	0.15	0.05
RO41	0.62	0.19	0.07	0.03	0.19	0.06
RO42	0.64	0.19	0.06	0.02	0.17	0.05
SK02	0.09	0.03	0.05	0.02	0.11	0.03
SI03	0.73	0.22	0.05	0.02	0.10	0.03
UKC2	0.13	0.04	0.03	0.01	0.12	0.04
UKE2	0.39	0.12	0.11	0.04	0.07	0.02
UKE3	0.05	0.01	0.01	0.00	0.15	0.04
UKE4	0.03	0.01	0.01	0.00	0.19	0.06
UKF1	0.18	0.06	0.05	0.02	0.16	0.05
UKG2	0.14	0.04	0.10	0.03	0.02	0.01
UKL1	0.00	0.00	0.13	0.05	0.11	0.03
UKL2	0.01	0.00	0.09	0.03	0.02	0.01
UKM7	0.40	0.12	0.06	0.02	0.02	0.01
UKM8	0.00	0.00	0.00	0.00	0.14	0.04
UKM9	0.14	0.04	0.11	0.04	0.06	0.02

*Note: Thermal Capacity represents the thermal input delivered by the biomass fuel (MWth/MW thermal).

Table 20. Estimated potential for bioenergy (forest biomass, high, medium, low scenarios) in the coal regions.

Region NUTS 2	Forest biomass					
	(high scenario)		(medium scenario)		(low scenario)	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)
BG34	2.10	0.63	1.06	0.32	0.72	0.22
BG41	1.69	0.51	0.87	0.26	0.60	0.18
CZ04	0.83	0.25	0.48	0.14	0.38	0.11
CZ08	0.67	0.20	0.39	0.12	0.31	0.09
DE40	4.24	1.27	2.32	0.70	1.75	0.53
DEA1	0.25	0.08	0.14	0.04	0.11	0.03
DEA2	0.67	0.20	0.38	0.11	0.30	0.09
DEA3	0.52	0.15	0.28	0.08	0.21	0.06
DEC0	0.30	0.09	0.17	0.05	0.13	0.04
DED2	0.80	0.24	0.44	0.13	0.34	0.10
DED5	0.21	0.06	0.11	0.03	0.09	0.03
DEE0	1.46	0.44	0.81	0.24	0.62	0.19
EL53	0.15	0.04	0.06	0.02	0.05	0.02
EL65	0.27	0.08	0.12	0.04	0.10	0.03
ES12	0.52	0.16	0.27	0.08	0.20	0.06
ES21	0.36	0.11	0.19	0.06	0.14	0.04
ES24	1.74	0.52	0.93	0.28	0.68	0.20
ES41	3.02	0.91	1.57	0.47	1.13	0.34
ES42	1.59	0.48	0.82	0.24	0.60	0.18
HU31	1.22	0.37	0.64	0.19	0.50	0.15
ITG2	0.30	0.09	0.14	0.04	0.10	0.03
PL21	0.86	0.26	0.49	0.15	0.38	0.11
PL22	1.35	0.41	0.76	0.23	0.58	0.17

* Note: Thermal Capacity represents the thermal input delivered by the biomass fuel (MWth/MW thermal).

Table continued. Estimated potential for bioenergy (forest biomass, high, medium, low scenarios) in the coal regions.

Region NUTS 2	Forest biomass					
	(high scenario)		(medium scenario)		(low scenario)	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*
PL41	2.50	0.75	1.36	0.41	1.04	0.31
PL51	2.26	0.68	1.26	0.38	0.96	0.29
PL71	1.02	0.31	0.56	0.17	0.43	0.13
PL81	1.29	0.39	0.71	0.21	0.55	0.17
RO41	1.84	0.55	1.01	0.30	0.77	0.23
RO42	2.88	0.87	1.59	0.48	1.22	0.36
SI03	0.81	0.24	0.44	0.13	0.33	0.10
SK02	3.42	1.03	1.93	0.58	1.47	0.44
UKC2	0.23	0.07	0.14	0.04	0.11	0.03
UKE2	0.12	0.04	0.07	0.02	0.05	0.02
UKE3	0.02	0.01	0.01	0.00	0.01	0.00
UKE4	0.02	0.01	0.01	0.00	0.01	0.00
UKF1	0.06	0.02	0.03	0.01	0.02	0.01
UKG2	0.09	0.03	0.05	0.02	0.04	0.01
UKL1	0.46	0.14	0.27	0.08	0.21	0.06
UKL2	0.23	0.07	0.13	0.04	0.10	0.03
UKM7	0.48	0.14	0.29	0.09	0.23	0.07
UKM8	0.07	0.02	0.04	0.01	0.04	0.01
UKM9	0.62	0.18	0.37	0.11	0.30	0.09

* Note: Thermal Capacity represents the thermal input delivered by the biomass fuel (MWth/MW thermal).

Table 21. Estimated potential for geothermal energy (maximum, realistic and sustainable) in the coal regions.

Region NUTS 2	Geothermal					
	Maximum technical		Realistic technical		Sustainable technical	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)	Power Capacity (GW)*
BG34	419.48	50.34	25.2	3.02	0.8	0.09
BG41	443.02	53.16	26.6	3.19	0.8	0.10
CZ04	205.24	24.63	12.3	1.48	0.4	0.04
CZ08	127.15	15.26	7.6	0.92	0.2	0.03
DE40	589.08	70.69	35.3	4.24	1.1	0.13
DEA1	88.35	10.60	5.3	0.64	0.2	0.02
DEA2	102.99	12.36	6.2	0.74	0.2	0.02
DEA3	140.48	16.86	8.4	1.01	0.3	0.03
DEC0	49.88	5.99	3.0	0.36	0.1	0.01
DED2	150.43	18.05	9.0	1.08	0.3	0.03
DED5	59.45	7.13	3.6	0.43	0.1	0.01
DEE0	421.48	50.58	25.3	3.03	0.8	0.09
EL53	157.06	18.85	9.4	1.13	0.3	0.03
EL65	373.25	44.79	22.4	2.69	0.7	0.08
ES12	243.27	29.19	14.6	1.75	0.4	0.05
ES21	179.01	21.48	10.7	1.29	0.3	0.04
ES24	1211.16	145.34	72.7	8.72	2.2	0.26
ES41	2310.58	277.27	138.6	16.64	4.2	0.50
ES42	1819.99	218.40	109.2	13.10	3.3	0.40
HU31	462.67	55.52	27.8	3.33	0.8	0.10
ITG2	607.94	72.95	36.5	4.38	1.1	0.13
PL21	315.06	37.81	18.9	2.27	0.6	0.07
PL22	284.02	34.08	17.0	2.04	0.5	0.06

* Note: Results for power capacity assume that all thermal capacity is transformed to power.

Table continued. Estimated potential for geothermal energy (maximum, realistic and sustainable) in the coal regions.

Region NUTS 2	Geothermal					
	Maximum technical		Realistic technical		Sustainable technical	
	Thermal Capacity (GWth)	Power Capacity (GW)*	Thermal Capacity (GWth)*	Power Capacity (GW)*	Thermal Capacity (GWth)*	Power Capacity (GW)*
PL41	691.74	83.01	41.5	4.98	1.3	0.15
PL51	430.47	51.66	25.8	3.10	0.8	0.09
PL71	398.54	47.83	23.9	2.87	0.7	0.09
PL81	487.55	58.51	29.3	3.51	0.9	0.11
RO41	651.88	78.23	39.1	4.69	1.2	0.14
RO42	790.14	94.82	47.4	5.69	1.4	0.17
SI03	413.97	49.68	24.8	2.98	0.8	0.09
SK02	205.19	24.62	12.3	1.48	0.4	0.04
UKC2	118.35	14.20	7.1	0.85	0.2	0.03
UKE2	140.15	16.82	8.4	1.01	0.3	0.03
UKE3	30.02	3.60	1.8	0.22	0.1	0.01
UKE4	35.48	4.26	2.1	0.26	0.1	0.01
UKF1	90.56	10.87	5.4	0.65	0.2	0.02
UKG2	102.80	12.34	6.2	0.74	0.2	0.02
UKL1	200.61	24.07	12.0	1.44	0.4	0.04
UKL2	124.47	14.94	7.5	0.90	0.2	0.03
UKM7	204.57	24.55	12.3	1.47	0.4	0.04
UKM8	34.12	4.09	2.0	0.25	0.1	0.01
UKM9	275.30	33.04	16.5	1.98	0.5	0.06

* Note: Results for power capacity assume that all thermal capacity is transformed to power.

Table 22. Estimated potential for carbon capture and carbon capture with BAT implementation in the coal regions.

NUTS 2	CCR		CCR BAT	
	GW	GWh/year	GW	GWh/year
BG34	3.96	29,456	2.84	21,117
BG41	0.00	0	0.00	0
CZ04	1.01	7,535	1.01	7,535
CZ08	0.00	0	0.00	0
DE40	0.94	7,029	0.00	0
DEA1	2.67	19,851	2.67	19,851
DEA2	0.91	6,754	0.91	6,754
DEA3	0.00	0	0.00	0
DEC0	0.00	0	0.00	0
DED2	1.59	11,839	1.59	11,839
DED5	1.28	9,494	1.28	9,494
DEE0	0.60	4,445	0.00	0
EL53	0.80	5,979	0.34	2,547
EL65	0.00	0	0.00	0
ES12	0.00	0	0.00	0
ES21	0.00	0	0.00	0
ES24	0.00	0	0.00	0
ES41	0.00	0	0.00	0
ES42	0.10	745	0.10	745
HU31	0.00	0	0.00	0
ITG2	0.34	2,532	0.34	2,532
PL21	0.29	2,144	0.00	0
PL22	2.07	15,376	0.24	1,750
PL41	0.24	1,750	0.24	1,750
PL51	0.51	3,760	0.00	0
PL71	0.34	2,494	0.34	2,494
PL81	0.00	0	0.00	0
RO41	0.00	0	0.00	0
RO42	0.11	819	0.00	0
SI03	0.11	789	0.00	0
SK02	0.00	0	0.00	0
UKC2	0.00	0	0.00	0
UKE2	0.00	0	0.00	0
UKE3	0.00	0	0.00	0
UKE4	0.00	0	0.00	0
UKF1	0.00	0	0.00	0
UKG2	0.00	0	0.00	0
UKL1	0.00	0	0.00	0
UKL2	0.00	0	0.00	0
UKM7	0.00	0	0.00	0
UKM8	0.00	0	0.00	0
UKM9	0.00	0	0.00	0

4. Technical capacity and potential in coal mines (NUTS 2)

Table 23. Estimated coal mine reclamation potential for wind and solar energy in the coal regions.

NUTS-2 region	Number of operating open-pit coal mines	Total potential (GWh/y)	Wind potential (GWh/y)	Solar Potential (GWh/y)	Wind generation share (%)	Solar generation share (%)	Total capacity (MW)	Wind Capacity (MW)	Solar Capacity (MW)	Wind capacity share (%)	Solar capacity share (%)
BG34	1	404.6	136.4	268.3	34	66	321.8	115.3	206.6	36	64
BG41	7	160.8	46.5	114.2	29	71	139	51.4	87.6	37	63
CZ04	5	543.1	215.5	327.6	40	60	513.8	182	331.8	35	65
DE40	2	288.7	136.8	151.8	47	53	248.3	86	162.3	35	65
DEA1	1	100.3	50.2	50.1	50	50	79.9	27.2	52.7	34	66
DEA2	2	198.3	89.6	108.8	45	55	169.4	57.3	112.1	34	66
DED2	2	123	54.4	68.6	44	56	110.5	38.8	71.7	35	65
DED5	1	40.6	18	22.5	44	56	34.8	11.3	23.5	32	68
DEE0	2	100.4	46.2	54.2	46	54	87.4	29.7	57.7	34	66
EL53	8	1,078.70	245.2	833.4	23	77	983.2	357.1	626.1	36	64
EL65	1	74.9	21.7	53.3	29	71	55.6	19.6	36	35	65
ES12	2	10.8	4.5	6.3	41	59	9.6	3.5	6.1	37	63
ES21	1	2.6	0.7	1.9	27	73	2.4	0.7	1.7	28	72
ES24	2	58.6	21.5	37.1	37	63	39.7	14.7	25	37	63
ES41	5	90.4	24	66.5	27	73	66.7	21.9	44.7	33	67
ES42	1	48.8	11.8	37	24	76	33.8	10.8	23.1	32	68
HU31	2	91.6	23.7	68	26	74	84	29.3	54.7	35	65

Table continued. Estimated coal mine reclamation potential for wind and solar energy in the coal regions.

PL41	8	565.5	293.5	271.9	52	48	435.2	153.3	281.9	35	65
PL51	1	125.7	53.3	72.5	42	58	100.8	28.2	72.6	28	72
PL71	1	201.8	97.4	104.4	48	52	158	54.2	103.7	34	66
RO41	1	260.5	78.5	182	30	70	214.8	69	145.8	32	68
UKC2	2	17.2	12.1	5.1	70	30	10.9	3.6	7.3	33	67
UKF1	1	4.3	3.2	1.2	73	27	2.7	1	1.7	38	62
UKG2	1	1.7	1	0.7	58	42	1.3	0.4	0.9	30	70
UKL1	3	38.9	24.5	14.4	63	37	26.3	7.8	18.6	29	71
UKL2	1	9.4	5.8	3.6	62	38	6.7	2	4.7	30	70
UKM7	2	12.5	8	4.6	64	36	8.3	2.7	5.6	33	67
UKM8	9	178	116.8	61.2	66	34	125.6	37.6	88	30	70

5. Methodology for defining the technical potential

The definition of the technology potential is based in the principle shown below similarly to what has been proposed by the US National Renewable Energy Laboratory (NREL) (Brown *et al.*, 2016) and customised to the specific technologies. The following sections indicate the exact aspects of the followed approach for each technology.

The renewable energy potentials have been estimated using an approach that can be described by the generic form:

$$Technical\ potential\ \left[\frac{MWh}{y}\right] = Area\ Available\ [km^2] \times System\ Yield\ \left[\frac{MW}{km^2}\right] \times Capacity\ Factor\ \left[\frac{h}{y}\right]$$

or also

$$= Area\ Available\ [km^2] \times System\ Yield\ \left[\frac{MW}{km^2}\right] \times Capacity\ Factor\ \ [\%]\ \times 8760$$

and also

$$= Resource\ or\ theoretical\ potential\ \left[\frac{MWh}{y}\right] \times \text{Technology efficiency}\ \left[\frac{MWh}{MWh}\right] \times \frac{\text{Area Available}[km^2]}{\text{Total Area}\ [km^2]}$$

We consider the capacity factor to reflect the regional differences in resource, even if this results in more conservative estimation of capacity.

Wind

The technical potential for wind power at NUTS 2 level in the coal regions in transition has been based on (Dalla Longa *et al.*, 2018) with associated data from ENergy Systems Potential Renewable Energy Sources (ENSPRESO) dataset (Joint Research Centre, 2019). For estimating this potential, it is important to firstly consider several categories that require different assumptions and methodological approaches as follows:

- The theoretical or resource potential which is the available amount of wind resource that can produce energy and depends on the estimation of wind speeds and directions reaching the area.
- The geographical potential which is determined by the suitable and usable areas for wind deployment depending on an appropriate set of exclusion criteria (e.g. sloped areas, minimum setback distances of wind farm installations to settlements, distances to the grid, water bodies, and natural protected areas, etc.).
- Definition of the specific technology for wind array installation in each unit of available area, i.e. the (array power density).

Therefore, the wind technical potential capacity as well as the assumptions considered are as follows:

- Onshore wind potentials are shown at NUTS 2 level while offshore wind potentials are given at country level.[53]
- **Technological characteristics**: the areas selected are dominated by wind conditions higher than 20% of the theoretical potential, for a wind turbine with 300 W/m^2 of specific power at 100 m of hub height.

[53] The data presented refer to a reference scenario with capacity factors > 20%. For more information on scenarios and underlying assumptions please see http://publications.jrc.ec.europa.eu/repository/handle/JRC116900

- **Legal requirements**: The assumptions met in (Dalla Longa *et al.*, 2018) and sources considered therein, follow the current (last update in 2015) legal requirements for exclusion zones and setback distances. Particularly, offshore arrays can only be installed in zones with a sea depth of 50 meters or more.

Restrictions of available area: The area classification is based on different datasets including the LUISA database[54] and World Data for Protected Areas, 2010.[55] Particularly, the areas excluded are:

→ Post-flooding or irrigated croplands (or aquatic)

→ Forests:

- Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
- Closed (>40%) broadleaved deciduous forest (>5m)
- Open (15-40%) broadleaved deciduous forest/woodland (>5m)
- Closed (>40%) needle leaved evergreen forest (>5m)
- Open (15-40%) needle leaved deciduous or evergreen forest (>5m)
- Closed to open (>15%) mixed broadleaved and needle leaved forest (>5m)

→ Transitional woodland-shrub:

- Closed to open (>15%) (Broadleaved or needle leaved, evergreen or deciduous) shrubland (<5m)
- Closed to open (>15%) broadleaved forest
- Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
- Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water

→ Urban areas:

- Artificial surfaces and associated areas (Urban areas >50%)
- Artificial surfaces, Urban fabric, Continuous and discontinuous urban fabric

→ Industrial, commercial and transport units

→ Road and rail networks and associated land, Port areas and Airports

→ Other type of land-uses: Green urban areas, sport and leisure facilities; Water bodies, permanent snow and ice, infrastructures, nature, wetlands, urban green leisure, protected areas and slopes< 2.1 degrees and minimum distances to settlements specifically from each MS.

Solar PV

Ground mounted systems

The analysis starts from the CORINE Land Cover data set ('Corine Land Cover (CLC) 2018, Version 20b2', 2018), which provides data on the type of land cover for the EU and candidate countries at a resolution of 100 m and is divided into four overall classes:

[54] https://data.jrc.ec.europa.eu/collection/luisa
[55] https://protectedplanet.net/

- Artificial surfaces (urban areas, buildings, road and rail networks, ports, airports, mineral extraction sites, sports facilities etc.);

- Agricultural areas (arable lands, rice fields, vineyards, pastures, agro-forestry areas etc.);

- Forest and semi-natural areas (scrub and/or herbaceous vegetation, bare rocks, dunes etc.);

- Glaciers, wetlands and water bodies.

Class 1 is excluded since the building rooftop area is calculated separately (see below). Other artificial surfaces or inland water bodies could also be exploited e.g. parking areas, roads, waste sites, lakes, reservoirs, and location-specific analyses are needed to systematically address these. Classes 3 and 4 are also excluded.

Only two sub-classes are considered from CLC Class 2 (agricultural areas): arable lands (CLC 211) and pastures (CLC 231). These are then subject to two further restrictions:

- Protected areas according to the Natura 2000 database are excluded (on average this accounts for 6% of arable land and 16% of pastures);

- Land forms where slopes are steeper than 20 degrees or north-facing and steeper than 5 degrees, are excluded based on the SRTM digital elevation model (SRTM, 2019). On average, the natural constraints exclude 12% of arable lands and 30% of pastures;

- 3% of the remaining land area is considered; this corresponds to the EU average for set-aside land. It is used here as a proxy for agricultural areas potentially available for non-agricultural purposes. It is also noted that PV is suitable for dual-use approaches combining electricity and agricultural production.

To estimate the PV energy productivity, the instantaneous PV power at a specific location is calculated taking into account the in-plane irradiance, spectral content of the sunlight, and the module temperature which again depends on air temperature, wind speed and irradiance. The PV system mounting configuration is assumed to be free-standing racks facing south at an inclination angle of 20 degrees (40 degrees for locations north of 60 deg. N). The area required is calculated assuming 5.5 m^2 per kWp of PV modules, i.e. 18.2 % efficiency. The distance between the module racks is calculated so the shadows of one rack will just avoid hitting the modules on the rack behind at noon at winter solstice. The PV energy yield calculation has been performed using the JRC's PVGIS methodology (PVGIS, 2019), using hourly solar radiation data for the period 2005-2016. The calculation assumes crystalline silicon modules, with balance-of-system losses of 10%. The annual energy yield per unit area of land varies from about 45 kWh/m^2 in northern regions to 160 kWh/m^2 in southern regions. A year to year variability of the order of 5% is expected.

Rooftop-Mounted Systems

Buildings offer considerable potential for deployment of PV and can allow better geographic correlation of supply and demand. A harmonized database on the EU building stock with the required level of detail is lacking. To overcome this, a multi-layer approach (Bódis *et al.*, 2019) is applied to determine the total detectable building footprint area, using the land cover dataset and the European Urban Atlas to validate information on EU built-up areas (to resolution of 10 m x 10 m and 2.5 m x 2.5 m) derived by the European Settlement Map. The results are then refined using correction factors derived from comparisons with cadastre data as well as analysis of building-by-building LIDAR digital elevation models for a limited number of benchmark locations.

The PV energy productivity is calculated for the rooftop locations following the methodology described above for ground-mounted systems. While the assumption of array spacing may be conservative for rooftop installations, it can compensate for not addressing other factors such as non-optimal orientation and shading effects.

Bioenergy

Forest biomass potentials

The energy potentials of biomass from forest (stemwood forest residues fuelwood) have been estimated using the EFISCEN model that considers the competition between the use of forest biomass for energy and material conversion (Verkerk *et al.*, 2011). The model uses data from the national forest inventory providing information on forest available for wood supply, including area, growing stock volume and net annual increment. It is assumed that both stemwood and residues available for energy can be used either as traditional fuelwood, or as forest residues for electricity and heat generation. The stemwood and residues not used for material products are then available for energy production. The fuelwood use is calculated as a regional and scenario specific percentage of the wood available for energy based on the statistical data for the fuelwood use (P. Ruiz *et al.*, 2015).

The evaluation of forest bioenergy potentials has been carried under three scenarios with different sustainability assumptions: High, Medium and Low biomass availability for energy. The High bioenergy scenario considers support measures that stimulate the use of biomass and lead to high demand for biomass and enhances the mobilisation of biomass. The Medium (reference) bioenergy scenario suggests a continuation of current trends and indicates the future development of bioenergy with stimulation and policy measures for biomass use for energy in line with currently agreed policies and targets. This implies that the use of biomass for bioenergy use is avoided if high sustainability risks are involved. In the Low bioenergy scenario biomass use for energy is not a key priority, while resource efficient use of biomass is a priority. In this case fewer stimulation measures in place for mobilisation of domestic biomass supply and sustainability criteria are strict limiting the use of biomass from forests. Competing uses for material production have higher priority than the use of biomass for energy due to stricter policy guided by overall resource efficiency (P. Ruiz *et al.*, 2015).

Biogas potential from manure

Anaerobic digestion of farm manure can provide renewable energy (electricity, heat or fuels) for local farm use or delivered to the grids (electricity, heat or natural gas), and also produce improved organic fertilisers. Biogas potential from manure has been estimated considering the manure produced from livestock farming that includes cattle (calves, bovine, male bovine, dairy cows, other cows), pigs (piglets, other pigs, sows), sheep/goats and poultry (broilers, laying hens, other poultry). The amount of manure (slurry) was calculated on the basis of actual animal populations for each livestock and poultry type and different age groups and the amount of manure produced per head each year using statistical data at regional level (EUROSTAT, 2016). The total amount of manure produced was calculated as the sum of manure produced by all animal types (Scarlat *et al.*, 2018).

The theoretical biogas potential from manure was calculated as the sum of the biogas amount produced by for each livestock and poultry type considering Total Solids (TS) content, Volatile Solids (VS) content in Total Solids, and the biogas yield for each feedstock type. The actual methane potential is less than the theoretical potential due to the lower capability of collecting manure and anaerobic conversion of the feedstock in the biogas plant and a realistic potential was estimated considering the availability of manure for being used for biogas production (Scarlat *et al.*, 2018). Detailed information about the spatial location of livestock and poultry was used to determine the amount and the spatial location of biogas feedstock using the revised and updated global maps of Gridded Livestock of the World (FAO) at a spatial resolution of 1 km (Robinson *et al.*, 2014). Geo-referenced data on the location of farms and livestock and poultry population might be available at local level through terrestrial surveys. The availability fraction of manure, which represents the amount of feedstock that could be actually collected, strongly depends on species, current farming system and disposal practices. The average livestock density per holdings across Europe was assessed at regional level and the number of animals per holding was combined in an availability indicator for manure collection (Scarlat *et al.*, 2018).

Crop residues

The potential of crop residues in the EU has been estimated using a spatially explicit approach at European level at 1 km spatial resolution, based on an improved methodology that assess theoretical, technical, environmental and sustainable potentials of crop residues. The distribution of crop areas was based on the EarthStats project, (Monfreda, Ramankutty and Foley, 2008) which provides geospatial information of harvested areas, production and yields of 175 distinct crops on a 5 minute latitude/longitude grid. The Land Use / Land Cover (LULC) data originated from the harmonised data from the Corine Land Cover (CLC) (European Environment Agency, 2017) dataset and from the Land Cover CCI project (European Spatial Agency, 2015).

The theoretical potential of crop residue represents the crop residues production and has been estimated by using the Residues-to-Product-Ratio depending on the crop yield for the most relevant crops in Europe (wheat, barley, oat, rye, maize, rapeseed, rice, and sunflower) (Scarlat, Martinov and Dallemand, 2010). The statistical data of crop production at regional and national levels has been obtained from the EU Statistical Office (EUROSTAT, 2017). Additional data was collected from national statistics for countries not covered by Eurostat. The collected data includes harvested area, crop yield and total production for the crops considered for the period between 2000 and 2015. The calculation of the technical potential was based on the harvestable biomass factors that consider the amount of crop residues that could be harvested and collected from the field, with current technologies and equipment. The estimation of the technical limitations for collection was based on a comprehensive analysis of the literature that considers the vertical distribution of biomass along the stem for the cutting height, together with biomass and harvesting losses associated with existing harvesting machinery (Scarlat *et al.*, 2019).

The environmental potential has been estimated as the amount of residues that could be collected from land without affecting soil fertility. For this purpose, the agro-ecosystem CENTURY model has been used to calculate the removal rates at 1x1 km grid which allows maintaining Soil Organic Carbon (SOC) at the level of the reference year (2015)(Lugato *et al.*, 2014). The model simulates the relation between crop residues removal and the dynamics of SOC stocks considering biomass production, soil properties (type, texture, moisture), climate data (precipitations, temperature), and the cultivation practices (tillage, crop rotation, nutrients input, etc.). Running different scenarios of straw removal an Optimal Collection Index (OCI) indicates the maximum amount of material that can be collected at a pixel level based on the SOC output. Finally, the sustainable potential provides the amount of the crop residues that could be mobilized considering both technical and environmental constraints in each location. It is defined as the minimum value obtained in each grid cell of the technical and environmental potentials previously determined. At the end, each value represents the most restrictive condition for removal of crop residues in each location.

Waste potential

The analysis of the energy potential of waste reviewed waste management practices (composting, recycling, incineration, landfilling) in European countries and provided the estimation of the amounts of waste which could be available, according to waste hierarchy (Scarlat, Fahl and Dallemand, 2018). This evaluation considered the spatial location of the waste generation, the various treatment options applied and the current waste incineration in existing waste to energy plants. Country specific data on waste generation, recycling, and incineration from statistics (EUROSTAT, 2016) has been used to identify the amounts of waste which might be potentially available for energy recovery through incineration and which are currently sent to landfills. The amount of municipal waste generation has been estimated according to waste generation per capita and spatial distribution of population density at 1 km spatial resolution. The study provided a survey of existing waste-to-energy plants that identified the capacity, type (electricity heat of Combined Heat and Power) of plants and location. The analysis revealed some important waste resources that are still not used for energy recovery in many regions and countries. A suitability analysis has been performed to identify the potential location and capacity for waste-to-energy plants based on the waste potential resources. An algorithm was developed to examine the whole map area in order to locate hot-spot areas with highest density of this resource and establish the optimal location for new potential waste to energy plants and their capacity (Scarlat, Fahl and Dallemand, 2018).

Geothermal energy

The potential for geothermal power at NUTS 2 level has been derived based on (Limberger *et al.*, 2014) who estimated the resource base for Enhanced Geothermal Systems (EGS) in Europe in the framework of the GEOELEC project (*Towards more geothermal electricity generation in Europe*, 2014) and based on (Chamorro *et al.*, 2014). (Limberger *et al.*, 2014) calculated then the heat in place depending on the temperature difference available for geothermal, the rock density and the heat capacity of rock. Based on the heat in place, we have estimated the theoretical potential for geothermal power which means the power that could be theoretically produced during the expected lifetime of a geothermal system which was assumed 30 years. This theoretical potential marks the upper limit of the theoretically realizable power output.[56] We have used the NUTS 2 dataset from Eurostat GISCO to obtain the geographical boundaries of the EU NUTS 2 regions ('Nomenclature of Territorial Units for Statistics (NUTS) 2016 - Statistical Units - Data set', 2018). We have then used ESRI ArcMap to calculate the mean value of heat in place (PJ/km^2) based on (Limberger *et al.*, 2014) according to NUTS 2 region. The theoretical potential for heat was then obtained by multiplying the heat in place with the area (in km^2). In addition, we assumed that a geothermal project will use only a 5 % share of the underground volume.[57] For the conversion of heat potential to electricity potential, a conversion factor of 0.12 according to (Limberger *et al.*, 2014) was used. Based on the theoretical potential, the technical potential can be calculated. The theoretical potential can be limited by a number of geological factors, such as heat recovery in the network of fractures, or temperature drawdown effects. According to (Limberger *et al.*, 2014), the average technical potential taking those issues into account is 12.6 % of the theoretical potential.

The maximum technical potential represents the upper limit of the geothermal potential assuming all the heat in place is extracted within 30 years. We have also calculated a more conservative technical ('realistic technical potential') potential assuming heat extraction over a period of 500 years.

Both approaches do not account for the actual replenishment of the resource. (Chamorro *et al.*, 2014) propose a methodology to calculate the sustainable potential of geothermal resources assuming that the energy extracted is equal to the heat generated in the underground. In the study of (Chamorro *et al.*, 2014), on average, the sustainable potential is about 0.5% of the technical potential. In order to calculate the sustainable geothermal potential for the CRIT regions, we have repeated the calculations above but

[56] It has to be noted that (Limberger *et al.*, 2014) have assumed a maximum depth of 7 km for EGS in 2020 and 2030 and 10 km for 2050. Furthermore, the injection temperature was assumed 80 °C in 2020 and 2030 and 50 °C in 2050.

[57] The heat in place (PJ/km^2) according to (Limberger *et al.*, 2014) is calculated for a depth of 10 km. We assumed that a geothermal project would utilise a rock layer of 500 m depth according to (Willemsen, Heller and Wees, 2011) which corresponds to 5 %.

we have set the number of years to such a value that the total potential matches the Chamorro sustainable potential.[58]

In addition, political restrictions such as land availability can play a role. For example, the exploitation of geothermal resources is not allowed in nature reserves or densely populated areas, and there might be other (legal) constraints for underground activity. (Limberger *et al.*, 2014) estimate that overall 25 % of land is restricted.

In contrast, we look more in detail at the restrictions at NUTS 2 level. For our analysis, we have used land cover data from the CORINE inventory ('Corine Land Cover (CLC) 2018, Version 20b2', 2018). The following land cover classes have been excluded (see Annex II):

- Industrial, commercial and transport units;
- Mine, dump and construction sites;
- Wetlands;
- Water bodies.

In total, the areas that were excluded account for between 0.9 % and 8.6 % of the land area in the CRiT regions. Excluded areas from wetlands can reach up to 7.8 %, followed by industry & transport (up to 5.9 %), and water bodies (up to 2.0 %).

In addition to the Corine exclusion areas, we have also excluded protected areas. Data for nature reserves are made available through the European inventory of Nationally designated areas (*Nationally designated areas (CDDA)*, 2018). The technical potential in this assessment is thus derived by excluding the respective areas for each CRiT region.

CCUS

Under article 33 of the CCS Directive, Member States have to ensure that operators of all combustion plants with a rated electrical output of 300 MW or more have assessed whether the conditions of 1) availability of suitable storage sites; 2) economic and technical feasibility of transport facilities and of 3) retrofit for CO_2 capture are met (European Parliament & Council, 2009).

The analysis conducted for this report is based on data from the JRC-PPDB68[59] and extending the methodology developed in house previously (Alves Dias et al., 2018). The results indicate existing capacity that could be "capture ready" in support of the transition to a low carbon future. As such, we present the indicative capacity (GW) of existing units in the coal regions that could be retrofitted with carbon dioxide capture technology.

Although the CCS Directive does not make a distinction on the age of the facility, we have only considered facilities of up to 20 years old even if this may be a fairly conservative assumption. In the literature, "recently" built fossil fuel-fired power plants have been considered these commissioned after 1997 (Ecofys, 2008; Graus *et al.*, 2011). This does not imply that older power plants cannot be retrofitted with carbon capture – see Boundary Dam CCS project where carbon capture was retrofitted to a renovated unit, commissioned originally in the 1970s. However, the increasingly important share of renewables, the anticipated restrictions on coal eligibility to participate in future capacity remuneration mechanisms, the post 2020 emission requirements of the Industrial Emissions Directive (2010/75/EU) (European Parliament & Council, 2010), as well as uncertainty over prevailing CO_2 prices are a few of the factors that the plant operator of a coal plant needs to consider before proceeding with any life-extension investment. Here we assume that owners/operators of power plants of the considered age band could be more likely to implement carbon capture to avoid early retirement.

[58] This corresponds to using the sustainable potential from (Chamorro *et al.*, 2014) and disaggregating it by the heat in place to NUTS 2 regions.

[59] JRC-PPDB is the comprehensive database of power plants in Europe (Kanellopoulos *et al.*, 2017).

We also consider the new standards for Europe's large coal-fired power stations published by the European Commission in 2017. Previous analysis indicated the risk of early retirement of coal fired power plants due to these new standards (Alves Dias et al., 2018) on which we further elaborate to evaluate carbon capture potential. We assume that the best available techniques (BAT) are incorporated to comply with the Industrial Emissions Directive (IED).

Other criteria to determine a "capture ready" facility and assumptions include but are not limited to:

• The facility is technically capable of being fully retrofitted for CO_2 capture and related units, and adequate space is available;

• Combustion plants with a rated electrical output of 300 MW or more are CO_2 capture ready;

• One or more choices of capture technology which are proven or whose performance can be reliably estimated as being suitable are available;

• Retrofitted capture equipment can be connected to the existing facilities effectively and without an excessive outage period;

• Pipeline or other route(s) such as shipping, to storage of CO_2 can be available;

• One or more potential storage areas which have been appropriately assessed and found likely to be suitable for safe geological storage of projected full lifetime volumes and rates of captured CO_2 are available;

• Additional water requirements have been identified and credible ways exist, in which these requirements could be overcome;

• The costs of retrofitting capture, transport and storage can be incurred;

• The public and local communities are engaged and consent;

• Consideration of health, safety and environmental issues has been taken and relevant approvals are in place, including a CO_2 monitoring plan.

Energy Efficiency in buildings

The estimation of the technical energy saving potential associated to the renovation of the regional building stocks was focused only on the residential sector, due to the lack of information about the number of non-residential buildings at regional level. Within the residential sector we have distinguished between single family houses (SFH) and multi-family houses (MFH).

In accordance with the EPBD recast, we refer to the cost-optimal and NZEB renovation levels, taking into account mainly the references provided by Member States and the ENTRANZE project,[60] about the investment costs for the renovation works and the energy consumptions before and after the refurbishment. Because these last are normally expressed in terms of primary energy, we express the final regional energy saving potentials at this energy level.

It should be noted that the energy values presented are available only at national level (or for a specific location selected as a representative of the national average). To obtain regional values we applied a climatic factor, calculated as the ratio of the regional Heating Degree Days (HDD) and the national or local ones.

Figure 73 provides the scheme of calculation, including the input data and the indicators calculated for each region.

[60] https://www.entranze.eu/

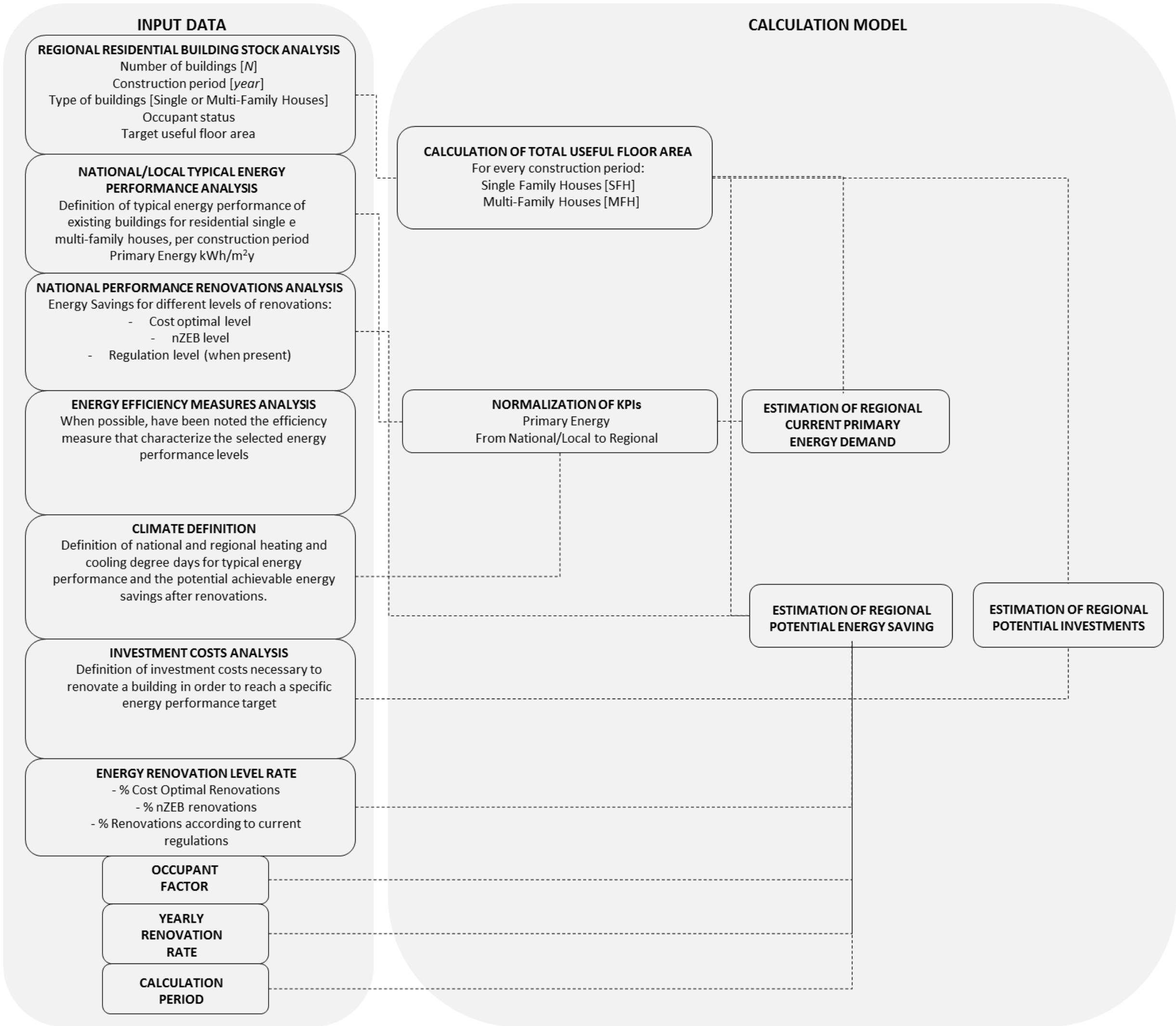


Figure 73. Calculation scheme

The Primary Energy Saving (PES) is calculated as the summation of the Primary Energy Saving for reference construction period (PES_i):

$$PES = \sum_{i=before\ 1919}^{after\ 2000} PES_i$$

Where i changes over the classes: before 1919; 1919-1960; 1961-1980; 1981-2000; after 2000, and PES_i is obtained as:

$$PES_i = \sum_{k=SFH}^{MFH} PE_{ref,k,i} \times A_{k,i} \times f_{occ} \times R \times Y \times (f_{co} \times ES_{co} + f_{nZEB} \times ES_{nZEB})$$

With:

k: building type (SFH and MFH);

$PE_{ref,k,i}$: reference primary energy demand of existing building type;

$A_{k,i}$: total useful area over all building stock, for building type, for specific construction period (m^2);

f_{occ}: occupation factor (%);

R: annual retrofit rate (%);

Y: number of years of the calculation period;

f_{co}: percentage of building retrofitted in compliance with the cost optimal level (%);

f_{nZEB}: percentage of building retrofitted in compliance with the NZEB level (%)(f_{co}+f_{nZEB} =1);

ES_{co}: cost-optimal energy saving respect to reference primary energy (%);

ES_{nZEB}: nZEB energy saving with respect to reference primary energy (%).

The total useful area $A_{k,i}$ is obtained as a function of the areas associated to different size categories (j: under 30 m^2, less than 40 m^2, less than 50 m^2, less than 60 m^2, less than 80 m^2, less than 100 m^2, less than 120 m^2, less than 150 m^2, 150 m^2 and over):

$$A_{k,i} = \sum_{j=under\ 30\ m2}^{over\ 150\ m2} N_{buildings,k,i} \times F_j \times S_j$$

Where $N_{buildings,k,i}$ is number of buildings, built in a specific construction period, for the type of building; F_j is the percentage of building within a certain size category (%) and S_j is the target useful area for every size category.

Similarly the capitals associated to the renovation works (RC) are calculated as:

$$RC = \sum_{i=before\ 1919}^{after\ 2000} RC_i$$

Where RC_i is:

$$RC_i = \sum_{k=SFH}^{MFH} A_{k,ì} \times f_{occ} \times R \times Y \times (f_{co} \times IC_{co} + f_{nZEB} \times IC_{nZEB})$$

With:

k: building type (SFH and MFH);

$A_{k,i}$: total useful area over all building stock, for the building type, for specific construction period;

f_{occ}: occupation factor;

R: total annual retrofit rate (%);

Y: number of years of the calculation period;

f_{co}: percentage of building retrofitted in compliance with the cost-optimal level (%);

f_{nZEB}: percentage of building retrofitted in compliance with the nZEB level (%);

IC_{co}: investment costs for cost-optimal renovation (€/m^2);

IC_{nZEB}: investment costs for nZEB renovation (€/m^2).

The main data sources used for this study are summarised in Table 24 (sources' links are given in the body of the report).

Table 24. Main data sources.

Input data	Source	Level
Number of dwellings per construction period Number of dwellings per type of building Useful area per type of building Status of occupation	ESTAT Census Hub	NUTS 2
Primary energy consumptions of typical building types Primary energy levels associated to cost-optimal renovations Primary energy levels associated to NZEB renovations	Cost-Optimal Reports ENTRANZE Database	National
Investment costs associated to cost-optimal renovations Investment costs associated to NZEB renovations	Cost-Optimal Reports ENTRANZE Database	National
Heating Degree Days (HDD)	Agri4Cast	Local NUTS 2 National

The key indicators characterising the regional building stocks were extracted from the Census Hub[61] of EUROSTAT, based on the 2011 Census national databases.

The energy and cost reference values were derived or assumed from the Member States' cost-optimal reports and/or the ENTRANZE Database. Referring to the Countries of the 42 regions-objects of study, on one hand the second round of cost-optimal reports (prepared in 2018) were available for Czech Republic, Greece, Hungary, Slovakia, Slovenia, Spain and the United Kingdom. On the other, ENTRANZE covered Czech Republic, Germany, Italy, Romania and Spain. Since Bulgaria and Poland remained uncovered, some assumptions were made for these countries taking into account similarities with other Member States.

About the investment costs, we applied a soft harmonisation process in order to increase the consistency of the final results among regions. To do this we used as reference the database developed in a previous study (Hermelink *et al.*, 2013).

The Heating Degree Days (HDD) used to derive the climatic factors were extracted from the JRC Agri4Cast database,[62] which provides data both at national, NUTS 2 and local level.

Note that the average primary energy consumptions pre-retrofit have been checked and in some cases adjusted, taking into account the regional energy consumption of residential derived from the indicators of the EUROSTAT database.[63]

[61] https://ec.europa.eu/eurostat/web/population-and-housing-census/census-data/2011-census
[62] http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx?o=d
[63] https://ec.europa.eu/eurostat/data/database

7. Methodology for estimating the wind and solar PV technical potential in coal mines

The optimum wind and solar PV share to maximize the technical potential in coal mines has been calculated for the 75 open-pit coal mines in operation in 2017 in the coal regions in transition considered in this study. Underground coal mines have not been considered as the area covered by this type of mines could not be identified.

An optimization model has been developed to estimate the optimum wind power and solar PV share to maximize the available technical potential in the operating open-pit coal mines in Europe. For each coal mine the model calculates the best wind and solar share based on the mine's site-specific resources, technical variables and land availability. The objective function of the model is to maximize the total RES-E technical potential (P) at hourly basis (h) on each of the coal mine (i) for a 30-year period as follows:

$$\text{Max (P)}_i = \sum_{h=1}^{30y/h} \{ X(\rho_w * CF_w * A_w) + Y(\rho_s * CF_s * A_s) \}_h$$

where the constraints of the maximization are that the wind and solar PV shares (X and Y, respectively) need to sum up to 100% in the available area used of the mine:

$X+Y \leq 1;\ 0 \leq X \leq 1;\ 0 \leq Y \leq 1.$

P represents the technical potential at mine level (GWh/y), while ρ_w and ρ_s refer to the capacity density of the wind and solar PV projects respectively. The capacity densities represent the power capacity installed per unit of available area and give the specific technical parameters for the RES-E installation (Figure 74). The wind and solar theoretical or resource potential expressed as dimensionless mean capacity factor (*CF_w and CF_s*) or hourly availability factors, represents the available amount of wind and solar resource that can produce energy. The coal mine area considered to be suitable and usable for specific RES-E deployment is represented as A_w and A_s for wind and solar PV respectively.

Area of wind and solar PV projects at coal mines

The existing wind and solar photovoltaic energy projects at closed open-pit coal mines have been analysed to estimate the share of area covered in the respective mine. Based on the Mining Atlas, 63 open-pit mining operations in Europe were identified with closure date before 2003, located mainly in Germany (54) followed by Spain (5), the United Kingdom (2), Greece and Poland (1 each) (Mining Atlas, 2019). These 63 coal mines were characterised to:

1. Identify which mines have already installed wind and solar PV projects.

2. Identify the area of the mine that is usually used by wind and solar PV projects.

To identify the closed open-pit coal mines with existing wind energy and solar PV projects and to measure the areas of these mines and projects, we used the web mapping software Google Earth Pro© (Google Inc., 2019). The installed capacity of the single wind power or solar PV plant was obtained from the (European Commission - Joint Research Centre - Unit C.7 Knowledge for the Energy Union, 2018), the installations register of the German Bundesnetzagentur and power plant information of different renewable energy developers (Bundesnetzagentur, 2018) (WEV, 2014; LMBV, 2015, 2016; Energiebauern-gmbh, 2018; Envalue, 2018; Solar-konzept GmbH, 2018b, 2018a).

The total area available in closed open-pit coal mines already hosting wind energy and solar PV energy projects is found at about 212 km^2 (8 mine sites) and 254 km^2 (13 mine sites) respectively (Table 25 and Table 26). Sixteen wind energy projects were identified in these coal mines covering between around 3 % and 17.5 % of the coal mine area with an average of about 10 %. Twenty six photovoltaic energy projects were found covering between around 0.5 % and 17 % of the coal mine area with an average of about 3.4 %.

The average values (9.8% and 3.4% of the coal mine area covered by wind energy and solar PV projects respectively) was used in the optimisation to estimate the technical potential in operating open-pit coal mines.

Table 25. Characteristics of closed open-pit mines with existing wind energy projects.

Name of former coal mine	Country	Mine area measured	Nº of wind projects at mine	Name of wind projects	Start year of operation of the wind project	Installed wind capacity	Wind array	Share of wind area at coal mine
		[km2]	[#]			[MW]	[km2/ha]	[%]
Scheibe	Germany	9.9	1	Burg/Spreetal	2004	10.0	0.54	5.5
Spreetal Nordost	Germany	9.3	1	Spreetal	2002 - 2004	22.0	1.63	17.5
Seese Ost	Germany	13.5	1	Luebbenau	2010	6.0	0.44	3.2
Greifenhain	Germany	34.6	2	Greifenhain	2009	20.0	1.70	10.7
				Woschkow	2003 - 2014	26.0	2.00	
Skado	Germany	17.0	3	Proschim	1997	2.4		
				Proschim I	2013	2.0	0.88	5.2
				Proschim II	2013	9.2		
Klettwitz	Germany	61.9	5	Klettwitz II + Klettwitz II Repowering (2014)	2006 - 2015	30.4	1.60	
				Klettwitz II Repowering (2015)	2015	62.7	3.23	12.9
				Kostebrau	2000	9.9	0.34	
				Sallgast	2004	26.0	2.12	
				Klettwitz II Southern Ext. (2017)	2017	16.5	0.69	
Seese West	Germany	28.5	1	Kittlitz	2006 - 2010	26.0	3.49	12.3
Nant y Mynydd	United Kingdom	37.6	2	Maesgwyn	2011	26.0	4.11	10.9
				Maesgwyn II (2016)	2016	2.5		
Total		**212.3**	**16**			**297.6**	**22.7**	
Min		**9.3**				**2.0**	**0.34**	**3.2**
Max		**61.9**				**62.7**	**4.11**	**17.5**
Average		**26.5**				**18.6**	**1.75**	**9.8**

Table 26. Characteristics of closed open-pit mines with existing solar PV energy projects.

Name of former coal mine	Country	Mine area measured [km2]	Nº of solar PV projects at mine [#]	Name of solar PV projects	Installed solar PV capacity [MW]	PV Array [km2]	Share of PV area at coal mine [%]	PV Array power density [MW/km2]
Vereinigte Ville	Germany	3.0	1	Unnamed/solar park at mine site	2.5[a]	0.05	1.8	46.6
Wolfersheim	Germany	n.a.[c]	1	Solarpark Wölfersheim	5.3	0.10	n.a.[c]	55.7
Trais Horloff	Germany	n.a.[c]	1	Abakus Solar Hungen PV Plant	2.9	0.06	n.a.[c]	46.2
Spreetal Nordost	Germany	9.3	1	CEE Elsterheide PV Plant	20.0	0.45	4.8	44.8
Kayna Sud	Germany	11.1	1	Unnamed/solar park at mine site	9.0*	0.19	1.8	46.2
Seese Ost	Germany	13.5	4	Solarpark Deponie Göritz	0.7	0.03	1.3	26.3
				Solarpark Göritz	3.2	0.05		59.3
				Solarpark Göritz	3.1	0.06		54.7
				Solarpark Göritz	2.1	0.03		63.1
Greifenhain	Germany	34.6	2	Unnamed/solar park at mine site	5.2[a]	0.11	0.9	46.1
				HEP Kapital Spremberg PV Project	5.3	0.18		29.0
Haselbach	Germany	10.5	2	Photovoltaik-Kraftwerk Haselbach	2.2	0.03	0.4	65.3
				Unnamed/solar park at mine site	0.4[a]	0.01		45.9
Espenhain	Germany	13.0	2	Photovoltaikanlage WEV Cröbern	1.0	0.01	1.4	76.0
				Geosol solar plant	5.0	0.16		30.6
Meuro	Germany	32.2	4	Luxcara Meuro Senftenberg PV Plant	18.0	0.71	16.7	25.2
				Saferay Meuro Seftenberg PV Plant	78.0	2.78		28.0
				GP Joule Meuro Seftenberg PV Plant	70.0	1.68		41.7
				Hochkippe	10.0	0.19		53.7
Klettwitz	Germany	61.9	4	Unnamed/solar park at mine site	2.6	0.03	0.9	86.4
				Unnamed/solar park at mine site	10.0	0.17		58.0
				Solar-Konzept GmbH - Schwarzheide	5.0	0.18		27.7
				Solar-Konzept GmbH - Schwarzheide	5.0	0.19		26.4

Table continued. Characteristics of closed open-pit mines with existing solar PV energy projects.

Name of former coal mine	Country	Mine area measured [km2]	Nº of solar PV projects at mine [#]	Name of solar PV projects	Installed solar PV capacity [MW]	PV Array [km2]	Share of PV area at coal mine [%]	PV Array power density [MW/km2]
Geiseltal	Germany	34.1	1	Solar-Konzept GmbH - Geiseltalsee	4.0	0.14		29.1
Kleinleipisch	Germany	30.7	2	Bergheider See I + II	1.4	0.03	0.4	45.8
				Finsterwalde Cluster 1-3	80.7	2.15	7.1	37.5
Total		**253.9**	**26**		**352.7**	**9.80**		
Min		**3.0**			**0.7**	**0.01**	**0.4**	25.2
Max		**61.9**			**80.7**	**2.78**	**16.7**	86.4
Average		**23.1**			**15.3**	**0.38**	**3.4**	46.0

Notes: a) Calculated values based on average array power density; b) Average array power density of all projects; c) Former mine area not visible in Google Earth given the date of the mine closure

Capacity density of wind and solar PV projects

The capacity density, i.e. the power capacity installed per unit of area, of the wind energy projects that could potentially be installed in operating open-pit coal mines has been estimated as the capacity density of the wind farms installed in the EU28 in the period 2000-2017 based on the JRC analysis. The time period 2000-2017 has been considered since the first wind farms installed in former coal mines in Europe started operating around the year 2000.

For multi-turbine projects, developers use different rules for laying out projects to achieve a balance between low installed cost and higher production. Wind turbines are usually spaced somewhere between five and nine rotor diameters apart in the prevailing wind direction, and between three and five diameters apart in the direction perpendicular to the prevailing winds (Danish Wind Industry Association, 2003) (Danish Wind Industry Association, 2003), (Windindustry, 2008). The layout of the wind farm is necessary to estimate the area covered by the wind farm. Since the layout of the wind farms installed in the EU28 in the period 2000-2017 is unknown,[64] the area covered by each wind turbine was estimated to be shaped like a rectangle where the long and short sides measure seven and four rotor diameters respectively. Under this assumption, the capacity density was computed by counting only the area directly occupied around each wind turbine. This method can be considered as a good proxy even though in practice some park arrays may deviate from this regular spacing due to specificities of the location.

Figure 74 shows the distribution of the capacity density calculated for the wind farms installed in Europe in the period 2000-2017. The mean capacity density (ρ_w) is estimated to be 10.2 MW/km^2.

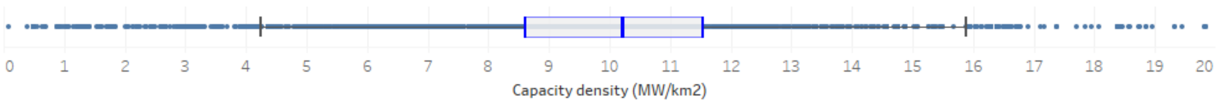


Figure 74. Capacity density of the onshore wind farms installed in the EU28 in the period 2000-2017

The capacity density of the solar PV projects that could potentially be installed in operating open-pit coal mines has been assumed as the average capacity density of the existing solar photovoltaic energy projects installed at closed open-pit coal mines. This average capacity density (ρ_s) is estimated as 46 MW/km^2 (see Table 26).

[64] No public information on the geographical coordinates of each wind turbine in each wind farm in Europe.

8. Battery-related activities in the 42 European coal regions considered

Table 27. Batteries activity by category

Raw materials

Company name	Headquarters	Material	Resources and reserves, tonnes	Manufacturing facility location		NUTS 2 region	Status
Eastern Iron Iron Mining	Australia Australia	Co ore	n.a.	Poland	Przecznica	PL51	Active, re-exploration

Functional materials

	Company name	Headquarters	Material	Annual manufacturing capacity, tonnes or m^2	Manufacturing facility location		NUTS 2 region	Status production
Cathode materials	Johnson Matthey	UK	eLNO	100,000	Poland	Konin	PL41	from 2021-2022
Anode materials	SGL Carbon	Germany	synthetic graphite, carbon, C -silicon composite	n.a.	Poland	Raciborz	PL22	operating
	SGL Carbon	Germany		n.a.	Poland	Nowy Sacz	PL21	operating
Electrolyte	Capchem Poland	China	electrolytes NMP (solvent) carbon nanotubes	40.000 5.000 5.000	Poland	Wrocław	PL51	announced
Separator	Jindal group	India	polypropylene	n.a.	Germany	Neunkirchen	DEC0	operating
	SK Innovation	South Korea	LIB separator	340 million	Poland	n.a.	PL22	from Q3 2021
			ceramic coated separator	130 million	Poland	n.a.	PL22	from Q3 2021

Cells

Company name	Headquarters	Annual manufacturing capacity, GWh	Manufacturing facility location		NUTS 2 region	Status production
LG Chem Ltd	South Korea	10 (70 by 2021-2022)	Poland	Kobierzyce	PL51	operating
Nissan	China	1.4-1.5	UK	Sunderland	UKC2	operating
MES	Czech Republic	1.2	Czech Republic	Horni Sucha	CZ08	from 2020
Farasis Energy	China	6 to 10	Germany	Bitterfeld-Wolfen	DEE0	from 2022

Packs

Company name	Headquarters	Annual manufacturing capacity, GWh	Manufacturing facility location		NUTS 2 region	Status production
LG Chem Ltd	South Korea	10 (70 by 2021-2022)	Poland	Kobierzyce	PL51	operating
Nissan	China	1.4-1.5	UK	Sunderland	UKC2	operating
Deutsche Accumotive	Germany	5	Germany	Kamenz	DED2	operating
Cummins	US	n.a.	Poland	Gliwice	PL22	operating
Foresee power	France	n.a.	Poland	Ligota Piękna	PL51	operating
Tesvolt	Germany	1	Germany	Lutherstadt Wittenberg	DEE0	from summer 2019
Farasis Energy	China	6 to 10	Germany	Bitterfeld-Wolfen	DEE0	from 2022
Daimler	Germany	n.a.	Poland	Jawor	PL51	from 2030

Recycling

Company name	Headquarters	Annual recycling capacity, GWh	Recycling facility location		NUTS 2 region	Status facility
Accurec Recycling	Germany	2500	Germany	Krefeld	DEA1	operating
Berzelius Logistik Services	Germany	n.a.	Germany	Gelsenkirchen	DEA3	operating
Indumetal recycling Recypilas	Spain	100	Spain	Asua-Erandio	ES21	operating
Recupyl Polska	Poland	n.a.	Poland	Gorzów Wielkopolski	PL43	development
Metalurgica de Medina	Spain	n.a.	Spain	Valladolid	ES41	development

9. Wind and solar value chains

Table 28. Average nominal capacity (units/year) of manufacturing facilities installed in countries with coal regions in transition.

	Bearings	Blades	Control systems	Foundation	Gearboxes	Generators	Hubs & Shafts	Nacelle Assembly	Power converters	Towers
BG	-	-	-	-	-	-	-	-	-	-
CZ	-	-	-	-	NA	-	-	120	-	-
DE	-	653	-	-	1500	NA	160	475	-	100
EL	-	-	-	-	-	-	-	-	NA	
ES	-	546	-	-	NA	690	-	550	4400	269
HU	-	-	-	-	NA	-	-	-	-	-
IT	-	NA	-	-	NA	-	-	-	-	-
PL	-	1125	-	80	-	-	-	-	-	-
RO	NA	-	-	-	-	NA	-	-	-	-
SI	-	-	-	-	-	-	-	-	-	-
SK	-	-	-	-	-	NA	-	-	-	-
UK	-	200	-	-	NA	NA	-	475	-	225

Note: NA means that country has some manufacturing facilities but no information on nominal capacity is available.

Source: JRC analysis (last update in December 2018)

Table 29. Solar PV companies and organisations in the coal regions (NUTS 2). Source data: ENF Industry Directory 2019/Q1, analysis: JRC.

Region		Prod. Equip.	Materials	Components	Panels	Sellers	Installers	Applications	Services	Total
DEA1	Düsseldorf	4	5	14	8	24	131	1	8	195
DEA2	Köln	5	3	8	3	6	125	1	9	160
UKL1	West Wales and The Valleys	2	3	4	1	2	118	5	6	141
DE40	Brandenburg		4	6	6	6	97	1	6	126
DEA3	Münster	5	1	4		4	91	1	4	110
UKE4	West Yorkshire			4	2	4	79	2	5	96
UKG2	Shropshire and Staffordshire		1	2	1	2	84	3	1	94
UKF1	Derbyshire and Notts		2	1		1	79	6	2	91
DED2	Dresden	7	2	2	3	2	67	2	5	90
DEE0	Sachsen-Anhalt	1	5	4	3	4	60		4	81
PL22	Slaskie			7	3	8	54			72
UKM7	Eastern Scotland			1			63		7	71
ES42	Castilla-La Mancha			7	1	5	54	1	2	70
UKL2	East Wales				3		60	1	3	67
ITG2	Sardegna			3		2	57		1	63
UKC2	Northumberland, Tyne and Wear		1	1	2		53		5	62
UKE3	South Yorkshire			1		3	52	3	2	61
ES41	Castilla y León		1	3	1		51		1	57
UKE2	North Yorkshire		2	1			45	1	4	53
DEC0	Saarland	1	1	2		1	46		1	52
ES24	Aragón		3	6	3	6	29	1	4	52
PL21	Malopolskie	1	1	3	2	4	38		1	50
ES21	País Vasco	2		8	3	2	29	2	1	47

Region		Prod. Equip.	Materials	Components	Panels	Sellers	Installers	Applications	Services	Total
DED5	Leipzig			3	2	3	29	1	5	43
UKM8	South Western Scotland	1		1			30	1	7	40
UKM9	North Eastern Scotland			1		1	35		2	39
BG41	Yugozapaden			2	3	8	22		3	38
SK02	Stredne Slovensko	1				2	31		1	35
PL41	Wielkopolskie		2	2		2	28			34
SI03	Vzhodna Slovnija	1		4	1	2	17	2	2	29
PL71	Lodzkie			1		2	23			26
ES12	Principado de Asturias			4	1	2	17			24
PL51	Dolnoslaskie			2		1	21			24
PL81	Lubelskie		1	1		1	20		1	24
RO42	Vest					1	21	1		23
CZ08	Moraskoslezko			1			20			21
HU31	Észak-Magyarország		1	2	1	4	11			19
CZ04	Severozápad					1	15		1	17
BG34	Yugoiztochen			1		3	5			9
EL65	Peloponnisos			1		1	5			7
EL53	Dytiki Makedonia						4			4
RO41	Sud-Vest Oltenia						4			4
Totals		31	39	118	53	120	1 920	36	104	2 421

10. Employment and investment estimations and methodology

Regional distribution

Establishing in which region the new capacity needed at national level will be installed is formulated from three main perspectives:

- *Macro to micro economic and activity models*.

  The EREBILAND project (Baranzelli *et al.*, 2016) is one example of this approach, in which regional production and consumption patterns are inferred from national results by analysing "structural characteristics of the regions, among which: population density and urbanisation trends, development of different economic sectors, availability of resources and technological infrastructure".

- *Technology diffusion theory*.

  An example of this approach can be seen in (Guidolin and Alpcan, 2019) where a diffusion model is set to study the transition to sustainable energy generation in Australia, or in (Guidolin and Guseo, 2016), where the competition and substitution between nuclear power and renewable energy technologies is modelled. (Sievers *et al.*, 2019) analyses the regional spill-over effects for renewable energy technologies. From the diffusion theory point of view, as said in (Guidolin and Alpcan, 2019), "a central role is played by learning, spread of knowledge and imitation among consumers, that are considered as the real drivers of change".

- *Investment decision making*.

  A state of the art review on multi-attribute decision making (MADM) methods applied to renewable technologies can be seen at (Ilbahar, Cebi and Kahraman, 2019). The authors find that "Analytic Hierarchy Process (AHP), one of the additive weighting methods, is the most commonly used MADM method to address renewable and sustainable energy problems." It also provides a listing of the most prominent criteria considered in the studies.

The problem of regional allocation of future capacity needs is not of deterministic nature so, the method proposed for the current approach proceeds as it follows:

1. Analyse the critical set of variables (indicators) considered influential by each field of the previously related.
2. Consider for which of those indicators coherent data sets EU-wide and coal regions-wide are available.
3. Analyse the selected data sets, their interdependencies and their redundancy
4. Propose a set of key coherent, independent and available indicators.
5. Formulate weights scenarios for those indicators, following the findings of each of the main perspectives (economic, diffusion and investment decision making)
6. Obtain the range of national capacities that each weight scenario assigns to each coal region.
7. Analyse the implications of the resulting maximum and minimum regional capacity installation.

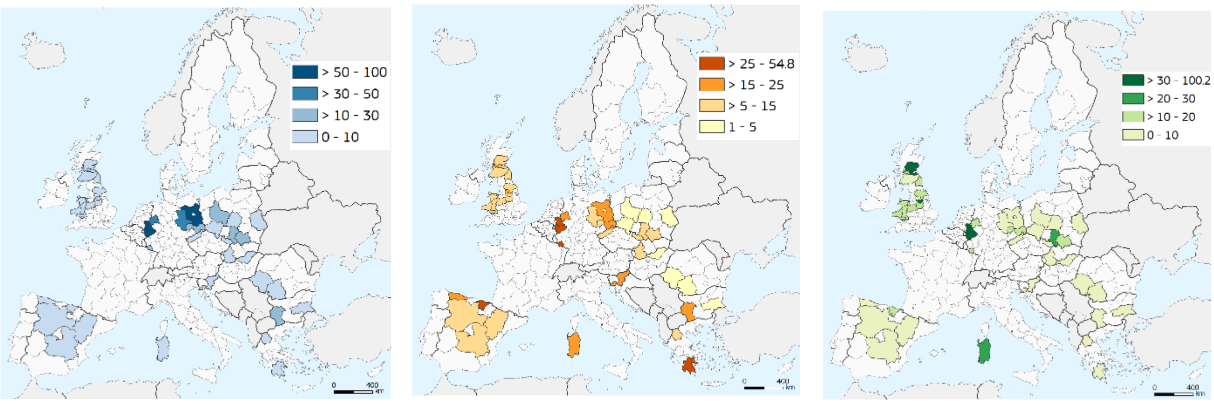
The analysis of candidate indicators has included three main groups:

- *Macro.* Regional surface, Gross Domestic Product (GDP), Gross added value and number of technology related employments.
- *Regional Competitiveness Index (RCI)*. Indicators elaborated within the European Regional Competitiveness Index initiative (Annoni, Dijkstra and Gargano, 2017). The RCI is a compound indicator obtained from other KPIs. Special detail has been considered for the (Labour market) Efficiency and Innovation sub-indexes.

Efficiency includes data on employment rate, labour productivity, disposable income per capita or potential market size. Innovation considers data on total patents applications, core creative class employment, scientific publications, total intramural R&D expenditure, High-tech patents or exports in medium-high/high tech manufacturing.

- *Capacity and potential.* Estimated regional technical potential available for each technology and currently installed capacity in the region.

The maps below indicate the share (%) of technical potential we have estimated, and what we estimated that is used within the EUCO3232.5 scenario regionally.



a) b) c)

Figure 75. Technical potential over EUCO3232.5 projected (%) for a) wind (onshore and offshore), b) solar PV and c) bioenergy

Investments

For each of the 42 coal regions in transition, we have estimated the investments that will be needed to deploy the technology capacity projected by EUCO3232.5 and distributed regionally with the methodology developed in this study. For the technology costs we use (DeVita et al., 2018) which is the underlying data of EUCO3232.5 scenario.

To estimate the Capital Expenditure (CAPEX) needed to deploy the capacity projected by EUCO3232.5 and distributed in the coal regions we use the formula below:

$$\begin{aligned} &\mathit{CAPEX\ Investments}\ [\mathit{EUR\ million}] \\ &\quad = \mathit{Projected\ newly\ installed\ capacity}\ [\mathit{MWe}] \\ &\quad \times\ \mathit{Overnight\ Investment\ Cost}\ \left[\frac{\mathit{EUR\ million}}{\mathit{MWe}}\right] \end{aligned}$$

To derive the "job efficiency", i.e. the investments needed over total jobs created, we use the following formula:

$$\begin{aligned} &\mathit{Investments}\ [\mathit{EUR\ million}] = \Big\{\mathit{Projected\ newly\ installed\ capacity}\ [\mathit{MWe}] \times \\ &\mathit{Overnight\ Investment\ Cost}\ \left[\frac{\mathit{EUR\ million}}{\mathit{MWe}}\right]\Big\} + \Big\{\mathit{Projected\ accumulated\ capacity}\ [\mathit{MWe}] \times \\ &\mathit{Fixed\ Operation\ and\ Maintenance\ Cost}\ \left[\frac{\mathit{EUR\ million}}{\mathit{MWe}}\right]\Big\} + \Big\{\mathit{Projected\ accumulated\ capacity}\ [\mathit{MWe}] \times \\ &\mathit{CF} \times 8\,760\ \left[\frac{\mathit{hours}}{\mathit{year}}\right] \times \mathit{Variable\ Non\ Fuel\ Cost}\ \left[\frac{\mathit{EUR}}{\mathit{MWh}}\right]\Big\} \end{aligned}$$

We use this formula taking into account operational costs too, as total jobs refer also to operation and maintenance and not only construction.

For bioenergy we estimate investments for electricity production capacity starting from EUCO3232.5 projections. As these refer to both heat and power, we derive the share of electricity using an electrical efficiency of ~ 30% and adopting the cost values as indicated in (De Vita et al., 2018). Investments refer to expenditure for bioenergy facilities and not for the production of biomass. For geothermal energy, the investment estimation uses capacities derived using an estimated NUTS 2 regions' share in the country. These shares do not take into account further land restrictions (e.g. protected areas).

Table 30. 2030 estimated range of employment induced by activity in the region and capital expenditure (CAPEX) by technology.

		Wind		Solar		Bio		Geo	
		Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)
BG34	**MAX**	1 409	468.06	309	21.40	932	39	0	0
	MIN	569	188.95	248	13.94	140	6	0	0
BG41	**MAX**	1 511	501.83	705	43.58	1 578	66	0	0
	MIN	567	188.34	235	22.23	526	22	0	0
CZ04	**MAX**	828	795.40	272	62.95	1 305	88	0	0
	MIN	185	177.95	192	24.14	261	21	0	0
CZ08	**MAX**	154	235.83	232	12.95	322	77	0	0
	MIN	246	148.25	167	9.22	1 137	25	0	0
DE40	**MAX**	3 329	2 998.13	2 843	11.04	5 744	724	0	0
	MIN	7 513	1 377.82	1 535	7.37	11 531	375	0	0
DEA1	**MAX**	3 243	1 381.25	2 194	144.37	3002	221	0	0
	MIN	6 850	612.09	1 131	77.93	7 225	196	0	0
DEA2	**MAX**	3 107	1 259.49	1 956	111.43	3781	454	0	0
	MIN	7 535	596.22	820	53.81	20 486	247	0	0
DEA3	**MAX**	1 440	1 385.43	1 012	99.32	919	1 287	0	0
	MIN	498	571.15	838	44.62	3 510	60	0	0
DEC0	**MAX**	16 307	264.74	421	55.92	386	73	0	0
	MIN	7 494	91.58	290	38.19	1 158	25	0	0
DED2	**MAX**	2 128	567.07	889	45.16	497	186	0	0
	MIN	3 084	391.18	662	33.42	2 958	32	0	0
DED5	**MAX**	1 079	367.71	431	26.01	338	97	0	0
	MIN	2 000	198.38	292	14.71	1 550	22	0	0
DEE0	**MAX**	5 924	2 643.01	1 763	109.06	652	451	0	0
	MIN	14 375	1 089.25	720	36.55	7 178	43	0	0

Table continued. 2030 estimated range of employment induced by activity in the region and capital expenditure (CAPEX) by technology.

NUTS2		Wind Employment	CAPEX investments (EUR mil)	Solar Employment	CAPEX investments (EUR mil)	Bio Employment	CAPEX investments (EUR mil)	Geo Employment	Wind CAPEX investments (EUR mil)
EL53	**MAX**	151	98.81	279	39.14	28	33	0	0
	MIN	208	71.51	148	14.50	332	3	0	0
EL65	**MAX**	582	522.62	432	42.34	47	31	0	0
	MIN	1 100	276.61	132	17.95	313	5	0	0
ES12	**MAX**	754	173.62	308	26.61	134	47	0	0
	MIN	1 104	118.62	153	15.72	480	14	0	0
ES21	**MAX**	2 986	469.74	827	71.41	700	139	0	0
	MIN	1 013	159.32	299	28.00	1 432	71	0	0
ES24	**MAX**	9 673	1 521.45	1438	124.13	1 040	229	0	0
	MIN	577	90.72	840	72.53	2350	105	0	0
ES41	**MAX**	17 182	2 702.65	2657	359.93	1 540	526	0	0
	MIN	3 282	516.25	1419	122.46	5 404	156	0	0
ES42	**MAX**	11 108	1 747.19	2545	310.26	1 566	290	0	0
	MIN	758	119.16	1242	107.19	2 981	159	0	0
HU31	**MAX**	153	20.61	153	9.66	411	39	0	0
	MIN	17	2.32	102	6.39	766	21	0	0
ITG2	**MAX**	4 641	1 983.61	1483	118.99	199	243	0	0
	MIN	1 169	499.54	755	60.54	2 609	19	0	0
PL21	**MAX**	862	536.30	348	10.67	693	134	0	0
	MIN	382	237.82	210	6.72	2 078	45	0	0
PL22	**MAX**	1 298	807.80	504	15.48	1 993	268	0	0
	MIN	457	284.38	258	7.82	4 157	130	0	0
PL41	**MAX**	1 405	1 049.84	499	15.65	2 294	235	0	0
	MIN	1 687	874.35	410	11.69	3 647	150	0	0

Table continued. 2030 estimated range of employment induced by activity in the region and capital expenditure (CAPEX) by technology.

NUTS2		Wind		Solar		Bio		Geo	Wind
		Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)
PL51	**MAX**	722	634.83	395	12.12	753	172	0	0
	MIN	1 020	449.40	266	8.52	2 664	49	0	0
PL71	**MAX**	764	515.49	307	10.00	543	186	0	0
	MIN	828	475.20	262	7.28	2 883	35	0	0
PL81	**MAX**	1 424	885.97	382	11.96	347	179	0	0
	MIN	465	289.50	254	7.79	2 767	23	0	0
RO41	**MAX**	170	281.23	157	11.45	205	55	0	0
	MIN	436	109.52	42	4.97	1 193	10	0	0
RO42	**MAX**	251	301.36	158	17.59	260	74	0	0
	MIN	467	161.95	122	8.29	1 603	12	0	0
SI03	**MAX**	244	145.85	1992	100.65	236	60	0	0
	MIN	45	26.78	699	84.10	1 251	11	0	0
SK02	**MAX**	212	0.00	183	5.49	594	64	0	0
	MIN	365	0.00	75	3.61	2 362	17	0	0
UKC2	**MAX**	952	683.74	254	11.69	189	145	0	0
	MIN	1 614	403.45	183	8.53	1 369	21	0	0
UKE2	**MAX**	945	400.17	342	18.03	960	226	0	0
	MIN	182	77.05	191	8.80	2 136	106	0	0
UKE3	**MAX**	174	199.18	136	6.27	424	338	0	0
	MIN	470	73.70	79	3.96	3 200	47	0	0
UKE4	**MAX**	857	363.02	256	11.81	502	763	0	0
	MIN	286	121.19	153	6.21	7 213	55	0	0
UKF1	**MAX**	360	313.58	277	16.73	282	130	0	0
	MIN	740	152.55	264	9.90	1 233	31	0	0

Table continued. 2030 estimated range of employment induced by activity in the region and capital expenditure (CAPEX) by technology.

NUTS 2		Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)	Employment	CAPEX investments (EUR mil)
UKG2	**MAX**	480	290.91	327	21.11	195	110	0	0
	MIN	687	203.21	228	10.49	1 036	22	0	0
UKL1	**MAX**	3 348	1 418.61	570	27.67	945	172	0	0
	MIN	749	317.12	325	14.97	1 626	104	0	0
UKL2	**MAX**	2 094	887.08	343	15.82	165	85	0	0
	MIN	291	123.41	92	5.41	808	18	0	0
UKM7	**MAX**	1 135	1102.90	262	12.10	3 329	926	0	0
	MIN	2 603	480.99	119	6.38	8 752	366	0	0
UKM8	**MAX**	573	543.26	175	8.07	223	71	0	0
	MIN	1 282	242.70	87	3.79	669	25	0	0
UKM9	**MAX**	4 847	2 053.73	253	16.95	484	255	0	0
	MIN	1 177	498.62	71	3.29	2 413	255	0	0

Ratio of investments per job

This section introduces the ratio of the required investment per job. It is obtained for each region and by clean energy production technology. Figure 76 presents total values, which represent the total investment needs to deploy the EUCO3232.5 projected capacity over the total jobs we estimate, i.e. the sums of estimations for all the technologies considered. The dedicated factsheets in Annex 2 indicate the corresponding break down for the regions.

This ratio (EUR millions/job) informs on the employment impact of the investments in each region, however some associate considerations include:

- A higher ratio can be perceived to indicate a less attractive choice, while it can be the result of a more developed and thus, a lesser labour-intensive technology, and vice versa.
- The EUCO3232.5 scenario provides the optimal energy system evolution that achieves the policy targets, taking into consideration the expected cost trajectories for each technology. As such, technology investment should not be prioritised driven only by their corresponding ratios within this context.
- Supporting policies for the regions should take into consideration all the involved factors: social urgency, technology contribution to climate targets, its competitiveness and the corresponding resource potential availability. Such factors are jointly analysed in the section discussing the Regional transition employment foresight.

As an example, Saarland, DEC0, shows the lowest average investment per job to be created. In this case, this numerical result is achieved due to a restricted job creation potential available, rather than to the existence of structurally efficient conditions. On the other extreme, the region with highest investment needs per job is Munster (DA3), driven the region’s wind potential. However, disregarding further investing in the region could lead, for example, hampering manufacturing potential.

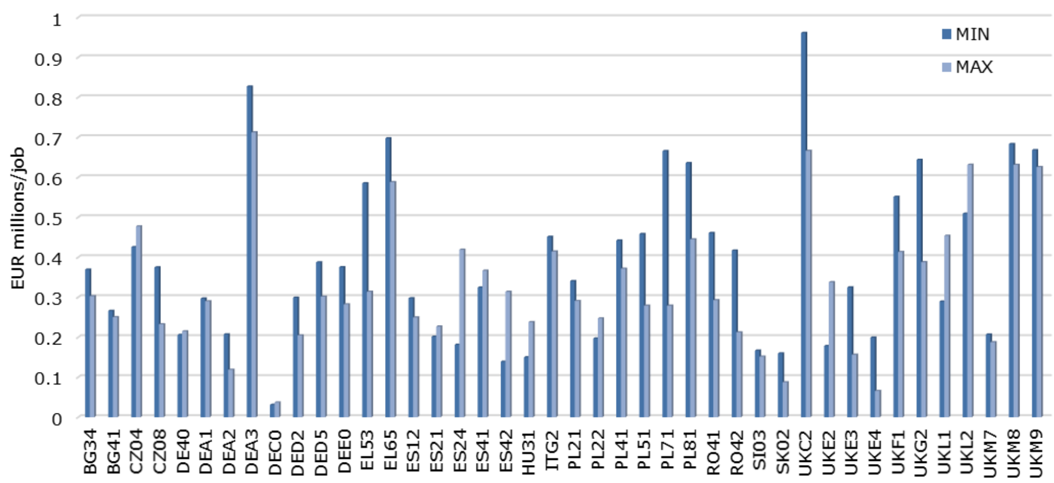


Figure 76. Ratio of investments over plausible jobs created (EUR million/job) for the coal regions.

Table 31. 2030 total employment induced by activity in the regions and ratio of investments (CAPEX+OPEX) per job induced.

NUTS 2		Total induced employment (FTE)	EUR mil/job
BG34	MAX	2 650	0.32
	MIN	956	0.37
BG41	MAX	3 794	0.25
	MIN	1 328	0.27
CZ04	MAX	2 405	0.48
	MIN	638	0.43
CZ08	MAX	1 614	0.23
	MIN	643	0.37
DE40	MAX	30 681	0.21
	MIN	14 772	0.21
DEA1	MAX	16 932	0.29
	MIN	7462	0.29
DEA2	MAX	29 293	0.12
	MIN	7 844	0.21
DEA3	MAX	5 962	0.72
	MIN	2 255	0.80
DEC0	MAX	17 886	0.04
	MIN	8 170	0.03
DED2	MAX	6 932	0.20
	MIN	3 286	0.30
DED5	MAX	3 981	0.31
	MIN	1 710	0.39
DEE0	MAX	23 316	0.29
	MIN	7 297	0.38
EL53	MAX	819	0.36
	MIN	326	0.59
EL65	MAX	1 846	0.59
	MIN	762	0.74
ES12	MAX	1 892	0.25
	MIN	1 041	0.31
ES21	MAX	5 245	0.23
	MIN	2 011	0.20
ES24	MAX	13 461	0.42
	MIN	2 457	0.18
ES41	MAX	25 243	0.39
	MIN	6 241	0.32
ES42	MAX	16 634	0.33
	MIN	3 566	0.14
HU31	MAX	1 072	0.24
	MIN	529	0.15
ITG2	MAX	8 733	0.41
	MIN	2 122	0.45

Table 32. 2030 total employment induced by activity in the regions and ratio of investments (CAPEX+OPEX) per job induced.

NUTS 2		Total induced employment (FTE)	EUR mil/job
PL21	MAX	3 287	0.29
	MIN	1 284	0.34
PL22	MAX	5 959	0.25
	MIN	2 708	0.20
PL41	MAX	5 833	0.37
	MIN	4 108	0.44
PL51	MAX	4 079	0.28
	MIN	1 741	0.46
PL71	MAX	4 018	0.28
	MIN	1 568	0.66
PL81	MAX	4 573	0.45
	MIN	1 066	0.64
RO41	MAX	1 786	0.29
	MIN	417	0.49
RO42	MAX	2 228	0.22
	MIN	633	0.41
SI03	MAX	3 487	0.10
	MIN	979	0.17
SK02	MAX	2 910	0.09
	MIN	882	0.17
UKC2	MAX	3 236	0.67
	MIN	1 324	0.96
UKE2	MAX	3 423	0.34
	MIN	1 333	0.18
UKE3	MAX	3 806	0.16
	MIN	677	0.33
UKE4	MAX	8 326	0.07
	MIN	941	0.20
UKF1	MAX	2249	0.43
	MIN	907	0.52
UKG2	MAX	2 049	0.41
	MIN	902	0.64
UKL1	MAX	5 544	0.46
	MIN	1 786	0.33
UKL2	MAX	3 227	0.63
	MIN	799	0.37
UKM7	MAX	11 617	0.19
	MIN	4 584	0.21
UKM8	MAX	2 126	0.63
	MIN	883	0.68
UKM9	MAX	7 512	0.64
	MIN	1 733	0.67

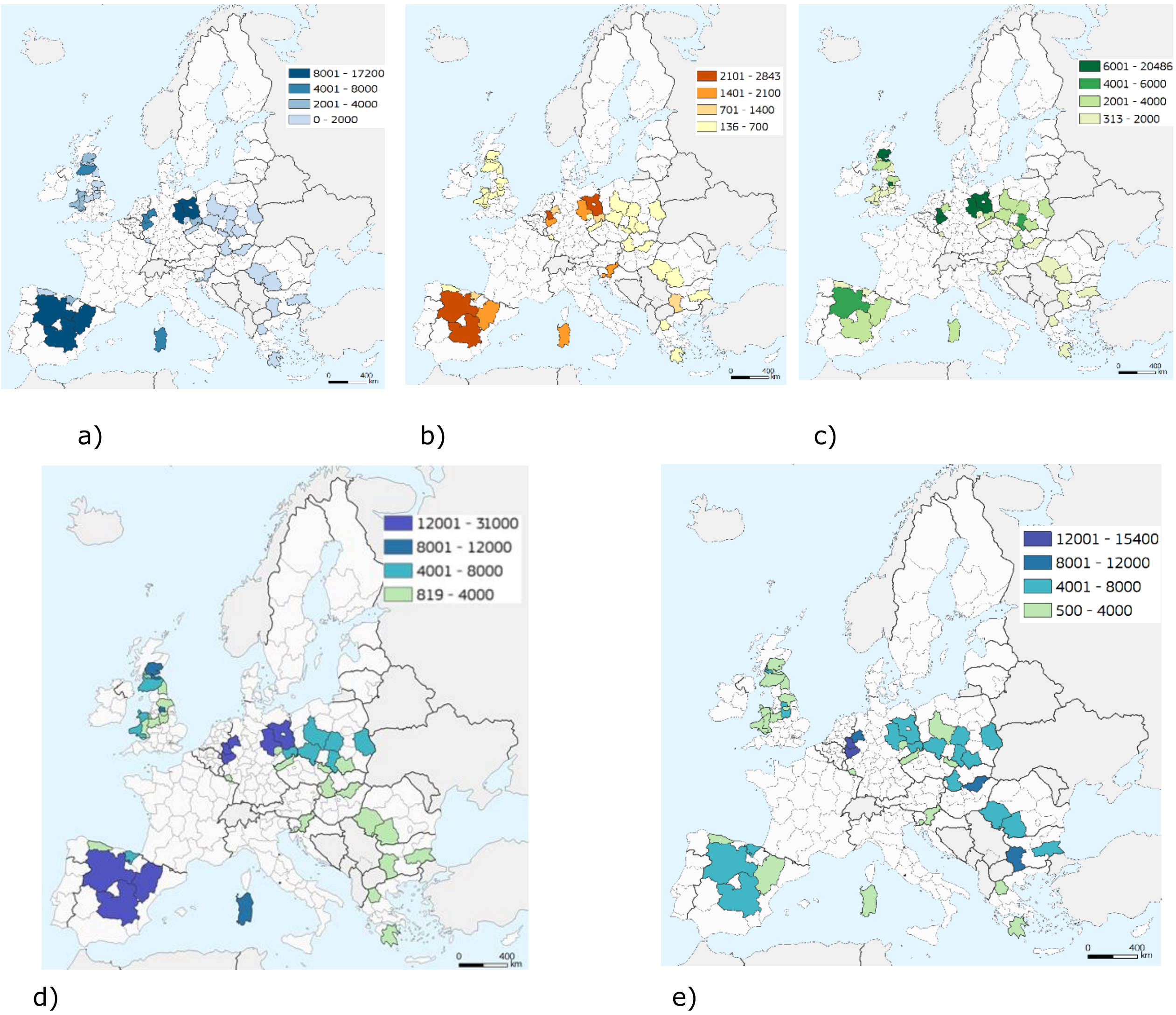


Figure 77. 2030 jobs induced (FTE) by a) wind (onshore and offshore), b) solar PV and c) bioenergy, their d) sum according to projections from EUCO3232.5 for technology deployment and e) from energy efficiency in buildings in the equipment and construction sectors, under the BAU scenario.

Coal mines lifetime investments

The lifetime investment needed to develop the technical potential estimated is based on the investment costs of the projects and operation and maintenance costs during their lifetime. CAPEX and OPEX assumptions are based on (Tsiropoulos, Tarvydas and Zucker, 2018b) as they are comparable to the data within EUCO3232.5 scenario for onshore wind and solar PV in 2020. Lifetime investments are derived using the formula below:

$$Lifetime\ investment\ (Million\ EUR) = CAPEX\left({}^{Million\ EUR}/_{MW}\right) * Technical\ capacity(MW) + OPEX\left({}^{Million\ EUR}/_{\frac{MW}{year}}\right) * Technical\ capacity(MW) * Lifetime(years)$$

Table 33. Estimation of lifetime investments requirements in wind and solar PV projects in operating open-pit mines in coal regions in transition.

		Wind energy projects (2020 data)		Solar PV projects (2020 data)	
NUTS 2 region	No of coal mines	(Million EUR)	(Million EUR/MW)	(Million EUR)	(Million EUR/MW)
BG34	1	264.3	2.3	171.5	0.83
BG41	7	136.1	2.6	73.1	0.83
CZ04	5	417.3	2.3	275.6	0.83
DEA2	2	131.3	2.3	93.1	0.83
DEA1	1	62.4	2.3	43.8	0.83
DE40	2	197.2	2.3	134.8	0.83
DED2	2	88.9	2.3	59.6	0.83
DEE0	2	68.1	2.3	48.0	0.83
DED5	1	25.9	2.3	19.5	0.83
EL53	8	946.3	2.6	520.1	0.83
EL65	1	44.9	2.3	29.9	0.83
HU31	2	77.7	2.6	45.5	0.83
PL71	1	124.3	2.3	86.1	0.83
PL51	1	56.0	2.0	60.3	0.83
PL41	8	304.0	2.0	234.3	0.83
RO41	1	158.2	2.3	121.1	0.83
ES24	2	33.7	2.3	20.9	0.84
ES12	2	8.1	2.3	5.2	0.85
ES41	5	50.3	2.3	37.4	0.84
ES42	1	24.7	2.3	19.2	0.83
ES21	1	1.5	2.3	1.5	0.86
UKF1	1	2.1	2.0	1.4	0.85
UKM8	9	74.6	2.0	73.4	0.83
UKM7	2	5.4	2.0	4.7	0.84
UKG2	1	0.8	2.0	0.8	0.87
UKC2	2	7.1	2.0	6.2	0.84
UKL2	1	4.0	2.0	3.9	0.84
UKL1	3	15.4	2.0	15.5	0.84
Total	75	3 330.1		2 206.5	

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