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Unlocking local value-added opportunities in the energy transition in former coal regions—the case of Lusatia (Lausitz)

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Abstract The main result of this study is that Lusatia, as an energy transition and structural change region, still has high expansion potential for photovoltaic and wind energy systems. In 2040, electricity production from wind turbines could reach four times the current level. In the case of photovoltaic systems, around seven to eight times the current level is possible. Only in the area of biomass has the expansion potential already been largely exhausted. The building sector can also contribute to achieving climate neutrality. If the renovation rate is significantly increased to 3.3% per year by 2040, the required heating energy can be reduced by around 60%.

At the same time, these energy transition scenarios are evaluated with regard to their regional economic opportunities for Lusatia. In an ambitious climate neutrality scenario, around 450 million euros in regional added value can be generated in 2040 and around 3560 full-time jobs can be filled. In order for this to succeed, however, the citizens and municipalities must first be given more opportunities for financial participation through appropriate framework conditions at federal and state level. We see financial benefits for the population and the municipalities as a critical success factor in order to be able to provide the necessary space, initiate investments and ultimately contribute to local acceptance.

Keywords Renewable energies · Energy transition · Climate neutrality · Regional economic analysis · Financial participation

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Mobilisierung endogener Energiewendepotenziale in ehemaligen Braunkohleregionen am Beispiel der Lausitz

Zusammenfassung Das zentrale Ergebnis dieser Studie ist, dass die Lausitz als Energiewende- und Strukturwandelregion noch hohe Ausbaupotenziale für Photovoltaik- und Windenergie- anlagen aufweist. So kann die Stromproduktion aus Windenergieanlagen im Jahr 2040 das Vierfache des heutigen Niveaus erreichen. Bei den Photovoltaikanlagen ist etwa das Sieben- bis Achtfache des heutigen Standes möglich. Lediglich im Bereich der Biomasse sind die Ausbaupotenziale heute bereits weitgehend erschöpft. Auch der Gebäudebereich kann dazu beitragen, Klimaneutralität zu erreichen. Wird die Sanierungsrate bis 2040 deutlich auf 3,3 Mio. pro Jahr gesteigert, kann der Heizwärmebedarf um ca. 60 % abgesenkt werden.

Diese erarbeiteten Energiewendeszenarien werden zugleich hinsichtlich ihrer regionalwirtschaftlichen Chancen für die Lausitz bewertet. So können in einem ambitionierten Klimaneutralitätsszenario im Jahr 2040 ca. 450 Mio. € regionaler Wertschöpfung generiert und ca. 3560 Vollzeitarbeitsplätze besetzt werden. Damit dies gelingt, müssen den Bürger*innen und Kommunen jedoch erst durch entsprechende Rahmenbedingungen auf Bundes- und Landesebene die Möglichkeiten geschaffen werden, sich stärker finanziell zu beteiligen. Den finanziellen Einbezug der Bevölkerung und der Kommunen sehen wir als kritischen Erfolgsfaktor an, um die erforderlichen Flächen bereitstellen, Investitionen anstoßen und damit letztlich zur Akzeptanz vor Ort beitragen zu können.

Schlüsselwörter Erneuerbare Energien · Energiewende · Klimaneutralität · Regionalwirtschaftliche Analysen · Finanzielle Beteiligung

1 Introduction

The geographical area under study in this paper, the German region of Lusatia (in the following “Lusatia”), is one of the largest lignite regions in Europe and the second biggest open pit lignite mining area in Germany. The historical region is located in two federal states of eastern Germany, stretching from the south of the State of Brandenburg to the east of the State of Saxony. In Brandenburg, four counties (Dahme-Spreewald, Elbe-Elster, Oberspreewald-Lausitz, Spree-Neiße) and the independent town of Cottbus constitute the regional planning area Lausitz-Spreewald, which is responsible for the creation of a regional energy concept. The counties Bautzen and Görlitz compose the regional planning area Oberlausitz-Niederschlesien in the Saxon part of Lusatia. In this article, we analyse the energy transition potentials of this coal region and address the conditions under which the potentials and implied regional economic effects can be tapped. In doing so, we consider two possible transition pathways, with differing degrees of ambition and levels of participation for citizens, municipalities and businesses, which we believe are critical for unlocking Lusatia’s techno-economic energy transition potentials.

1.1 The energy transition and structural change in Lusatia

Lusatia is a peripheral rural area: The region's population density was 98 inhabitants per km^2 in 2019, compared to 4227 inhabitants per km^2 in the city-state of Berlin and 233 inhabitants per km^2 in Germany (Statistische Ämter des Bundes und der Länder 2021d; 2019; Amt für Statistik Berlin-Brandenburg 2020; Statistisches Landesamt des Freistaates Sachsen 2021).

Compared to other regions of Germany, Lusatia has below-average indicators for growth, employment and per-capita productivity (Hirschl et al. 2022; Berger et al. 2019). In terms of the respective gross value added figures (per person employed) of the federal states of Saxony and Brandenburg, the Saxon part of Lusatia tends to belong to the economically underdeveloped part of Saxony, while the Brandenburg part of Lusatia is slightly above Brandenburg's gross value added (Hirschl et al. 2022). The gross value added per person employed in Lusatia is far below the national average in Germany (€70,135 vs €92,310). This holds true both for Lusatia as a region and for its individual districts (ibid.).

Subsequent to the German reunification, Lusatia has been affected by a sharp decline in population: Between 1990 and 2019, the regional population decreased by 20%; the share of people under the age of 40 has decreased by one third since 2000 (Frondel et al. 2018; Statistisches Landesamt des Freistaates Sachsen 2019; Amt für Statistik Berlin-Brandenburg 2020). It is expected that this trend will continue until the year 2035 (ibid.). If not counterbalanced by structural policy changes, the decline in the working-age population (18–65) in the coming years is expected to proceed much faster than any conceivable loss of employment related to coal-fired power generation (Markwardt et al. 2022).

The German reunification also led to rapid deindustrialisation in general, and the dismantling of jobs in the energy sector in particular; it fuelled emigration and the decline of regional economies in the region. Since 1989, jobs in the fields of mining and energy generation have decreased by around 80% (Hermann, Schumacher, and Förster 2018; Nagel and Zundel 2021b). Today, coal-fired power generation corresponds to roughly five percent of value added and creates jobs for only three percent of the working population in Lusatia (Frondel et al. 2018; Berger et al. 2019). With regard to the current structure of the regional economy, Lusatia has a well-developed chemical and plastics industry and is strong in metals, food production and mechanical engineering (Berger et al. 2019; Nagel and Zundel 2021a). In certain locations, the tourism sector has also begun to utilise its economic potential (ibid.).

In terms of economic indicators, Lusatia may no longer be considered a mining and energy generation region. Only in particular sub-regions in Lusatia does the coal sector remain an important economic factor, first and foremost in the district Spree-Neiße, and to a lesser extent also in the cities of Cottbus, Spremberg and Weißwasser (Nagel and Zundel 2021b). The Lausitzer Energie AG (LEAG), operating the remaining mines and plants in Lusatia, is highly regarded for paying above-average wages and salaries to its employees (Köster et al. 2020). Perhaps most importantly, it must be noted that the legacy of lignite mining has created a social and cultural identity (ibid.); political actors as well as strategic documents for regional development and planning still maintain the narrative of Lusatia as an energy region (Bundesregierung 2020; Nagel and Zundel 2021a) or an "economic and energy region" (Sächsische Staatskanzlei 2022). In light of the existing infrastructure, a differentiated energy industry, various research and educational centres, and potentially suitable land for renewable energy (RE) projects, Lusatia can in fact be considered as a region with strong potential for the development of a sustainable energy transition industry (Richwien et al. 2018; Hirschl et al. 2022). To put Lusatia squarely on a map as an attractive region in a post-fossil fuel era, massive investments and funding is needed in the areas of economy, science, infrastructure and civil society (Agora Energiewende 2018). With Germany's decision to end coal-fired power generation by 2038 at the latest, a support package for German coal regions in transition has been introduced and structural support laws were adopted in 2020. The federal government of Germany provides financial aid of up to € 17.2 billion to the Lusatian mining area between 2020 and 2038 (Sächsische Staatskanzlei 2022). The research and development of so-called Power-to-X-technologies (the conversion of renewably sourced electricity to a substance or energy carrier ("X") for use in other sectors) is one central pillar in Lusatia's development strategy to become a sustainable energy region (Bundesregierung 2020). An important prerequisite for an innovative and climate neutral regional economy is the production and efficient use of electricity from renewable energies. The uptake of renewables needs to accelerate rapidly, even more so in the context of the ongoing energy supply shortages due to Russia's war of aggression in Ukraine. This paper focuses on the development potentials of energy transition technologies and measures in two different energy transition scenarios, with a focus on wind energy and photovoltaics.

1.2 Regional economic opportunities of the energy transition

The local expansion of renewable energies to achieve national climate neutrality targets provides opportunities to expand and strengthen local energy value chains and to reduce capital exports from individual regions for their energy imports. These opportunities may strengthen the local economy in terms of long-lasting business models, the preservation and new addition of highly qualified jobs, and also long-term energy independency. Ideally, this will also empower greater participation of the municipalities, citizens and other local stakeholders in the energy transition, financially and procedurally. In Sect. 4 we discuss crucial assumptions for regional energy transition measures and their regional economic potentials.

In order to know what the local energy transition will imply, economically valid regional data and indicators are needed. However, since these are not usually made available at the regional level, while supra-regional data cannot simply be broken down regionally, specific model approaches and empirical data are required in order to make a case for a region. With this in mind, in 2010 the IÖW began developing a value chain approach to calculate these regional value-added and employment effects for energy transition value chains. The approach covers renewable energy value chains (WeBEE model) as well as value chains for the energetic refurbishment of residential buildings (WeBeG model). Regional value added can be understood as the sum of the income and earnings of the stakeholders and shareholders involved in the value chains of a region. The value added contains the income shares of

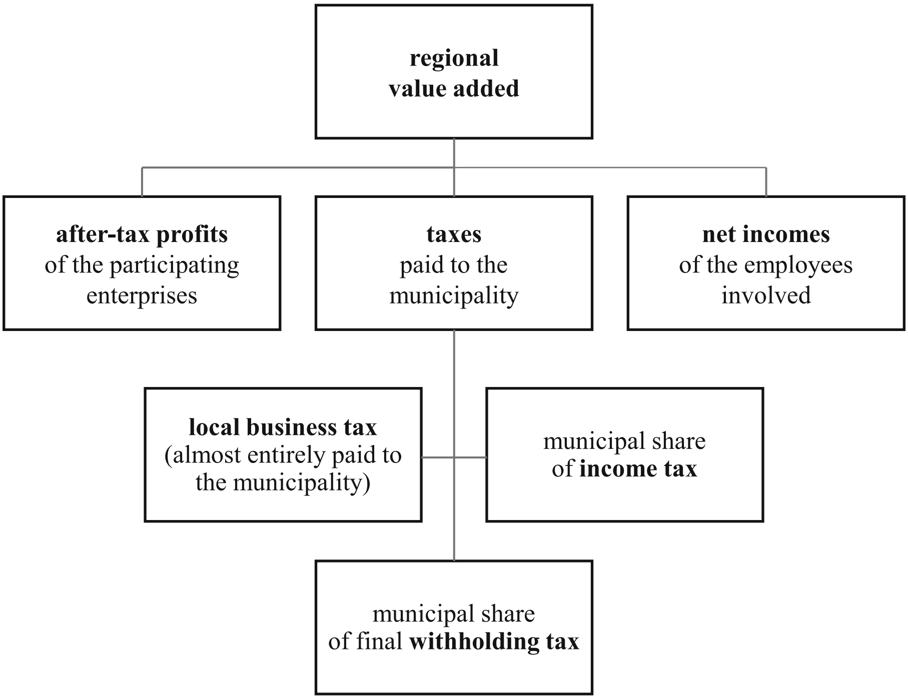

Fig. 1 Additive definition of regional value added in the IÖW model, *source*: own representation

the employees (wages and salaries) in the municipality, the capital donors (interest expenses) based in the municipality, the state or municipality as a regional authority (taxes and levies) and local companies (profit) (cf. Haller 1997; Hirschl et al. 2010). Taxes and levies are distinguished on the basis of municipal, state or federal income. At the regional level, the tax revenues flowing directly into municipal budgets are relevant. In Germany, municipalities receive the largest part of the local business tax (Gewerbesteuer), of which they transfer an apportionment to the federal and state governments. In addition, the municipalities participate proportionately in the assessed income tax (15%) and the final withholding tax (12%). Employee income at the participating companies and company profits also contribute to increasing citizen purchasing power in the municipality (see Fig. 1).

The central basis for determining the value added and employment through renewable energies using the WeBEE model is the analysis of the specific sales in relation to the installed capacity along the value chain of RE technologies. The chains are limited to sales directly linked to RE, which are derived from the costs for system production, installation and operating. The sales of supplier companies further upstream and the resulting value creation and employment effects are not taken into account, since they usually do not occur in these regions.[1] The RE value

[1] The value chain approach of the IÖW model can be complemented by an input-output analysis including every upstream economic activity (see Hirschl et al. 2015). This approach was not pursued because there is

chains are uniformly divided into four value-added stages, which reflect the different economic phases in the life cycle of a RE system, i.e. one-time effects generated in the years of the RE plant installations in the stages of 1) manufacturing and 2) planning and installation, as well as annually repeated effects from already installed RE plants in the stages of 3) plant operation and maintenance as well as 4) operating profits.

Detailed information on the procedure for calculating the value creation and employment effects from renewable energies can be found in Heinbach et al. (2014), Hirschl et al. (2015) and Rupp et al. (2017). The most important insight from the value-added analyses conducted to date is that the participation of regional stakeholders, especially the investment of financial capital, is crucial for retaining value added in the region. Therefore, the level of regional stakeholder financial participation is an important parameter in the two energy transition scenarios for Lusatia that will be introduced in the following section.

2 Energy transition potentials in Lusatia

This paper presents findings for two possible development scenarios with respect to the relevant energy transition technologies and measures in Lusatia for the period 2018 (base year) to 2040. The first scenario, *Current Policies,* is modelled according to the federal and state-specific energy and climate regulations in place at the time of writing. The second and more progressive of the two scenarios, *Climate Neutral 2045*, depicts the regional efforts considered necessary to adequately comply with Germany's climate neutrality targets. The five technologies and associated measures presented in our study (Hirschl et al. 2022) were selected primarily for their potential to drive regional value added and increase the participation of regional stakeholders, as well as for technology readiness and data availability reasons. This paper, summarising Hirschl et al.'s (2022) findings, focuses especially on wind energy and photovoltaics, since they are considered the mainstay of decarbonised energy systems of the future (Falkenberg et al. 2021; SMEKUL 2021; Luderer et al. 2021; Sterchele et al. 2020; dena 2021). This is followed by a brief consideration given to biomass technologies, heat pumps and the energetic refurbishment of residential buildings (see Hirschl et al. 2022 for a detailed analysis). Hirschl et al. (2022) first calculated the technical and economic potentials of the technologies and measures and then compared and discussed them in the context of both location-dependent and location-independent restrictions, resulting in potentials considered realisable under the respective assumptions of the two scenarios. Technology-specific assumptions and methodology can only be briefly introduced in the following sections (see Hirschl et al. 2022 for a detailed analysis).

only limited information on required economic statistics and also an uncertainty about the future economic structure of Lusatia in 2040.

2.1 Wind energy

Onshore wind energy will play a vital part in Lusatia's future energy system, as wind turbines can offset wintertime reductions in solar power. Alongside photovoltaics, onshore wind energy will enable the export of electricity to the neighbouring metropolitan areas of Berlin and Dresden (especially in winter). Furthermore, wind turbines can provide the full load hours necessary to operate Power-to-X technologies as envisioned in Lusatia's regional development strategy (see Sect. 1.1). Against the backdrop of the amendments to Germany's Renewable Energy Sources Act (EEG) in 2014 and especially in 2017, the expansion of wind power has faced a chequered development in Germany. Subsequent to an average additionally installed capacity of 4 GW in the onshore market segment between 2014 and 2017, installation activities collapsed to almost a quarter of this (1078 MW gross) in 2019 as a result of the new public tendering rules and a large number of lawsuits and planning restrictions (BWE 2021a). New installation figures climbed steadily in 2020 and 2021, to almost 2 GW gross addition per year (BWE 2022). However, recent studies—and industry representatives—are insisting upon an annual gross addition of at least 5 GW to cover future electric demand and to meet Germany's updated climate protection targets (BDEW 2021; BWE 2021b; Luderer et al. 2021; Prognos, Öko-Institut, and Wuppertal-Institut 2021).

The low population density in the rural area of Lusatia generally facilitates the construction of wind farms—under certain conditions. First and foremost, there needs to be sufficient provisioning of land for wind energy use. In 2018, the Saxon planning region Oberlausitz-Niederschlesien made only 0.22 per cent of its regional area available for wind farms, versus 1.85 per cent in the Brandenburg Lausitz-Spreewald planning region. To put this into perspective, a new law (Windenergieflächenbedarfsgesetz) came into force in February 2023 that gives all federal states binding targets for the amount of lands to be designated to wind turbines by the end of 2027 and the end of 2032 (Bundesregierung 2023). While an average value of 2% is used for overall Germany, the 2032 target in Saxony is 2%, that of Brandenburg is 2.2% (ibid.).

In addition to land use designation, the choice of turbine setup is also important for achieving a satisfactory utilisation of wind energy potential. With more powerful

Table 1 Comparison of the wind energy status quo in 2018 with the *Current Policies* and *Climate Neutral 2045* scenarios for the two Lusatian planning regions Lausitz-Spreewald (L-S) and Oberlausitz-Niederschlesien (O-N)

	Status Quo in 2018	*Current Policies* scenario in 2040	*Climate Neutral 2045* scenario in 2040
Electricity Generation (in GWh/a)	L-S: 3268 O-N: 536 Lusatia: **3804**	L-S: 6250 O-N: 3036 Lusatia: **9286**	L-S: 7425 O-N: 3680 Lusatia: **11,105**
Installed Capacity (in MW_p)	L-S: 1766 O-N: 339.8 Lusatia: **2105.8**	L-S: 2267 O-N: 1022 Lusatia: **3289**	L-S: 2385 O-N: 1182 Lusatia: **3567**

Source: Own calculations, see Hirschl et al. (2022) for details turbines and a greater number of full load hours, electric power generation output increases disproportionately compared to the increase in land use (see Table 1). In the *Current Policy* scenario, around 9300 GWh/a can be achieved in 2040 with a mix of 3 MW and 5.3 MW model wind plants, using around 2% of the regional land area. The 3 MW model plant depicts the average onshore wind turbine performance in the base year 2018, while the 5.3 MW model plant approximates the average performance of wind farms by 2040 (Richwien et al. 2018; LANUV 2021; Deutsche WindGuard GmbH 2020). In this scenario, Hirschl et al. (2022) assume that a repowering of old turbines can stabilise the current stock of plants (3 MW) while additional wind farms with more powerful plants (5.3 MW) are being built. In the *Climate Neutral 2045* scenario, more than 11,000 GWh/a can be generated with wind farms consisting of 5.3 MW model plants on around 2.2% of the land area. The choice of the 5.3 MW model plant in the *Climate Neutral 2045* scenario as the average performance level is based on the assumption that more powerful wind farms would be built in the coming years while at the same time existing wind farms are extensively being repowered with more powerful turbines.

In both scenarios, the expansion of wind energy will have to accelerate in the coming years. This holds especially for the Saxon planning region Oberlausitz-Niederschlesien, which has installed only a fraction of the wind energy capacity found in the Brandenburg part of Lusatia. By 2040, the installed capacity (in MW) will have expanded by more than 150% in both scenarios. Given that public protests are a major hurdle for new wind farm projects, it is necessary to expand opportunities for financial and procedural participation among the local population. Of equal importance is increasing administrative capacity in order to speed up planning processes. As part of Lusatia's path towards a sustainable future, the reshaping of former mining sites for the use of RE sources such as photovoltaic plants, biomass, wind turbines or a combination of them should be supported. The wind farms Forst Briesnig I and II that are being installed on recultivated areas of the open pit mine Jänschwalde set an auspicious example.

Table 2 Comparison of the photovoltaics status quo in 2018 with the scenarios *Current Policies* and *Climate Neutral 2045* for the Lusatian planning regions Lausitz-Spreewald (L-S) and Oberlausitz-Niederschlesien (O-N)

	Status quo Year 2018	*Current Policies* scenario Year 2040	*Climate Neutral 2045* scenario Year 2040
Installed capacity rooftop PV façades* (in MW$_p$)	L-S: 294 O-N: 185 Lusatia: **479**	L-S: 775 O-N: 1180.7 Lusatia: ~ **1960**	L-S: 2968 + 1096* O-N: 2921 + 1061* Lusatia: **5889 + 2157***
Installed capacity ground-mounted PV systems agrivoltaics floating PV*** (in MW$_p$)**	L-S: 1000 O-N: 265 Lusatia: **1265**	L-S: 1800 O-N: 1108 Lusatia: ~ 2910	L-S: 3087 + 1305** + 356*** O-N: 1009 + 928** + 322*** Lusatia: **4096 + 2233** + 678*****
Total installed PV capacity (in MW$_p$)	Lusatia: ~ 1740	Lusatia: ~ 4860	Lusatia: ~ 15,050

Source: Own calculations, see Hirschl et al. (2022) for details

2.2 Photovoltaics

Hirschl et al. (2022) find that Lusatia has enormous photovoltaics (PV) potential and solar panels are the biggest energy transition driver for the region. Given that PV systems are one of the most decentralised RE technologies (Wirth 2021), their expansion should promote the meaningful procedural and financial participation of stakeholders and shareholders throughout the region (see Sect. 3). In the case of Lusatia and its status as an underdeveloped region, appropriate federal and state funding schemes will have to accommodate the limited investment capacities of its municipalities and citizens.

As Table 2 shows, 1.7 GW of PV capacity was installed in the region in 2018. In the *Climate Neutral 2045* scenario, another 13.3 GW could be installed by 2040 by tapping the potential of building-integrated systems (rooftops and façades), conventional ground-mounted systems, and integrative photovoltaic innovations such as so-called floating photovoltaics on pit lakes and agrivoltaics (dual-use solar). Agrivoltaics offer the benefit of protection from heat and drought stress, which can lead to above-average crop yields in addition to the solar power generation (Trommsdorff et al. 2020). With a total of 15 GW installed capacity, the expansion potential in this more progressive scenario is almost three times higher compared to the *Current Policies* scenario, where solar panels installed on roofs and in conventional ground-mounted systems reach a capacity of 5 GW in 2040 (see Table 2). In both scenarios, rooftop PV panels contribute to around 40% of the overall installed PV capacity.

In order to accelerate PV expansion in Lusatia, the policy framework needs to be strengthened. Binding targets and mandatory implementation mechanisms ensure a clear, legally established regulatory framework and help to establish a solid basis for capital-intensive investments (Hamilton 2009). Moreover, the planning, approval, connection and operation of PV plants need to be streamlined in terms of bureaucracy. As with wind turbines, open pit mining areas offer additional potential siting opportunities for PV that have not been explicitly considered in Hirschl et al. (2022); see Richwien et al. (2018) for an analysis of RE potentials on open pit mining areas in Lusatia. Land-saving and biodiversity-friendly approaches must be rewarded; district energy-sharing has to be facilitated. For an equitable and inclusive energy transition, policy measures should be designed in a way that citizens with inadequate access to RE can still participate (Robins et al. 2019). Finally, regardless of the type of PV system installed, reskilling and redeployment initiatives are pivotal measures for countering the shortage of skilled workers in the region.

2.3 Other energy transition technologies and measures

Unlike PV and wind energy, the potential of bioenergy in Lusatia has been largely tapped—with 0.35 GW in 2018 (Hirschl et al. 2022). In the *Current Policies* scenario, a significant decline in the energetic use of biomass to 0.07 GW by 2040 is expected due to land competition. Meanwhile, material use for bioeconomy activities will grow (ibid.). The *Climate Neutral 2045* scenario foresees a moderate increase in the energetic use of biomass, up to 0.45 GW. In this scenario, biomass will be used less for electricity (0.13 GW_{el}) and more in the heating and transport sectors (0.32

GW_{th}). The cascading use of selected biomass is of utmost importance, as is the cultivation of hybrid-use areas with carbon sink functions and the co-generation of multiple RE technologies (e.g. agrivoltaics on rewetted wetlands).

With respect to heat pumps, expansion figures need to increase significantly in the next decade in Lusatia, as only approximately 150 MW_{th} had been installed as of 2018 (Hirschl et al. 2022). By the year 2040, both scenarios foresee a substantial increase in installed capacity—by roughly a factor of 6 (~875.5 MW_{th}) in the *Current Policies* scenario and a factor of 12 (~1820 MW_{th}) in the *Climate Neutral 2045* scenario. There will be a particularly strong increase in air source heat pumps, which are predominantly used in single-family and terraced houses. Ground source heat pumps are more suitable for multi-family houses due to their higher efficiency (ibid.).

To further reduce the heat energy demand in residential buildings, energy-efficient refurbishment increases from less than one percent in 2018 to 1.6% in 2040 in the *Current Policies* scenario. In this scenario, energy consumption for heating could be reduced by 50% if every third retrofit were carried out ambitiously, i.e. with the goal of attaining a high-efficiency thermal insulation standard comparable to the Passive House standard (*Passivhaus*). In the *Climate Neutral 2045* scenario, both refurbishment rate and depth are greater, with an overall energy-efficient refurbishment rate of 3.3%, of which the share of ambitious retrofits is 90%, thereby reducing the heat energy demand by 60% (Hirschl et al. 2022). For the expansion of heat pumps and energy-efficient building refurbishment, sustained public financing is essential to facilitate long-term, capital-intensive investment in skilled workers and the respective technologies (Hamilton 2009). Moreover, binding targets can build confidence in the stability of the policy regime (ibid.). The gradual energy-efficient refurbishment obligation currently planned at the EU level should also be introduced in Germany in the medium term. For a just transition towards more energy-efficient buildings, the financial burden on tenants must be addressed and limited.

3 Resulting regional economic effects through energy transition measures

3.1 Overall value-added and employment effects

The two energy transition potential scenarios (see Sect. 2) were combined with assumptions made about the regional residence of actors along the value chains. Most importantly, we took into consideration the lower income level of private households in Lusatia and therefore assumed that only a lower proportion of the RE investments could be supported by regional actors (see Hirschl et al. 2022 for details). The following results were obtained for regional value creation and employment with energy transition measures in the region: in the *Current Policies* scenario, the regional value added from the three selected renewable energy technologies and two energy efficiency measures for buildings considered here totals almost €185 million, entailing around 1630 full-time employees. In the *Climate Neutral 2045* scenario, the regional value added may reach €433 million in the year 2040,

Table 3 Regional value-added and employment effects in 2040 by value chains, calculated for the scenarios *Current Policies* and *Climate Neutral 2045*

Value chains	Regional value added *(million EUR)*		Employment *(FTE)*	
	Current Policies	Climate Neutral 2045	Current Policies	Climate Neutral 2045
Building refurbishment	31.4	50.5	1004	1620
Wind energy	77.9	125.1	178	396
Photovoltaics (rooftop)	39.5	132.7	205	761
Photovoltaics (ground-mounted)	18.7	87.9	65	221
Heat pumps	7.0	13.4	128	241
Biogas (on-site conversion)	8.8	11.0	26	32
Biogas upgrading	0.5	2.4	11	40
Wood combined heat and power	0.5	7.9	12	189
Wood central heating	0.1	2.4	3	56
Total	**184.5**	**433.3**	**1632**	**3556**

Source: Own calculations, see Hirschl et al. (2022) for details.

accumulating to more than EUR two billion over a five-year horizon. In addition, the scenario anticipates the creation of almost 3560 full-time jobs in new employment opportunities (see Table 3), which count for even more employees. The significantly higher effects achieved in the *Climate Neutral 2045* scenario can be attributed both to more ambitious expansion figures for RE technologies and to higher renovation rates and depth. The more progressive scenario also builds on a higher share of regional stakeholders in the value chains, including financial participation and co-ownership in RE projects (see Sect. 4.2).

Table 3 shows the resulting regional economic effects for both scenarios in 2040 for the energy transition areas under consideration. In both scenarios, the value-added effects are mainly due to wind energy and photovoltaics (rooftops and ground-mounted PV) as well as energy-efficient building refurbishment. A similar picture emerges for jobs, but the biggest driver of employment is the skills needed for energy-efficient building refurbishment.

In both scenarios, a large part of the regional value added (around 80%) in 2040 is due to annual effects from plants which were installed in the years before. They generate effects from the operation and maintenance and from their annual return on investment. The remaining 20% of the effects calculated for the year 2040 is comprised of one-time effects from system components trade, the project planning and installation of renewable energy systems, and the planning and execution of refurbishment measures, all calculated for the year 2040. Since the planning and assembly of RE systems and the energy-efficient retrofitting of buildings are comparatively labour-intensive, the picture is somewhat different for employment. In the *Current Policies* scenario, as much as 80% of the identified full-time jobs are one-off effects from these installation and refurbishment activities in the year 2040. In the *Climate Neutral 2045* scenario, this number is just under 70%. However, these

Table 4 Regional value-added and employment effects in 2040 by value-added component, calculated for the *Current Policies* and the *Climate Neutral 2045* scenarios

(million EUR)	Current Policies	Climate Neutral 2045
After-tax profits	92.6	253.8
Net income of employees	38.8	89.1
Taxes and payments to municipalities according to § 6 EEG	53.1	90.4
Total regional value added	**184.5**	**433.3**

Source: Own calculations, see Hirschl et al. (2022) for details

one-off effects can be considered as annually repeated benefits since the expansion of renewable energies and renovation activities is expected to happen at similar rates in previous and subsequent years.

3.2 Value-added components and stakeholder profit

Table 4 shows how the total regional value added in the two scenarios is distributed among the individual components. In the *Current Policies* scenario, the after-tax profits amount to 50% of the total regional value added of €184.5 million, while about 21% is from employees' net income. Another 29% of regional value added is generated by taxes and payments to the Lusatian municipalities in accordance with paragraph 6 EEG 2021. In the *Climate Neutral 2045* scenario, the significantly higher regional value added of €433.3 million is comprised as follows: roughly 59% is attributable to profits after taxes, almost 21% is from the net income of employees, while taxes and payments to the municipalities in accordance with paragraph 6 EEG 2021 account for the remaining 20%.[2]

Another distinction can be made regarding the stakeholders receiving these value-added components as income. Municipalities, important stakeholders with respect to the entire planning process, profit from tax revenues as well as from lease payments for RE plants on public grounds and rooftops. Furthermore, municipalities can theoretically invest in local RE projects, either by operating their own plants or by investing in RE plants operated by other stakeholders (see Sect. 4.2). (Co-)ownership of RE projects, however, is often associated with major obstacles, especially for financially marginalised municipalities. Indebted municipalities, subject to the budgetary regulations of the federal states, may have very limited opportunities to make investments in RE plants.[3] Although there are strategies for financial participation without own investment, such as via lease income from municipal land (see Sect. 4.2), there is a need for action to enable municipalities the active participation in the energy transition and to profit from its economic benefits—a key factor for fostering local acceptance (Hübner et al. 2020; Salecki and Hirschl 2021).

[2] § 6 EEG 2021 enables the operators of wind energy and ground-mounted photovoltaic plants installed in 2021 or later to transfer a payment based on the produced amount of electricity directly to the municipalities.

[3] For further information see Heinbach et al. (2020).

Table 5 Comparison of the calculated regional economic effects of energy transition measures and the economy-wide dimensions in Lusatia

Indicator	Economy-wide dimension	Calculated results *Current Policies*	Calculated results *Climate Neutral 2045*	Share of energy transition effects *Current Policies*	Share of energy transition effects *Climate Neutral 2045*
Total value added *(million EUR)*	24,555	184.5	433.3	0.8%	1.8%
Municipal tax revenues *(million EUR)*	1125	53.1	90.4	4.7%	8.0%
Employment *(FTE)*	416,102	1632	3556	0.4%	0.9%

Source: Own calculations, based on (Statistische Ämter des Bundes und der Länder 2021a; 2021b; 2021c)

In the *Current Policies* scenario, the municipal share of the regional value added in Lusatia in 2040 is almost €94 million—51% of the total value added. At around €53 million, taxes to the municipalities account for the largest share. Moreover, payments in accordance with § 6 EEG 2021 of approx. €21 million make a significant contribution to the municipal share of the regional value added. Municipalities' income from equity investments in RE projects is comparatively low at just under EUR eight million. In the *Climate Neutral 2045* scenario, on the other hand, it is assumed that in the future, with appropriate measures and instruments, a significantly higher financial participation of regional actors—and thus also municipalities—can be achieved. Here, the total municipal share of regional value added amounts to roughly €185 million for the year 2040, with tax revenues accounting for nearly half of this amount (€90 million). In this scenario, however, one quarter (€46 million) consists of the revenues of the municipalities from equity participation. The payments according to § 6 EEG 2021 add up to €34 million and lease payments to the municipality total roughly €15 million.

3.3 Energy transition effects compared to the regional economic situation

With respect to the overall economic activity in Lusatia, the calculated effects of the energy transition measures can comprise a significant share and therefore strengthen the regional economy. The total value added in the two scenarios comprises 0.8% and 1.8%, respectively, of the regional value added in 2040 (see Table 5). The share of municipal tax revenues generated by energy transition measures amount to 4.7% and 8.0%, respectively. Job creation opportunities from RE and building-refurbishment measures can achieve shares of 0.4 and 0.9%, respectively, which is significant for a region that has seen a demographic decline in recent decades.

In summary, the analysed energy transition potentials can yield substantial regional economic effects. These RE expansion and building-refurbishment measures, including other measures not addressed here, should be prioritised and accelerated by policymakers to accomplish the climate-neutrality goals. The required technological and regional economic framework conditions will be discussed in the following section.

4 Discussion: Advancing participation in the regional energy transition

Our analysis shows that Lusatia's high energy transition potential can advance regional economic development. However, unlocking the associated regional value added in a structurally weak region like Lusatia—a coal region in transition with higher unemployment rates and relatively lower-income households—will require the long-term participation and pro-active involvement of a broad range of local stakeholders. In the following, we discuss how our assumptions for regional transition potentials affect the obtained results and how to reduce barriers to participation in the regional energy transition as a prerequisite for regional economic development.

4.1 Energy transition as a long-term economic development strategy

It is important to note that the conclusions made in this paper cannot automatically be applied to all former or present coal regions. The specific geographic and socio-demographic context, respective policy framework and economic profile will all influence and determine which social innovations emerge and which local stakeholders are able to contribute to the energy transition. In a region of higher population density and higher economic prosperity, for example in the Ruhr area (Germany) and in Upper Silesia (Poland), we are likely to see a different account of energy transition potentials and regional economic effects (Reitzenstein et al. 2021). At the same time, given that factors such as insufficient funding or planning capacity, as well as a lack of skilled workers are commonly cited in the literature as challenges to a successful energy transition in coal regions (OECD 2017; Reitzenstein et al. 2021), we do consider our results to be transferable to other regions, but with some limitations we want to address in this section. The British coal regions, for example, experienced a long transformation process with partial success in generating new jobs and some continuing imbalances in the labour market. One of the key lessons from the UK is that the economic transition of former coal communities is not a quick fix. In the UK, the transition required forward planning and a mixed-strategies approach based on other regional economic potentials, public support and funding of the transition process (Fothergill 2017). We agree that structurally weak regions need more target-oriented strategies accounting for both location-dependent and location-independent development challenges.

Although there has been an overall positive economic development in Brandenburg in recent years, particularly in municipalities near Berlin, the majority of the region Lusatia has a regional GDP per capita below the national level as well as a below average local business tax capacity and infrastructure expenditure (Lenk et al. 2021; BRAVORS 2022). Economically marginalised municipalities are often unable to implement costly climate protection measures as these are not part of the primary services they are responsible for providing (Heinbach et al. 2020). Additionally, in regions with lower incomes, private households potentially lack the upfront capital or access to credit to invest in regional RE projects (Statistisches Bundesamt 2022)—a situation that we took into account when developing the regional economic scenarios. This may also be a structural obstacle in other regions in eastern Germany, where the average net wealth of adults (older than 17) was measured to be less than half of the average in western Germany in 2017 (bpb 2020). We set a moderate level of direct RE investment in the *Current Policies* scenario, whereas we assumed that sufficient financial and policy support for private households, municipalities and business actors would enable a significantly higher share of regional investment capital in the *Climate Neutral 2045* scenario.

Other coal regions suffer from structural weaknesses similar to those in Lusatia, namely the challenge of demographic change due to an ageing population and emigration, as well as relatively low income levels (OECD 2017; Reitzenstein et al. 2021). The former coal and steel producing regions in the U.S. and their specific challenges were analysed by Bartik (2019; 2020), who also focuses on low-income households and policy measures for economic stimuli. Amongst other things, Bartik (2019) concludes that financial incentives should focus on specific problem areas and not be widely spread, advocating funding and direct investments in infrastructure and high-tech cluster areas. Bartik (2019) also warns against long-term aid of large companies, because it may cut financial opportunities for large-scale economic development strategies. This is in line with Richwien et al. (2018) who indicate that large companies have the potential to bring significant economic development, but there is also the risk of closure or relocation from the region if, for example, global price changes adversely affect a monostructural regional economy. Against this background, a political focus on small and medium-sized enterprises seems more sustainable and resilient. To realise local job creation, Bartik (2020) recommends targeting the local level, allowing for the installation of development policies at affordable costs due to location-specific resources and the insights of state and local governments rather than exclusively introducing federal regulations or grants. These recommendations are in accordance with the energy democracy movement that advocates the decentralisation of economic and political power in renewable energy systems by means of new energy companies, ownership models and financial investment systems under social and public control (Burke and Stephens 2017). Accordingly, we will take a closer look at the preconditions for implementing and designing a participatory energy transition process with a focus on community energy.

4.2 Financial participation as a key challenge for an inclusive energy transition

To achieve the assumed participation level of the *Climate Neutral 2045* scenario and the calculated regional economic effects, it is of utmost importance to address the barriers that community energy is confronted with in general and specifically in structurally weak regional economies. We understand community energy as an auspicious socio-technical innovation for a democratic transition pathway. At the same time, we are aware of the varying political, institutional and socio-economic contexts in which community energy projects develop (Burke and Stephens 2017). Community energy projects typically require sufficient "practical capacities", i.e. time, money and expertise in light of complex and often costly preparatory activities (Park 2012; Tarhan 2022). Since economically marginalised communities in Lusatia may be poorly positioned to follow "localist approaches" (Catney et al. 2014), we recognise "community energy" as an umbrella term covering a range of actors and business models, e.g. regional RE suppliers, local financial institutes, RE cooperatives and renewable energy communities (REC). In line with RED II provisions (European Parliament and Council of the European Union 2018), we view citizens, local small and mid-size enterprises and public authorities including municipalities as potential community energy members and/or shareholders.

The following section outlines possibilities to widen the often limited scope for municipalities and citizens to engage in RE expansion. In case municipal land areas are not used for the operation of RE plants, the municipalities are left with the local business tax revenues, which, according to the legal regulations, are to be paid for the most part (90%) to the municipality where the RE plant is located (§ 29 GewStG). The hitherto voluntary payments of the plant operators to the municipalities according to § 6 EEG should become mandatory in the future. Thereby, the regulation can unfold its intended effect to offer financially weak municipalities a financial participation opportunity. In case municipal land areas are used for the operation of RE plants, there are not only opportunities for the municipalities to participate in the plant revenues through lease income, but also to actively shape the RE expansion in the municipality. For instance, municipalities can decide which actors are granted access to the land and negotiate participation opportunities for themselves and local citizens (LEA LandesEnergieAgentur Hessen GmbH 2022). Ideally, municipalities can secure a higher regionally embedded share of the value added by RE plants through their own initiative. With the planning processes in their own hands, their own investment funds and a planning and financial participation of the citizens, they can achieve their own objectives for the RE expansion, benefit economically and strengthen acceptance among the population. One best practice example is the municipality of Hünfelden in the state of Hesse which has established three sources of income out of community energy: the lease income from the local wind farm on municipal land, its own profit sharing through co-ownership of the farm, and the tax income from the local citizens' energy association (Hildebrand et al. 2023).

When developing new innovative funding instruments for RE installations, there should be a focus on participatory policy design processes and close community consultation with marginalised communities (Tarhan 2022). In a case study of Ontario, Tarhan (2022) recommends explicitly addressing practical capacity inequities between and within communities to ensure just outcomes of community-led RE investments and emphasises the importance of engaging marginalised groups in the policy design processes. At the moment, community energy projects in Germany lack diversity and representativeness, as members are mainly affluent men with university degrees (Yildiz et al. 2015; Radtke and Ohlhorst 2021). One possible mechanism to enhance the financial inclusion of private households with lower incomes and/or savings is to reduce the minimum deposit for equity investments in community energy projects, such as RE cooperatives in Germany do (DGRV 2022). This can be done by specific arrangements in the company statutes or by interposing a financial intermediary such as a local cooperative bank that issues low-threshold bonds for financial participation in local RE and/or other sustainable projects. This can also serve to minimise investment risk—another investment barrier (Holstenkamp et al. 2018). Moreover, innovative on-bill financing and on-bill repayment programs (utilities supply capital with low-to-zero interest rates to customers which is repaid through regular payments on existing utility bills e.g. for electricity) could be tested in cooperation with public sector entities and supportive local utilities (Burke and Stephens 2017). There is some experience in Germany with discounted regional electricity tariffs, but there is no public support for such schemes to date (IÖW, IKEM, and BBH 2020). In the Netherlands, regional energy strategies were developed with the aim of realising 50% local ownership in wind and solar projects by 2030 (Palm 2021). To achieve this target, an incentive program known as the Postal Code Regulation (*postcoderoosregeling*) was introduced in 2014. It provides a tax rebate to consumers for local investments in community energy (Wagemans et al. 2019). The postal code scheme was designed for citizens without their own installation site but with a willingness to participate in local community energy projects and can be considered a collective form of net metering (Meitern 2022). Besides addressing specific regulatory barriers (see Burke and Stephens 2017), it is important to establish transparent processes and to inform local stakeholders at the earliest stages about their participation opportunities including ownership (Burke and Stephens 2017; Hübner et al. 2019).

Scientific studies in non-EU countries confirm that an unsupportive national institutional and policy framework is a major challenge for community energy projects (McMurtry 2018; Klein and Coffey 2018; Raupach-Sumiya 2019). Since energy policy is generally designed for centralised systems and in need of profound structural reforms, changing the institutional setting on multiple levels is as important as it is challenging (Cantarero 2020). Italy, for example, has few existing community energy projects to date; however, it is among the frontrunners in transposing the EU RED II provisions for community energy (Palm 2021; Krug et al. 2022); November 2021 saw the completion of a regulatory framework with a set of promising policy measures and incentives that have contributed to the emergence of new community energy projects throughout Italy (Krug et al. 2022). A key element of the enabling framework are fiscal incentives for new community energy plants up to 1 MW_p and a feed-in premium of €110/MWh for energy sharing (ibid.). Furthermore, Italy is an early adopter of smart meters and allows net metering, thereby supporting a rise in storage facilities at the community level (ibid.). As part of the Italian Recovery and Resilience Plan, a fund of €2.2 billion has been set aside for the promotion of collective self-consumption in municipalities below 5000 inhabitants, substantiated by the quantitative policy target of 2 GW capacity installed by RECs by 2026 (Krug et al. 2022). Alongside favourable legislation at the national level, regional governments have started to create their own support frameworks that can account for specific local conditions and serve to create an effective multi-level governance (ibid.). A lack of supportive local institutions can otherwise act as a barrier to social innovations such as community energy (Ecker et al. 2018, pp. 21–24; Davies, den Hoed, and Michie 2020, p. 19). While regional funds have now started to emerge throughout Italy, in Germany, only the state of Schleswig-Holstein has taken any steps in this direction, introducing a revolving fund providing risk capital for community energy (Krug et al. 2022). The mobilisation and coalition-building of existing political, economic and civic institutions, organisations and networks at the state level and below is a key strategy to boost community energy (e.g. Ministerium der Justiz des Landes Brandenburg 2022).

Establishing a level-playing field with big energy suppliers is an essential factor for a decentralised transition. A major challenge for community energy projects, particularly for wind energy projects, is the replacement of feed-in tariffs and premiums with auctions, as this tends to worsen their refinancing perspectives (Lowitzsch and Hanke 2019; Meister et al. 2020). A phase-out of feed-in tariffs without compensatory support measures does nothing to create a non-discriminatory market, making it instead more difficult for community energy projects to compete with the big energy suppliers in light of differing economies of scale and learning. High taxes and fees that are often raised indiscriminately for larger energy suppliers and small-scale citizen-led projects, as well as administrative barriers regarding planning and authorisation, impose further challenges for community energy initiatives (Horstink et al. 2020; Palm 2021; Schwarz et al. 2022; Krug et al. 2022). In reaction to the collapse of citizen energy efforts in Germany, the current federal government has introduced exceptions for citizen-led wind energy projects in auctions (the so-called *de minimis* regulation, § 36g EEG 2021). Moreover, access to the grid, financial support and cost-efficient energy sharing are considered essential if community energy is to compete on a level playing field with large energy suppliers (Krug et al. 2022; DGRV 2021). Tailor-made policies and subsidy mechanisms in terms of financial aid and technical expertise are needed for community energy projects to blossom and to tap their full potential.

The potential value-added contributions of new employment opportunities emphasise the need for a skilled workforce throughout the value chain (Kapetaki et al. 2020). Therefore, drawing on the skills of former coal workers as well as on the capacity of the local industrial network should be combined with broader education and (re-)training measures (Davies, den Hoed, and Michie 2020, p. 19). Access to a highly skilled workforce is a key challenge for Lusatia in light of its demographic development (see Sect. 1). Another crucial factor lies in the debate about the crowding-out of coal-industry jobs (see Wörlen, Keppler, and Holzhausen (2017) and Rinscheid (2018) for socio-economic studies and Deutscher Bundestag (2020) as an example of the controversial parliamentary debate on the national level). Besides the need for a coal phase-out as a strong climate protection measure, there are indications that a strategy to promote sustainable energy generation in former coal-regions can indeed replace a high share of the crowded-out coal-industry jobs or even generate a multiple of these crowded-out jobs (as estimated on a NUTS2-level by Kapetaki et al. 2020, p. 66, Table 16). It must be made clear to regional stakeholders that the climate transition will not only affect their region through the phase-out of fossil fuels as important economic drivers—it also implies a level of uncertainty for other energy-intensive industries like automotive engineering and metals. Therefore, climate protection strategies, in particular the decarbonisation of energy production, will not only bring about new economic potentials but must also be fully integrated into a superior sustainable economy policy (Davies, den Hoed, and Michie 2020, pp. 17–18). Therefore, regional policy makers must establish clear forward planning structures. Given that surrounding regions might well face similar challenges, innovative regional solutions should be proactively implemented by regional policy makers in cooperation with industrial stakeholders to strengthen regional labour markets.

5 Conclusions

With the targeted phase-out of coal, which is essential for climate protection, Lusatia as a traditional coal region is facing a comprehensive transformation of its regional economy. The existing economic infrastructure, research and training facilities, a differentiated energy industry and the availability of land area that can be used for the energy transition can favour the conversion to an energy transition economy. The analysis of five selected climate protection technologies shows that the Lusatian region indeed has strong energy transition potential.

All in all, the more ambitious and participatory *Climate Neutral 2045* scenario can generate around €450 million in value added by 2040 through the technologies considered here, compared to around €200 million in the *Current Policies scenario*. This takes activities in the stages of planning and installation as well as operation into account, but not the manufacturing of RE components as this is unlikely to be located in Lusatia. The value-added effects will remain in the region in the form of municipal taxes, income or profits. These effects, as well as local acceptance, can only be created, maintained and increased if particular conditions are met: the financial and procedural opportunities for participation need to be strengthened considerably, including early information and consultation efforts with the local community and possibly neighbouring communities. Equally important is the increase in administrative capacities in order to speed up planning processes, as well as the auspicious utilisation of the existing open-cast mining sites. By means of a participatory policy design process and targeted support measures, a large number of actors in the region can be economically involved, benefiting the overall regional economic development. Stable and, ideally, growing RE expansion paths and building renovations can ensure value added for regional companies, citizens and municipal budgets.

Our analysis of Lusatia's potential to develop into an energy transition economy, on the one hand, and the prerequisites for transition processes and community energy frameworks in Germany and other countries, on the other hand, show that opportunities to exploit the estimated regional value-added potential of renewable energies and energy-efficient building refurbishment strongly depend on the financial situation of municipalities, private households and other investing stakeholders. There is a need for dedicated local stakeholders as well as regulatory and financial support schemes on multiple governance levels to implement effective energy transition measures. The local economy can only benefit from these measures if local stakeholders are involved and given the opportunity to design and establish their own visions of a sustainable local energy sector and diversified economy. Community energy in its diverse facets can play an important role in the transition to a sustainable and resilient economy.

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