

## ON THE PATH TO SUSTAINABLE ENERGY LANDSCAPES? THE SOCIAL SHAPING OF ENERGY LANDSCAPES IN THE FACE OF CLIMATE PROTECTION MEASURES

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With 6 figures

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**Summary:** Potential spatio-temporal patterns of renewable energies that take into account international climate protection strategies have been neither analysed nor visualised exactly in terms of their landscape complexity. Furthermore, it is unclear what land uses would be prevalent in new energy landscapes, due to a lack of restrictions, and which social conflicts would be associated with these land use changes. There is no knowledge at all about the extent to which existing land use, which has emerged from a capitalistic order, affects the achievement of a carbon-neutral and socially just society. It is also not clear how far it is possible to identify alternative spatial patterns of sustainable energy transition by altering spatial restrictions concerning renewable energies. For this reason, we want to model and visualise a regional energy landscape that corresponds to the objectives of the UN Climate Conference in terms of its regional greenhouse gas balance in the electricity sector. In this regard, the study provides a detailed analysis of the landscape transformations that would occur in rural spaces if those values which attempt to link energy transition to the Paris Agreement were to prevail. The analyses reveal that a strict orientation of the expansion of renewable energies towards climate protection goals would strongly mechanise rural areas, thus significantly transforming their social patterns.

**Zusammenfassung:** Die potenziellen räumlich-zeitlichen Muster des Ausbaus erneuerbarer Energien, die den internationalen Klimaschutzstrategien Rechnung tragen, wurden in ihrer landschaftlichen Komplexität weder analysiert noch exakt visualisiert. Zudem ist unklar, welche Flächennutzungen aufgrund fehlender Restriktionen am stärksten in die neuen Energielandschaften miteinzubeziehen wären und welche sozialen Konflikte mit diesen Landnutzungsänderungen einhergehen würden. Überhaupt liegen keine Erkenntnisse darüber vor, inwieweit die bestehende, aus einer kapitalistisch-marktwirtschaftlichen Logik heraus entstandene Landnutzung den Aufbau CO<sub>2</sub>-neutraler sowie sozial ausgewogener Energielandschaften beeinträchtigt und inwiefern es möglich ist, alternative räumliche Lösungen aufzuzeigen. Daher wollen wir eine regionale Energielandschaft modellieren und visualisieren, die in Bezug auf die regionalen Treibhausgasemissionen den Zielsetzungen der UN-Klimakonferenz Rechnung trägt. Dabei wird zum ersten Mal analysiert, welche Transformationen der Landschaft in den ländlichen Räumen zu beobachten wären, wenn sich jene Werte durchsetzen würden, die die Energiewende an das internationale Klimaschutzabkommen von Paris zu knüpfen versuchen. Die Analysen offenbaren, dass eine stringente Orientierung des Ausbaus erneuerbarer Energien an Klimaschutzzielen die gelebten ländlichen Räume stark technisieren und damit ökologisch und sozial erheblich transformieren würde.

**Keywords:** energy landscape, energy transition, renewable energies, social conflicts, local contexts, climate protection

### 1 Introduction

At the 2015 Paris Climate Conference, the parties agreed to keep global warming below 2°C, compared to pre-industrial levels, and to limit it to 1.5°C, if possible (UN 2015). The political, economic and technological transition processes that currently go hand in hand with these goals must be initiated swiftly by the nation states involved, because, in view of the 43 gigatons of carbon dioxide emissions per year worldwide and a remaining carbon dioxide budget of between 1,080 and 330 gigatons, the threshold will be reached in just a few decades – or even years (MCC

2020). According to the Paris Agreement, Germany had a population-related carbon dioxide budget of 7.3 gigatons (at 1.75°C global warming) available at the beginning of 2019, and so assuming a linear emission reduction of 6% annually, this budget should be used up by 2035 (RAHMSTORF 2019). However, the country is not moving along this path: in recent years, the annual carbon dioxide budget has always been used up by the end of March, even though renewable energies already account for 46.1% of net electricity generation (ISE 2020). Thus, in order to comply with the Paris Agreement, this share still needs to be significantly increased over the next few years. To this end,



the German government has presented its Climate Action Plan 2050, which aims to achieve a renewable energy share of 80-100% of electricity production by 2050, and an 80-95% reduction in greenhouse gas emissions compared to 1990 (BMU 2017). As no course of action has been linked to this decision, the Climate Action Programme 2030 has been submitted, specifying the measures on which Germany's contribution to international climate protection will be based (BUNDESREGIERUNG 2019). The transformation of the energy sector is of central importance in this context, as it involves the gradual phasing-out of high-emission coal-fired power generation (by 2038) and the continuous expansion of renewable energies (aiming at a share of gross electricity consumption of 65% by 2030). This is intended to reduce carbon dioxide emissions in the energy sector to 175 megatons in 2030, or by 55% on an intersectoral basis compared to 1990. However, how this transformation can succeed in view of the limited land resources available, and what social consequences would accompany such an intervention in rural spaces, is currently barely foreseeable. The 1.8 million photovoltaic systems (BSW 2020), 31,000 wind turbines (BWE 2020) and 9,400 biogas plants (FACHVERBAND BIOGAS 2020) that have so far been constructed – primarily in rural areas – have mechanised the landscapes to such an extent that any further expansion will likely engender very low acceptance amongst the general population (BOSCH 2020). The reasons for the gap between society's desire for a climate-friendly way of life and the reality of rejecting the technologies needed to achieve this end have a strong geographical reference. However, it is yet to be thoroughly systematised to what extent energy landscapes arise from the social production of values concerning the climate movement, and what landscape transformation processes could be expected if the objectives of those social groups that regard the expansion of renewable energies as a key agent of global climate policy were to win through. In view of the large amount of land required for renewable energies, numerous competing land uses, the very few restriction-free locations and the low level of acceptance, however, the drawing up of a national climate contribution plan would not be very helpful if corresponding spatial scenarios, which are able to depict the long-term quantitative goals in their potential spatial dimensions, were not outlined at the same time.

Hence, a regional case study will be presented herein, in order to illustrate how our landscapes would have to change if a specific, climate protection-oriented form of energy landscape were to be

established. In accordance with the climate movement's values, which are based on the rational foundation of decades of research on the influence of humans on recent climate change, this social lobby stands for the radical reduction of greenhouse gases and, consequently, the stark deployment of renewable energies (IPCC 2011). Therefore, it sees the expansion of energy landscapes as an inevitable development within rural areas. Based on this socio-political framework, the example of the Augsburg planning region will be used to analyse and visualise, with high spatial accuracy, what consequences for a landscape could be expected if the expansion of renewable energies were linked to the Paris Agreement as well as to the corresponding German Climate Action Plan 2050.

VAN D. HORST (2017) links the deployment of renewable energies directly to climate targets in his study "Energy landscapes of less than two degrees global warming." Unfortunately, the author does not elaborate further on his proposal and only abstractly argues for the creation of energy landscapes that fulfill the promise of being able to limit global warming to fewer than two degrees compared to pre-industrial levels. In view of the looming climate collapse, the author recommends a complete renunciation of aesthetic principles and the subordination of landscapes in the sense of the spatial priority of climate protection measures. Considering the growing climate movement, this argumentation, which is radical in landscape planning and consistent in climate policy, seems to hit the nerve of time. Both VAN DER HORST'S as well as the climate movement's demands heavily affect popular notions of the 'lived energy landscape' (BOSCH and SCHMIDT 2020a).

The need to put this specific social construction of the lived landscape at the centre of spatial analyses arises, on the one hand, from the steadily decreasing time frame in which to effect adequate responses to the threatening consequences of anthropogenic climate change. On the other hand, the demands to define climate protection goals, and to meet these goals by means of a forced expansion of renewable energies, have become part of the social mainstream, so spatial concretisation of this social perspective on the landscape seems somewhat appropriate. However, this should by no means negate those perspectives that stand for a strongly restricted expansion of renewable energies and therefore strive for a completely different form of 'lived energy landscape'. FRAUNE and KNODT (2018, 1) emphasise that climate policy has become a 'positional issue' and therefore strongly polarises

society. There is no doubt that the energy transition has already led to a large consumption of land by renewable energies. This so-called ‘energy sprawl’ (KIESECKER and NAUGLE 2017) has become a decisive driver of land use change (TRAINOR et al. 2016). The ecological and social consequences of these landscape changes are drastic and challenge the intended path of ecological modernisation and climate protection (YENNETI et al. 2016), so it is therefore important to explore the spatial dimensions of potential future renewable energy landscapes. In this sense, we proceed from the following research questions:

- 1) To what extent is it possible to model regional energy landscapes that comply with the Paris Agreement under current spatial conditions?
- 2) To what extent do climate change mitigation strategies alter landscapes, and what alternative spatial developments are possible?
- 3) What spatial quantities and social qualities of energy landscapes must be expected in the sub-regions of Germany if a regional contribution to limiting global warming to below 2°C is to be made?

In order to answer these questions, the following objectives are pursued:

- **Modelling and visualisation of potential sustainable energy landscapes**

The expansion of renewable energies is linked to the Paris Agreement and the corresponding German climate protection contribution. The potential spatial patterns of renewable energies that will make it possible to limit global warming to below 2°C shall be modelled. Taking into account the natural site factors of wind energy and photovoltaics, and in coordination with competing land uses, the power sector in the Augsburg planning region must be climate-neutral at the latest when the respective regional CO<sub>2</sub> budgets have not yet been exceeded.

- **Analysis of the effects of variable spatial restrictions**

The next step is to analyse what energy landscape options arise if the spatial restrictions that apply to renewable energies remain variable in the models. This variability results from the different weightings of those restrictions that are based on numerous competing land uses (e.g. regional planning law, nature and species

protection, distance areas). This makes it possible to determine the extent to which a particular type of land use, and the exclusionary effect it has on renewable energies, affects climate protection measures, and the extent to which adjustments in the exclusion criteria could help to create alternative spatial solutions for establishing climate-neutral energy landscapes.

- **Reflection of probable social conflicts**

Based on the insights above, it is appropriate to reflect probable social conflicts, since coordinating energy production with competing land uses may lead to significant land use changes. The aim is to anticipate to what extent the establishment of CO<sub>2</sub>-neutral energy landscapes will be accompanied by conflict-prone spatial developments, and to what extent possible social conflicts can be countered with adapted spatial strategies. In particular, it is necessary to discuss which actors could be most affected by the conflicts resulting from energy landscape transformations.

## 2 Theoretical background

Technology in general functions as a vehicle for the realisation of social patterns of communication, coexistence and the exercise of power. Furthermore, technology makes it possible – as an instrument of the ruling class – to reproduce social conditions (HÄUSSLING 2019; RECKWITZ 2003; RAMMERT and SCHUBERT 2017). Consequently, renewable energy technologies and the landscapes arising from them are also carriers of social structures, processes and orders (CALVERT et al. 2019). Language plays an important role in this scheme, since the practice of discourse gives objects their meaning and significance, thus making landscapes tangible and structured (DIAZ-BONE 2006, 73). LEFEBVRE (1991, 28/49ff./57) points out that it is precisely the immaterial spatial products (e.g. culture, values, tradition, art), which are generated through respective language systems, that give each space its very specific meaning. In this regard, the linguistic codes of the bourgeoisie dominate, decisively shaping the construction of institutions as well as the legislative procedures according to capitalist criteria. This gives rise to spaces of quantification and calculation in which commodification is at the forefront – next to which the necessities of ordinary people tend to be marginalised (FUCHS 2019, 136f.).

This results in the following. If scenarios on the possibilities of a climate-neutral society are to be modelled, it must be considered that the landscapes produced in this process cannot be created on the basis of neutral institutional prerequisites and legal framework conditions. Capitalist principles have already shaped the planning foundations of landscape design too much to be circumvented by the envisaged spatial models. Therefore, the results of the study – i.e. the potential climate-neutral energy landscapes – must be understood as a landscape output in a capitalist-dominated world. This can manifest in an unfair distribution of renewable energies (BOSCH and SCHMIDT 2020b) whereby technological concentrations could accumulate in certain peripheral subspaces, and technology-free landscapes could be preserved elsewhere due to power constellations, as shown by COWELL (2010).

ZIMMERER (2017, 465ff.) explains that energy systems are always associated with social, economic and technological power and that neoliberal economic methods, which reduce landscapes to a production factor, dominate the deployment of renewable energies. Ultimately, social control can be wielded through the economic control of energy landscapes (HARRISON and POPKE 2017, 491). According to this logic, locations that have already suffered from severe technological intervention and ecological degradation are the main sites for the expansion of renewable energies (COWELL et al. 2012). BICKERSTAFF (2017, 439ff.) refers to this scenario as ‘peripheralisation’ and describes that politically powerless areas are often the target of neoliberal calculus when choosing a location for power plant installation. The consequence, according to the author, is the development of an ‘energy underclass’. BRIDGE et al. (2018, 176) add that every energy landscape produces winners and losers. According to the theoretical approach taken by LEFEBVRE (1991) in ‘The Production of Space’, the domination of capitalist actors finds its expression in ‘conceived space’. This space represents capitalist elements that have been conceived by powerful persons, with a focus on the creation of territorial structures and the establishment of institutions – cf. GAILING (2012, 198ff.) – that legitimise these constructs through laws, land use rights, spatial planning guidelines and maps. In order to break up the dominance of ‘conceived space’, we want to vary the existing spatial planning bases for renewable energies that have emerged over many decades from a capitalist order (cf. BOSCH and SCHMIDT 2019). To do so, we try to create scenarios in a way that in principle enables the fairer spatial redistribution of technologies.

We assume that this approach has a significant impact on the ‘lived space’, which is subordinate to the ‘conceived space’. The ‘lived space’ arises from a process of transcending social conditions (CALVERT et al. 2019, 193), and we believe that analysis thereof is crucial for understanding support for and resistance to new energy technologies, as it considers the perspectives of common people and residents. This is particularly relevant, as these people experience space in a more passive way, forced as they are to accept infrastructural changes brought about by projects negotiated by more powerful energy transition actors. Social life, which consists of verbal and non-verbal links between culture, art, symbols, signs, memories, identities and images, reacts to these developments, finding its expression in the ‘lived space’ (FUCHS 2019, 137). After completing the modelling or whilst discussing the results, it will therefore be necessary to pay attention to the effects the modelled energy landscapes might have on ‘lived spaces’ – as well as to the social conflicts that might be implied. With regard to the social acceptance of energy concepts, such a reflection is of great importance.

The extent to which these concepts can be implemented locally also depends on the opportunities for civic participation. For example, projects initiated on a communal basis attain much greater acceptance than those initiated by supraregional investors or large corporations. In this sense, ‘community energy’ (DUSYK 2017, 502f.), as a symbolic contrast to large, centralised energy networks, represents a form of public protest. It suggests an alternative planning approach for energy transition, in which municipal commitment, municipal control and municipal ownership are the leading principles (VAN VEELEN and VAN DER HORST 2018, 22). Moreover, the symbolism of community energy goes hand in hand with the symbolism of a small-scale venture – as a premise for a prosperous human-nature relationship (GÄBLER 2019, 331ff.). Behind this lies people’s desire for an understandable and harmonious world that is challenged by globalisation.

Furthermore, renewable energy landscapes also symbolise inefficient policies that consume public money (SIJMONS and VAN DORST 2013, 57). FRAUNE and KNODT (2019) note that right-wing populist parties are challenging climate protection measures and ensuing energy transition, by attacking moderate parties that are committed to climate protection and who advocate stronger civic participation, especially in the deployment of wind energy; however, the right-wing parties by no means understand this to be a transparent and open-ended process but rather

a destructive campaign directed against energy transition (EICHENAUER et al. 2018, 641). Even though it may be difficult to understand, this strong aversion to climate-neutral energy landscapes is also an expression of ‘lived spaces’ and must be taken seriously in this respect. Therefore, a considerate expansion of renewable energies, which could generate more acceptance for climate protection measures, must take into account the spatial identities of all citizens. Often, there are strong emotional bonds between places and the people living in them. DEVINE-WRIGHT (2009) refers to this phenomenon as ‘place attachment’, which the expansion of energy infrastructure can harm severely. A closely related concept is that of ‘place identity’. This term labels the way the physical-material and symbolic-immaterial properties of a place affect the self-perception of an individual or a group (BRIDGE et al. 2018, 192).

Spatial modelling within large investigation areas, however, quickly reaches its limits when it comes to capturing spatial identities, as these are primarily bound to local contexts. This venture therefore goes beyond the scope of this study. For the concrete implementation of climate-neutral energy landscapes, in which many planners, municipalities and citizens could participate, the inclusion of these contexts would certainly be an option. The present study does not pursue this strategy, since it is first of all concerned with the large-scale exploration of potential spatial energy sources. Nevertheless, the social implications of these potentials are discussed.

### 3 Method and Results

#### 3.1 Approach and data preparation

The modelling of energy landscapes is based on a Geographic Information System (GIS), which helps identify the spatial patterns of renewable energies that would most likely make it possible to limit global warming to below 2°C. Taking into account the natural site factors of wind energy and photovoltaics, and in accordance with competing land uses (e.g. nature conservation), the electricity sector for the selected study region needs to be carbon-neutral at the latest when the corresponding regional emissions budget has just been used up, i.e. when it has not yet been exceeded.

In view of the currently existing global carbon dioxide budget (2° target), a regional carbon dioxide budget is derived that will allow for the gradual development of climate-neutral energy landscapes.

Based on linear modelling, starting in 2020 and ending in 2070, the spatial diffusion of renewable energies is thus linked to the speed of the phasing-out of fossil-nuclear power generation. The average exit speed targets the year 2050, because, according to the German government, society should be carbon-neutral by then. The German government’s absolute minimum target is to provide 80% of electricity from renewable sources by 2050. Assuming this minimum, aligned with a linear deployment programme, the full transformation of the electricity sector will be completed in 2070. In this sense, the development of renewable power capacities is to be understood as a capacity-related countermovement to the dismantling of fossil power generation. Consequently, the calculations must be made in such a way that the sum of the electricity yield from fossil and regenerative generation capacities corresponds to regional electricity demand at all times.

In this regard, regional carbon dioxide budgets have a time-limiting effect. For this purpose, the current global carbon dioxide budget (1,083 gigatons) was determined and converted into a per capita budget in reference to the world population (129.5 tons per capita). Based on the size of the regional population (903,487), the regional carbon dioxide budget for the Augsburg planning region (406,541 hectare) was derived (126 megatons). The emission shares of the heat and fuel sector were then subtracted from the respective regional total budget of still permissible carbon dioxide emissions, so that the carbon dioxide budget of the power sector remained (currently approx. 30% = approx. 39 megatons).

When the amount of electricity from fossil fuel generation is reduced as a result of dismantling power plants, the restriction-free sites of the respective study region are filled with renewable energies until the electricity gap is closed. This compensation mechanism takes place in annual steps. For each grid cell (resolution 1 hectare), the renewable energy source (wind power or photovoltaics) that delivers the highest electricity yield per area at the respective location, and for which there are no spatial restrictions (e.g. nature protection, residential area, no subsidy by law) in terms of land use and accessibility, prevails in the competition between the various renewable energies. In the following years, this process is repeated until the electricity sector is carbon-neutral and thus transformed.

Since the Augsburg planning region, which has an annual electricity requirement of six terawatt hours, already obtains 50% of its electricity from renewable energies, of which photovoltaics, biogas,

and hydropower are the most important sources, any future expansion would only have to cover half of the regional electricity requirement. However, we assume that the expansion of e-mobility will lead to a 15% increase in total electricity demand in the long term. This additional amount was therefore added to the current electricity demand.

As the potential of hydropower has already been exhausted, and the increased cultivation of energy crops is no longer politically desired, the study focuses on wind energy and photovoltaics. Within the framework of the study, we assume that the substitution of fossil-nuclear power plants, whose share in the electricity mix currently still accounts for 50%, will be taken up equally by wind energy and photovoltaics, i.e. 25% each. In the case of total competition, i.e. without technological defaults, the focus of future expansion will shift to photovoltaics, as the Augsburg planning region offers better natural conditions for solar power. In view of the volatile character of renewable energy systems, however, it seems reasonable to aim at optimal coordination among the weather-dependent technologies, in order to ensure greater grid stability. For the spatial modelling of wind energy, the plant system Enercon E-138 EP3, with an installed capacity of 3.5 megawatts, was used. The modelled photovoltaics consist of polycrystalline modules (silicon-based). The solar plant system, developed by Hanwha Q.Cells, is called Q.Plus BFR-G4.1 and has a peak capacity of 285 watts.

In order to carry out the modelling, the first step was to acquire and prepare the necessary geodata. The focus was on central key figures in the regional energy system, such as regional electricity consumption and population size, shares of fossil and renewable energy sources in the energy mix, CO<sub>2</sub> emissions for the electricity, heat and fuel sectors, technology-specific CO<sub>2</sub> emissions, plant technology (e.g. efficiency) and the plant registers of existing renewable energies. In addition, data on the spatial distribution of land use classes (CORINE Land Cover, OpenStreetMap), natural site factors (Deutscher Wetterdienst, Energy Atlas of Bavaria), cultural landscape classifications (data from the district offices and the Office for the Protection of Historical Monuments) and energy infrastructure (data from the Bundesnetzagentur and network operators) were obtained (cf. BAYStMWI 2018; COPERNICUS 2018; DWD 2020; OSM 2020).

Furthermore, data on slopes and slope exposures – ‘Digitales Geländemodell (DGM)’ – were integrated (see LDBV 2020), which made it possible to exclude sites with a slope of more than 10 degrees, or

17.6%, for photovoltaics, as special equipment would be required on such sites and profitability would decrease due to inflated installation costs. Moreover, for potential PV sites with slopes between 5 and 10 degrees, the south-exposed slopes (SW, S, SE) were preferred to the north-exposed ones (NW, N, NE). Flatter slopes were modelled as flat surfaces. Finally, it should be emphasised that when expanding photovoltaics, an ecological compensation area equal to 30% of the module area must always be integrated into each solar power plant. This requirement was therefore implemented in the models. In addition, PV plants along freeways and railroad lines could only be modelled within a 110-metre corridor in accordance with the law (except scenario ‘Renewable Energy Act’). In agriculturally disadvantaged areas, it was necessary to ensure that no more than 70 PV plants could be installed per year (except scenario ‘Agriculture’ and scenario ‘Renewable Energy Act’).

For wind energy, the 10H rule valid for Bavaria, which states that wind power projects must maintain large distances between plants and settlements as long as no local majority legitimises smaller distances, was integrated into the models. Slopes steeper than 10 degrees were excluded for wind energy projects, since the installation costs would increase disproportionately. On steep slopes, installation is hardly possible anyway, since safe operating spaces for cranes cannot be provided.

After data preparation, the investigation area was divided into grid cells with a resolution of 100 metres. The following information was available for each grid cell: type of land use, technology-specific restrictions, power yield/area/year per renewable energy plant (depending on plant technology and natural potential) and accessibility (slope, exposure, access).

### 3.2 Scenarios

The determining factors in the transition are the spatial restrictions of renewable energies. In order to analyse these, data from the CORINE Land Cover dataset (COPERNICUS 2018) were used. It divides the earth’s surface into 44 land use classes (e.g. artificial surfaces, agricultural areas), thus making it possible to define on which areas renewable energies are restricted; for example, biosphere reserves currently represent strict exclusion areas. However, these restrictions have remained variable within GIS-based modelling, because if sustainable energy landscapes cannot be represented or are too conflict-prone in

view of the current planning law, it should be discussed to what extent changes in the restrictions still allow the low-conflict establishment of a CO<sub>2</sub>-neutral power sector. Therefore, it was necessary to analyse the extent to which existing spatial-legal interpretations (e.g. regional planning, nature and species conservation) affect the establishment of a CO<sub>2</sub>-neutral electricity sector, and to determine which spatial adjustments might offer alternative spatial solutions. For this purpose, six basic scenarios were developed. With the help of these scenarios, the access of renewable energies to specific land categories (e.g. nature conservation, agriculture) varied. As a result, a cartographic visualisation based on a GIS is available for each scenario, which, similar to the annual rings of a tree, depicts the necessary or possible annual “expansion rings” of renewable energies against the background of the Paris Agreement. In the following, only those scenarios are cartographically visualised in which significant spatial changes compared to the reference scenario can be observed.

**Reference Scenario:** This scenario investigates to what extent climate-neutral energy landscapes are feasible if current social framework conditions are kept stable. This concerns the presently existing distance regulations for renewable energies, planning regulations (e.g. spatial planning, energy laws), industrial manufacturing equipment, as well as restrictions regarding competing land uses (e.g. nature and species protection). Excluded areas for renewable energies are national parks, biosphere reserves and nature reserves, with bird sanctuaries added as restricted areas for wind energy. Additionally, the technology-specific distances away from settlements must be observed (10H-rule). The main focus of the expansion of wind power plants is in the north of the region, claiming several spatial clusters with increased growth (cf. Fig. 1). The spatially even more concentrated expansion of photovoltaics takes place in the south. A total of 120,367 hectares are available for expansion in this scenario (wind energy: 44,934 ha, pv: 75,433 ha). For the entire transformation, 5,337 ha are needed for wind energy and 4,235 ha for photovoltaics.

**Scenario Nature Protection:** Since renewable energies are excluded from many locations for reasons of nature and species protection, this scenario analyses on the one hand how a careful adaptation of nature conservation to the requirements of climate protection would affect the spatial diffusion patterns of renewable energies. Thus, it is examined to what extent the opening of landscape protection areas for a stronger use of renewable energies could alter the

spatial pattern of carbon-neutral landscapes (nature protection minus). Bird sanctuaries, biosphere reserves and nature reserves are therefore included in the energy landscapes. Compared to the reference scenario, national parks remain excluded areas. The reduction of restrictions concerning nature conservation does not lead to major spatial changes, since in the Augsburg planning region, the most profitable locations for renewable energies hardly overlap with those areas worthy of protection. Compared to the reference scenario, only the area available in principle increases by 433 ha for wind energy and by 9,480 ha for photovoltaics. A total of 130,280 hectares are available for expansion in this scenario (wind energy: 45,367 ha, pv: 84,913 ha). Again, for the entire transformation, 5,337 ha are needed for wind energy and 4,235 ha for photovoltaics.

On the other hand, this scenario also models how the spatial pattern of renewable energy landscapes changes if nature and species protection is further enhanced (nature protection plus). The assumption is that nature parks and landscape conservation areas will no longer be accessible to renewable energies. The spatial changes are enormous, as the expansion of renewable energies in the reference scenario takes place to a significant extent in the now additionally excluded areas (cf. Fig. 2): not only does the composition of the wind energy clusters in the north of the region change, but also new clusters of wind energy deployment emerge in the south, east and partly in the west of the region. The focus of the expansion of photovoltaics is shifting completely towards the east, and a total of 54,545 hectares are available for expansion in this scenario (wind energy: 22,801 ha, pv: 31,744 ha). On this occasion, for the entire transformation 5,767 ha are needed for wind energy and 4,250 ha for photovoltaics.

**Scenario Agriculture:** Due to the socially little accepted competition with food and animal feed production, arable land was excluded from the expansion of renewable energies, except for locations close to major roads, freeways and railroads. Recently, however, so-called “agriculturally disadvantaged” areas in Bavaria have been reopened for the deployment of open-space PV systems. In this scenario, this trend is reinforced, and it is examined to what extent the additional inclusion of unneeded arable land can affect the spatial patterns of renewable energies (Fig. 3). In order to model this, the limit of 70 PV plants that may be projected per year in agriculturally disadvantaged areas was removed. Compared to the reference scenario, the expansion of wind energy in the south slightly accelerates, and

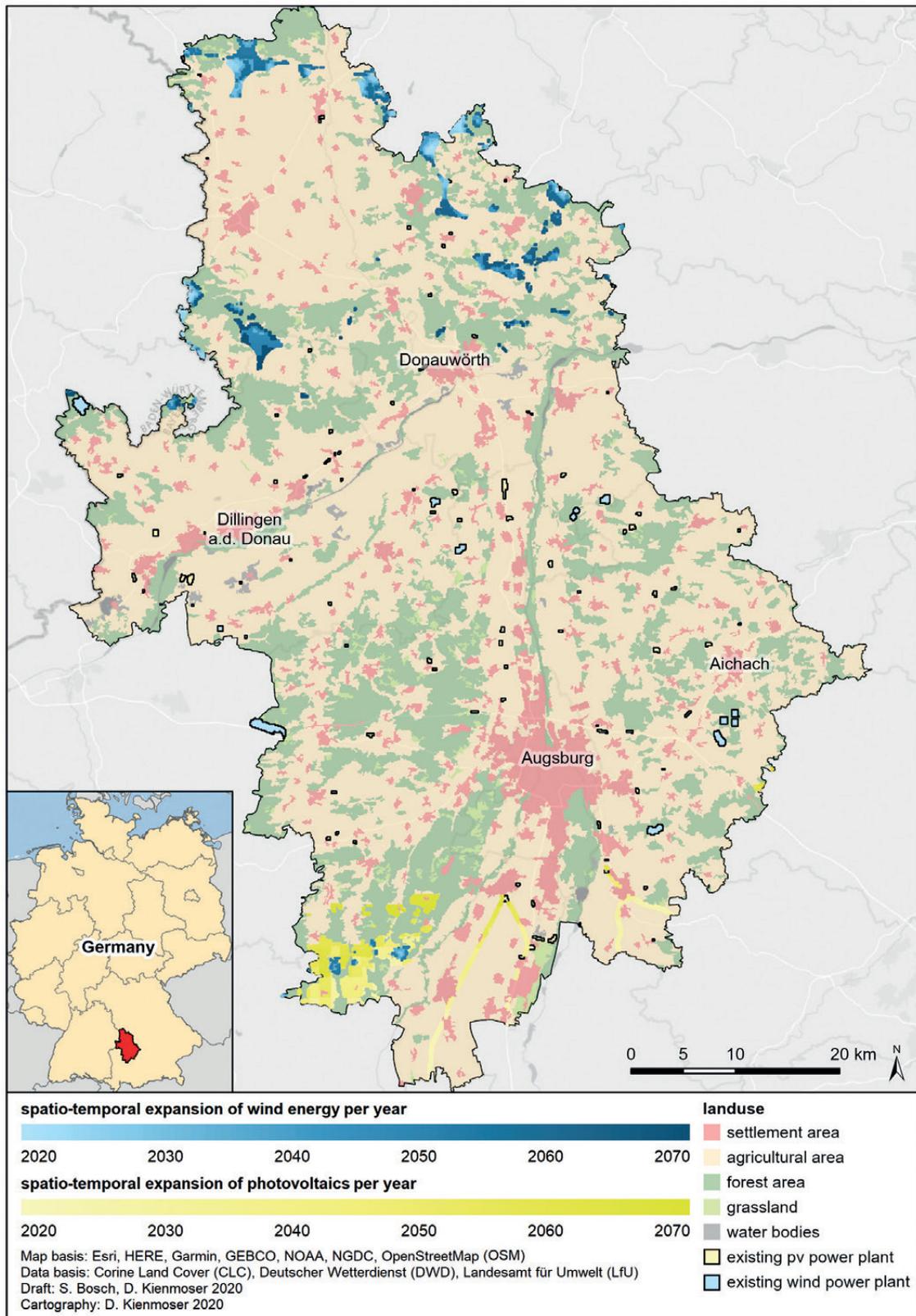


Fig. 1: Spatio-temporal expansion of renewable energies in the reference scenario

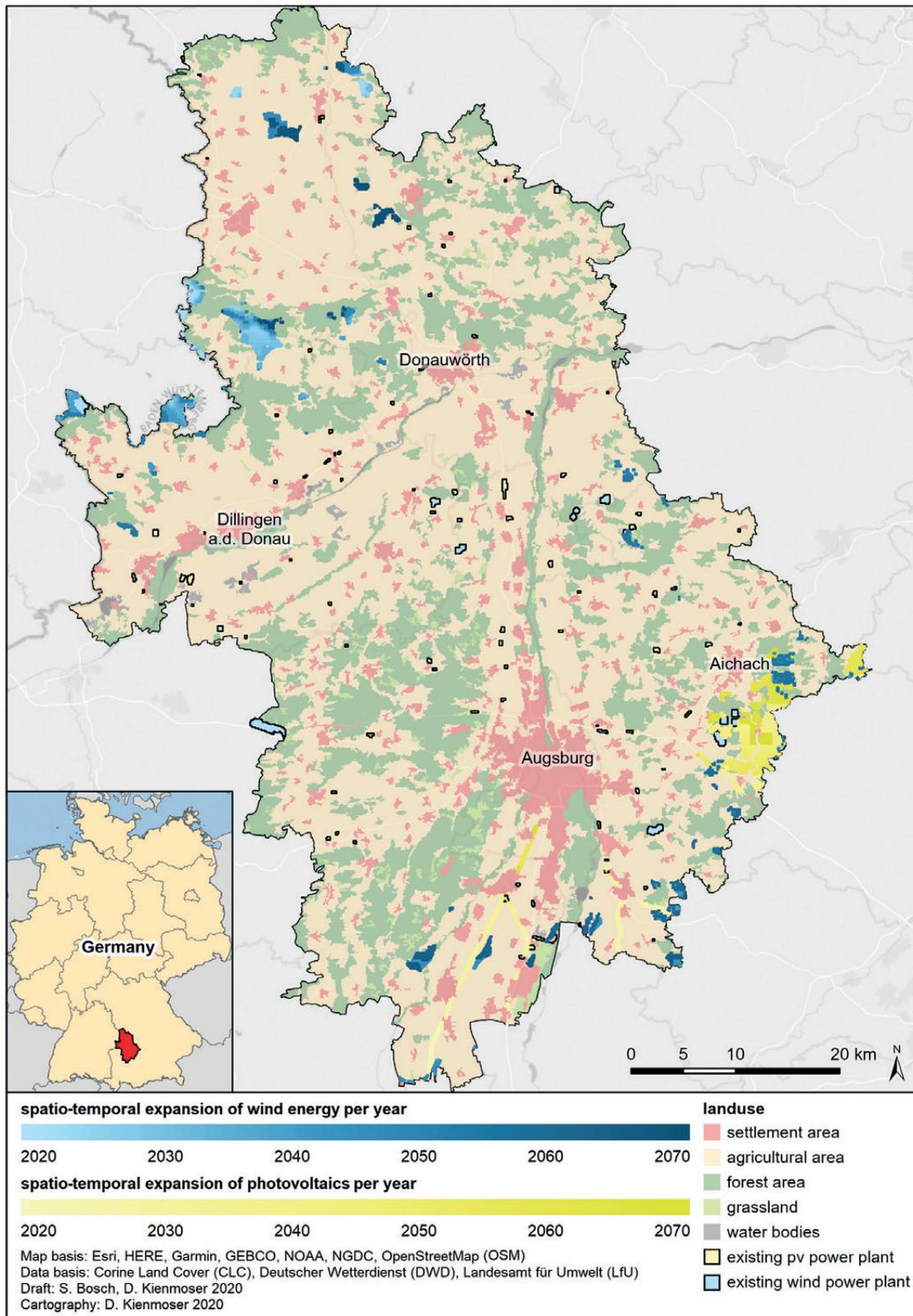


Fig. 2: Spatio-temporal expansion of renewable energies in the scenario nature protection plus

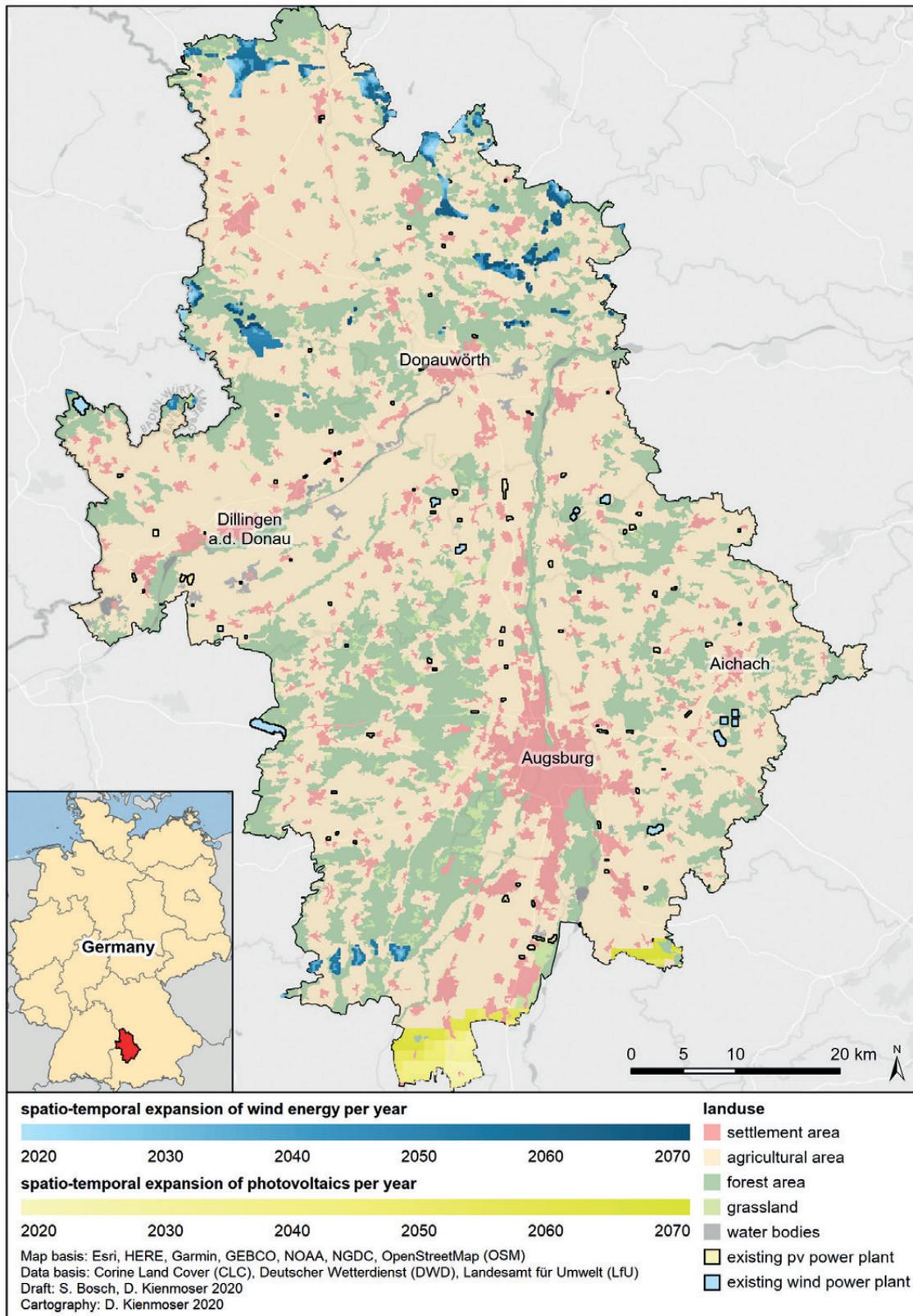


Fig. 3: Spatio-temporal expansion of renewable energies in the scenario agriculture

the expansion of photovoltaics shifts even more to the south of the region (cf. Fig. 3). The increase in the amount of land available in principle is remarkable, especially in the photovoltaic sector. A total of 295,466 hectares are available for expansion in this scenario (wind energy: 44,934 ha, pv: 250,532 ha). For the entire transformation, 5,323 ha are needed for wind energy and 4,206 ha for photovoltaics.

**Scenario Efficiency:** Technological progress (e.g. increase in efficiency) will produce more powerful energy plants and improve the space efficiency of the whole energy transition process. The extent to which this will have a spatial impact, and facilitate the achievement of objectives with regard to climate protection, is analysed in this scenario. Currently, many wind power plants in the 3.5 megawatt-power class are being expanded (e.g. ENERCON E-138 EP3). This type of power plant is the subject of successive further development, so that in a few years it can be assumed that more powerful wind turbines up to 5 megawatts will be expanded (e.g. ENERCON E-147 EP5 E2). The effects of an increase in efficiency were not calculated for photovoltaics, as the polycrystalline modules in use are already industrially highly mature, so no comparable increases are currently expected. Spatial modifications compared to the reference scenario are moderate, and yet it is noteworthy that an increase of 1.5 megawatt in the installed capacity of each wind power plant leads to an overall reduction of 719 hectares of land required. This increased land use efficiency has a particular impact on the northern landscape (cf. Fig. 4). Beyond this, a total of 120,367 hectares are available for expansion in this scenario (wind energy: 44,934 ha, pv: 75,433 ha). For the entire transformation, 4,618 ha are needed for wind energy and 4,235 ha for photovoltaics.

**Scenario Renewable Energy Act:** In this scenario, the spatial effects of legal adjustments that are planned by policymakers for the coming period – and are therefore likely to occur – are analysed. On the one hand, this concerns the enlargement of the expansion corridor along freeways and railroad lines, from 110 to 200 metres. On the other hand, they include the possibility to project not only 70 PV plants per year but 200 in agriculturally disadvantaged areas. The spatial changes in this scenario compared to the reference scenario are as follows (cf. Fig. 5): a total of 124,004 hectares are available for expansion in this scenario (wind energy: 44,934 ha, pv: 79,070 ha). For the entire transformation, 5,337 ha are needed for wind energy and 4,233 ha for photovoltaics. In contrast to the reference scenario, the targets – in

accordance with the legal framework – must already be achieved by the year 2050. The expansion therefore takes place much faster.

**Scenario export:** The basis of this scenario is the assumption that the region under investigation not only has to supply itself with renewable electricity, but also partly supplies a neighbouring planning region. Such interregional alliances are quite conceivable, as both regions could benefit from them: the supplying region could better exploit its renewable energy potential and thus boost the regional economy, while the receiving region could cover its large renewable power demand without having to deform the landscape. To model this in an exemplary way, we assumed that the Augsburg planning region must take over one-third of electricity production for the Munich planning region, which would correspond to an additional electricity production in the Augsburg region of 52%. The densely populated area of Munich, which is poor in suitable sites for renewable energies, and whose open land areas are of greater relevance to tourism than is the case in the Augsburg region, would be preserved in terms of landscape. The Augsburg region, on the other hand, could make those areas that are less attractive for tourism more valuable in terms of energy production. In this scenario, the expansion of wind energy and photovoltaics will again be significantly increased and thus greatly expanded spatially. Nevertheless, there is little change in the basic spatial-technological division of the region (cf. Fig. 6). A total of 120,367 hectares are available for expansion in this scenario (wind energy: 44,934 ha, pv: 75,433 ha). For the entire transformation, 9,126 ha are needed for wind energy and 7,037 ha for photovoltaics.

## 4 Discussion

The conducted modelling revealed that, in principle, there is enough space available to convert the electricity sector to carbon neutrality before regional carbon budgets are exhausted. However, grave landscape changes would accompany this energy transition, as the example of the Augsburg region shows.

In general, it is remarkable that the expansion of wind energy and photovoltaics would lead to strong spatial concentrations and spatial-technological polarisation: while the expansion of wind energy takes place primarily in the north of the region, photovoltaics has its spatial focus in the south. In contrast, existing wind and PV plants are located between these two future spatial expansion poles (cf. Fig. 1).

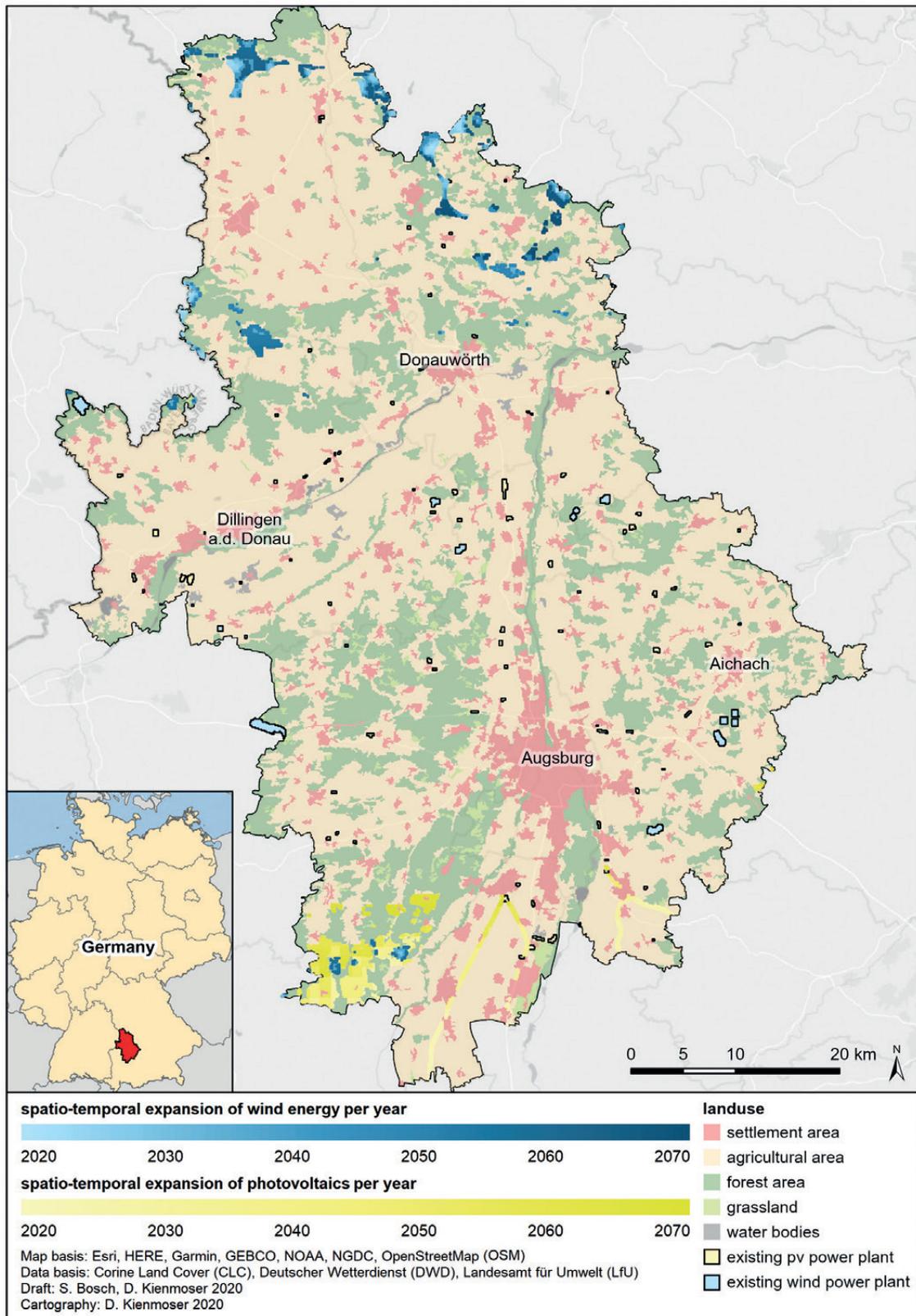


Fig. 4: Spatio-temporal expansion of renewable energies in the scenario efficiency

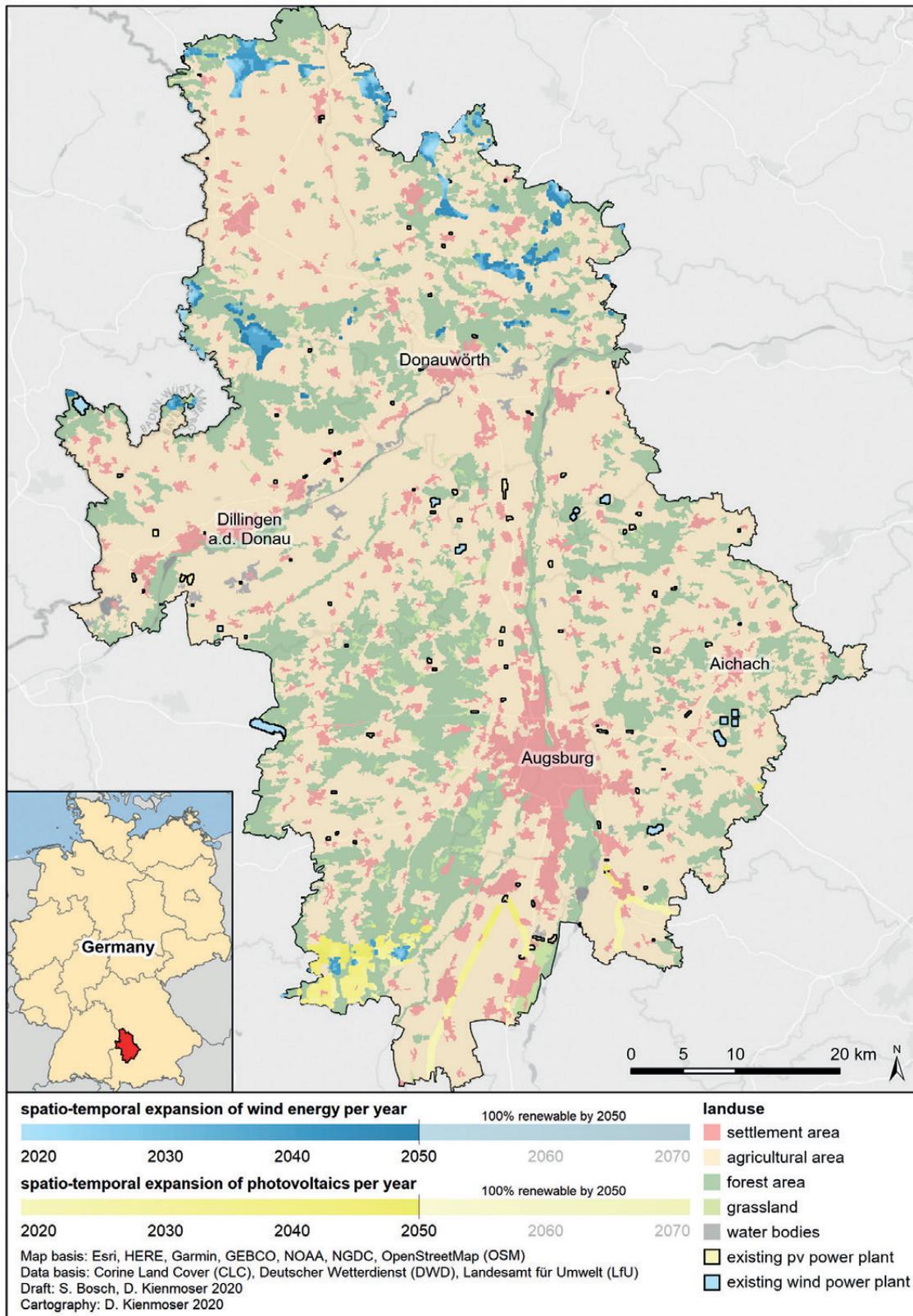


Fig. 5: Spatio-temporal expansion of renewable energies in the scenario Renewable Energy Act

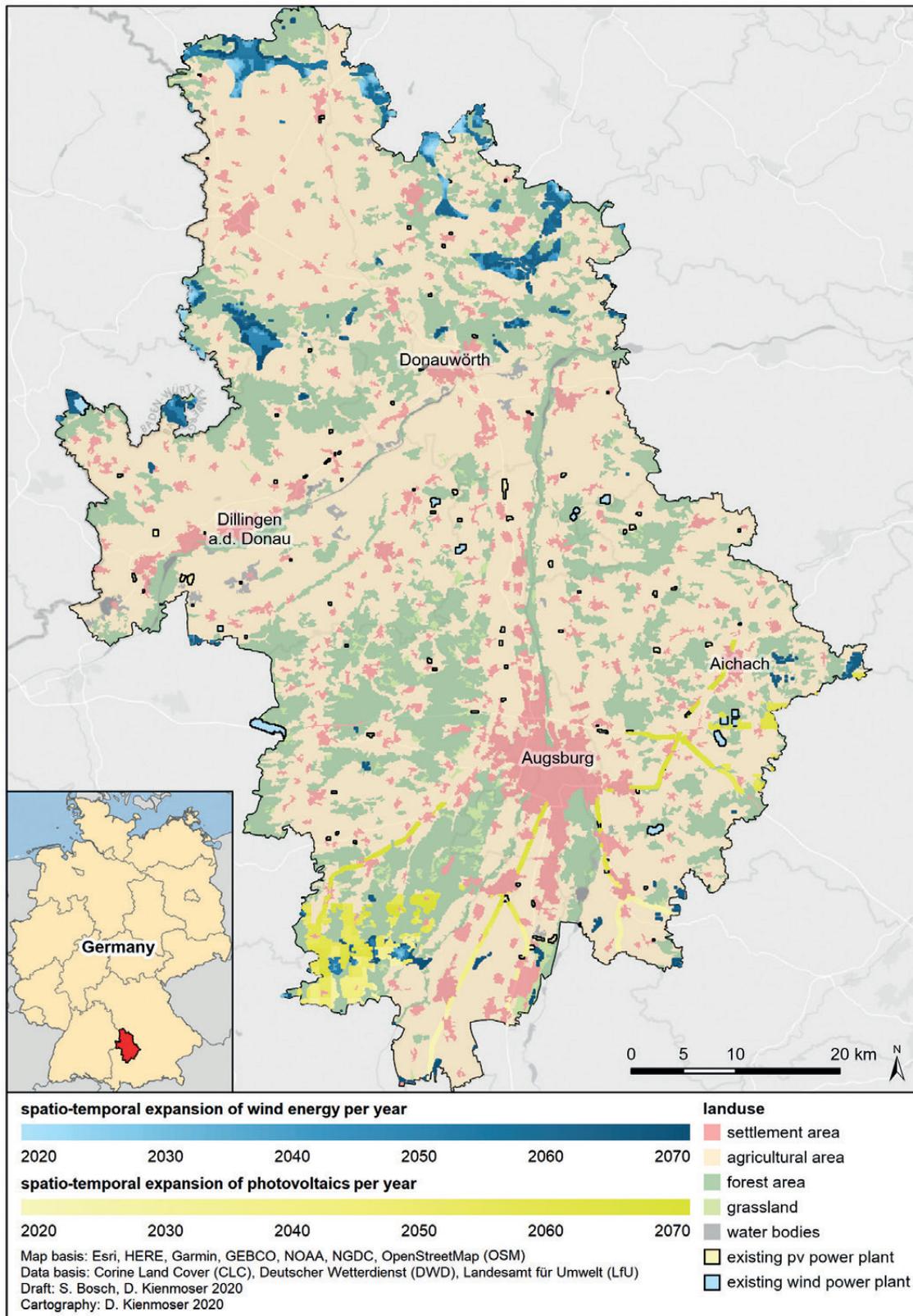


Fig. 6: Spatio-temporal expansion of renewable energies in the scenario export

If restrictions due to nature and species conservation are attenuated, there are no significant differences to the reference scenario, since the best locations for wind energy and photovoltaics, which are needed for the ratification of the Paris Agreement, are largely located outside nature conservation areas in the region. Apart from that, biosphere reserves do not exist in the region at all, so it may therefore be stated that there is currently, at least in the Augsburg region, no spatial conflict between climate protection and nature conservation. The existing legal framework for nature conservation provides sufficient spatial options for energy transition. In regions in which biosphere reserves play a greater role and, in addition, electricity demand is so great that renewable energies would have to penetrate much further into the protected areas than is the case in Augsburg, easing nature conservation and species protection would have a much greater impact on the feasibility of climate strategies. The intensification of nature and species protection, which in our scenario goes hand in hand with the exclusion of protected landscape areas and nature parks, would lead to a completely different spatial pattern of renewable energies compared to the reference scenario (cf. Fig. 2). Especially in the north-east of the region, wind energy projects would barely be possible. Their expansion would be even more concentrated in the north-west and on new sites in the south-east of the planning region. The spatial focus of photovoltaics would shift completely from the south to the west.

Beyond doubt, the spatial consequences related to future political decisions concerning the relationship between nature protection and climate protection are considerable, as the modelling demonstrates. The legal handling of nature and species conservation is associated with remarkable effects on the spatial patterns of renewable energies – and these in turn influence the living conditions of adjacent residents. It is currently still unclear whether social discourses are moving in the direction of easing or tightening nature and species protection. Differences in values concerning nature protection result from uncertainty as to whether actors adopt an anthropocentric or physiocentric perspective, and whether the landscape conflicts of energy transition are about protecting the landscape as a cultural achievement or preserving a clean natural environment (BERR 2018, 63). Anthropocentrism places humans at the centre of creation and assumes that they are the beings with the greatest value. In contrast, physiocentrism is based on the assumption that nature – and thus all natural entities – has a moral value (KREBS 2008). With regard to energy landscapes, rep-

resentatives of the anthropocentric perspective regard new technologies as a materialisation of the promise of growth, which generates tax revenues, low energy prices and jobs (INGLES-LOTZ 2016), whilst representatives of the physiocentric perspective prioritise the concerns of ecosystems, animals and plants (JACKSON 2011; WANG et al. 2015).

Beyond the legal handling of nature and species conservation, strengthening the strategy adopted by the state government of releasing agriculturally unfavourable locations for the expansion of photovoltaics has a significant impact on the spatial pattern of renewable energies (cf. Fig. 3). As the map shows, there is a shift in the spatial focus of photovoltaics towards the south, away from the relatively large cluster of wind turbines. This shift can be explained by the fact that the sunniest locations, which are restricted areas in the reference scenario, are located in the extreme south of the region. The energy landscape in the south, which is technologically mixed in the reference scenario, is thus once again more polarised in spatio-technological terms.

A feature that all scenarios have in common is that there are strong spatial concentrations of renewable energies. This is due on the one hand to the methodical approach, which for reasons of space efficiency includes the most profitable restriction-free locations first and foremost in the spatial expansion concept. On the other hand, planning law and legislation already provide a relatively narrow spatial corridor within which the deployment of renewable energies may take place. As mentioned in the context of ‘conceived space’ at the beginning, these spatial specifications are the result of powerful, capitalist-oriented decisions. The expansion of renewable energies is thus literally pushed in predetermined directions that make sense from a market economy perspective or are acceptable to the presently dominant actors in a society. Even nature reserves, which have been established as a counter-world to the ecologically heavily polluted capitalist centres of our society and have so far been completely spared by the energy transition, can be regarded as a very stable social construct of market-based regional planning, as BRIDGE et al. (2013, 335) showed. As a consequence, some ‘lived spaces’ would bear the landscape burden resulting from the climate protection measures, while large parts of the study region would be hardly or not at all affected. Those people in whose homeland the spatial concentration of renewable energies would occur would be marginalised by the energy transition. This would perpetuate the unfair spatial structures of a market-based regional planning scheme that is not

yet calibrated to sustainability. Undoubtedly, a new form of environmental (in)justice, renewable energy (in)justice or energy (in)justice (PELLEGRINI-MASINI et al. 2020) may be seen therein. Not least, the social balance of the transformation process, which was also intended to ensure sustainable social development, is jeopardised if certain social groups are excluded from decisions concerning the deployment of renewable energies. This represents a major threat to the acceptance of energy transition.

One way of minimising the social impact of such an ambitious project could be to give people who are significantly affected by the infrastructure measures a share in the profits of the corresponding energy projects, or to enable them to purchase renewable electricity at favourable rates – in keeping with the principle of distributional justice (LILJENFELDT and PETTERSSON 2017). Moreover, in the context of conceived space, it is necessary to consider to what extent the planning laws should be modified to allow a fairer and more even distribution of renewable energies. This could be achieved by adjusting the restriction regulations. However, spatial concentrations of renewable energies cannot be condemned and excluded per se, since they offer the opportunity, especially for economically peripheral regions, to use endogenous potential and to boost the regional economy (cf. Fig. 6).

## 5 Conclusion

The aim of this study was to show for the first time how our landscapes would change if the demands of the climate movement were actually implemented. The primary object was not to create a cartographic basis for concrete regional planning but to analyse the landscape and social dimensions that would have to be taken into account when transforming the energy supply towards climate neutrality.

In general, the study revealed that a strict orientation of 'lived spaces' to climate protection goals would make rural areas even more technologically deformed, thus radically transforming them both ecologically and socially. In concrete terms, the Augsburg planning region was used as an example to analyse what quantities and qualities of energy landscapes could be expected if international climate goals were taken seriously and converted to aid the transformation of the power sector. In principle, it was shown that given current planning law, existing plant technology and natural site factors, such an ambitious project could in fact be implemented within the foreseeable future. It also became clear, however,

that this transformation would entail considerable landscape changes, at least in certain sub-regions, and would greatly transform the 'lived spaces' of many inhabitants. This is not least due to existing planning and legal foundations, the structures of which have not yet been adapted to the requirements of a society striving for comprehensive sustainability and which have thus become an essential prerequisite for a spatially and socially polarising energy transition. A forced expansion of renewable energies under these spatial conditions, which, according to Lefebvre's theory, are the result of an economic system based on capitalist principles, has great socially explosive force and could undermine the acceptance of a transformation that is urgently needed. The ratification of the Paris Agreement therefore only seems realistic if the implementation of the energy transition more carefully considers the values, emotions, identities, perspectives and, ultimately, the needs of that large social group, which, while being equipped with less power of action, has had to submit itself to the installation of renewable energies in close proximity to its own living environment.

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