IRENES
Interreg Europe

European Union

# ANALYSIS AND MAPPING OF TRADE-OFFS BETWEEN RENEWABLE ENERGY AND ECOSYSTEM SERVICES

FIVE CASES FROM THE IRENES INTERREG PROJECT

SPECIAL ISSUE / AGENDA SETTING

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# 1. INTRODUCTION

## 1.1. BACKGROUND

IRENES is an Interreg project that aims at bridging renewable energy and ecosystem-services related concepts and at integrating them into energy-related policies at the regional level. One of the specific obejctives of the project is to explore the trade-offs between key ecosystem services (ES) and the provisioning of energy from renewable resources (RES). Thus, RES represent a subset of ES, and their provisioning may trigger negative impacts on the provisioning of other ES (for example, in the case of solar farms installation, the agricultural production might be affected). Hence, to pursue proper decarbonization it is key to understand our territories, identify where RES provisioning is promising, and where it would compromise the provisioning of goods and services that are key to the economies and the communities. If not, the reduction of emission will not underpin any sustainable development and there will be monetary, social and environmental costs that we cannot afford anymore.

Under this perspective, the work here presented shows mapping exercises of trade-off between RES and other ES undertaken by the consortium for the 5 contexts interested by the project. Namely, East Anglia (UK), Lower Saxony (Germany), Estonia, Veneto Region (Italy), Romania.

The adopted approach aimed at taking advantage of existing available data and methods. Thus, in line with the Interreg principle, the work aims at bridging theory and practice, and capitalizing on existing knowledge. Overall, the integration of methods and data were used to build, through GIS, trade off analysis for one (or a set of) RES, based on the interests declared by the Managing Authorities. ES investigated also differ by case and reflect highlights from meetings with stakeholders. Overall, it is possible to say that, even though for each of the five contexts data and methods used are different, the approaches and the processes draft a common path.

To conclude this brief introduction, the maps reported in this volume represent a fundamental part of the IRENES Interreg project, as first the methodology for producing the maps were chosen based on the needs of the Managing Authorities that emerged thanks to the dialogue of the consortium with the local stakeholders and second, the maps produced were delivered to the Managing Authorities as technical basis for decision making and to support the design of new coming energy-related policy instruments and measures.

## 1.2. RELATED LITERATURE: A BRIEF REVIEW

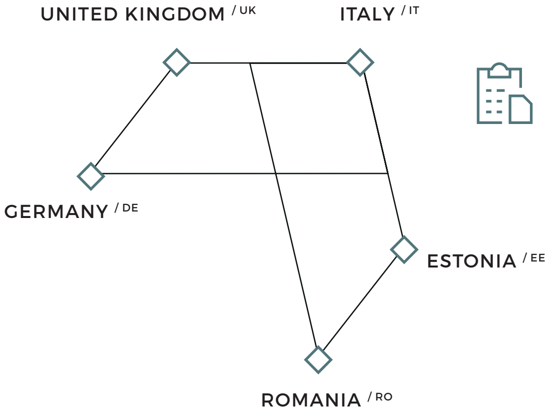
A large literature has highlighted the problem that energy production from RES involve ecosystems and the ecosystem services (ES) they provide (Braat and De Groot, 2012; Bouwa et at., 2018). For this reason, RES provisioning may affect or be affected by the supply of other ecosystem services in ways that have become critical for the wellbeing of communities and the sustainability of their economies (De Pascali et al., 2020; Howells & Roehrl, 2012). Since ecosystems, as a whole, may deliver several ES at the same time, the provisioning of RES, being one specific ES, can trigger synergies or trade-offs with other ES (Haase et al., 2014).

Typical examples of such trade-offs can be seen in, food-production loss due to biomass production or installation of solar panels, or in the interference with landscape visual perception due to the installation of windfarms (Hastik et al., 2015), putting at risk the sustainability of the transition to RES (Picchi et al., 2019).

Moreover, the upscaling of RES while introducing competition in terms of land use, thus impacting environmental sustainability, can also negatively affect the social acceptability of RES and thus undermine their diffusion (Jackson, 2011; Tilman et al., 2009; Bertsch et al., 2016). Hence, if these trade-offs remain unsolved, the operationalisation of energy plans (e.g., regional energy plans, local climate mitigation strategies) and the sustainability of RES can be compromised.

While research has progressed in the ES trade-off analysis – including RES production – bridging theory to policy and practice, remains a challenge, one that this project aims to address. For policy effectiveness, it is essential that the trade-off analysis, based on detailed mapping, focuses on the local scale. This renders it concrete and close to the work of the relevant decision-makers (Smith et al., 2017). Hence, the localised dimension of our research, is particularly useful as it could support the wide governance of RES integrated strategies, as well as the development of virtuous models regarding ESs. Often, within the EU context, the local dimension of RES production and energy plans does not address and integrate with ESs (De Pascali et al., 2020). This report, describes and compares the efforts to address the RES-ESs nexus with a trade-off analysis, in some cases also including a local energy plan.

# 2. REGIONAL CASE STUDIES: AN OVERVIEW




In the following we briefly describe the findings, relative to mapping of the trade-offs (and synergies), between potential generation of renewable energy and an array of ecosystem services distributed across the territories in our five regions/countries. In doing so we have been only applying established methods. For a more complete and advanced analysis of alternative methods, please do refer to our different project report focussing on the literature review.

The analysis in the individual case studies, discussed below, was guided by a common structure. In the first instance, the key idea was on how to introduce the concept of RES-ES trade-offs and synergies, through the interactions with the local stakeholders and the managing authorities involved for the assessments in RES-related spatial planning processes and achieving policy change. This dimension was labelled as "**Fit-for-purpose policy demand"**, which means that it is based on the policy needs expressed through the set of meetings with local stakeholders and the managing authorities involved, the objectives to reach through the RES-ES trade-off assessment and mapping was defined for each case. Thus, the second dimension of the analysis focuses on the knowledge needs, i.e. to identify both the spatial data on the supply of ES and on the potential supply of RES, at the local scale, combining them to make them useful for the spatial planning processes and policies. This dimension was labelled as **"Knowledge needs (specified from the analysis of the related policy demand)"**. The third, and final, dimension used in guiding the case studies, was to focus on the methods to be applied to ascertain Trade-offs and Synergies (TOs&Ss). This was labelled as **"Method for ES and RES TOs&Ss". In other words, based on the objectives to reach and existing potentials and constraints for the analysis (determined by the policy demand and the knowledge needs), a method for the RES/ES assessment and mapping was selected for each of the case studies.** Table 1 below, provides a description about the specific implementation of this scheme across the five regional case studies. The detailed implementation is then discussed, case by case, in the next section.

| CASE STUDY | FIT-FOR-PURPOSE POLICY DEMAND | KNOWLEDGE NEEDS (SPECIFIED FROM THE ANALYSIS OF THE RELATED POLICY DEMAND) | METHOD FOR ES AND RES TOS&SS |
|---|---|---|---|
| **ESTONIA** | After introducing the concept of RES-ES trade-offs in several events, members of the IKAs have repeatedly expressed an interest in its applications. Beyond its potential use in reshaping financial instruments, IKAs representatives were especially keen on using trade-offs assessments in RES-related **spatial planning processes. Specifically, in the context of wind and solar energy development, the Ministry of Finance alongside with regional and local planners are currently encountering difficulties in achieving balanced planning solutions.** In order to better guide spatial planning processes for RES, the IKAs expect to utilize IRENES readymade trade-offs and synergies maps, at spatial scales relevant to local planning processes. Using these tools, the IKAs expect to overcome the current lack of information and guidance in **spatial planning** for RES, and eventually achieve policy change. | The knowledge needs can be summarized as follows:<br>• Spatially explicit data on the supply of ES, ES hotspots and trade-offs among ES. Data is needed at a local scale, so it can serve as an input to currently ongoing spatial planning processes.<br>• Spatially explicit data on the potential supply of RES, at the local scale, so that it can be combined with the above and used in ongoing spatial planning processes. | A stepwise methodology is followed:<br>1. ES hotspots<br>2. ES bundles derived from PCA analysis<br>Production frontier across a range of ecosystem conditions, to unveil TOs&Ss. |

| CASE STUDY | FIT-FOR-PURPOSE POLICY DEMAND | KNOWLEDGE NEEDS (SPECIFIED FROM THE ANALYSIS OF THE RELATED POLICY DEMAND) |
|---|---|---|
| **ITALY** | Considering the state of the art of RES production in Italy, the policy makers have considered that there is interest in understanding potential trade-offs and synergies deriving from strategies and projects implementing RES production from solar energy. There is also an interest for agricultural biomass, however doubts due to the potential conflicts with food production are present. In addition, there is awareness that in some EU countries, agricultural biomass is only considered if obtained from leftovers, not from dedicated crops, right to overcome such conflict with food production. | Based on the present state of policy instruments and energy strategy (Piano Energetico Regionale, 2012), there is interest by the MA to further understand suitable areas and trade-offs related to the production of energy from solar farms and from agricultural biomass from left-overs (in order to choose among the two and/or identify combinations of solutions). At present, the bigger ratio of RES in Veneto derives from hydropower. Water represent a precious resource in the Region for energy production, but the MA stated that at present it is not recommended to increase the production of energy through hydropower. With regard to wind, wind speed does not comply with eolic plants requirement in most of the region's areas: hence, no room to increase energy production through wind mills either. Geothermal looks promising but needs further time and money-consuming investigations. Biomass from woodlands may be an option for mountainous areas, but the Region needs strategies to face the energy demand of urban and industrialized flat areas. Hence, given the urgent need to produce increasing amounts of energy from renewables, the MA has interest in understanding if promoting either solar or agricultural production, without creating trade-offs with the agricultural production, and possibly without compromising the landscape (with negative effects on tourism). |
| | **METHOD FOR ES AND RES TOS&SS** | A stepwise methodology is followed:<br>• Mapping suitable areas based on ES trade-offs analysis for agricultural biomass from leftovers<br>• Mapping suitable areas based on ES trade-offs analysis for solar farms<br>• Compare mismatches and common highlights |

| CASE STUDY | FIT-FOR-PURPOSE POLICY DEMAND | KNOWLEDGE NEEDS (SPECIFIED FROM THE ANALYSIS OF THE RELATED POLICY DEMAND) | METHOD FOR ES AND RES TOS&SS |
|---|---|---|---|
| **UK** | From the work on the UK SWOT, it is clear that the interaction between renewable energy and other ecosystem services is recognised as an important issue at a national level, but the policy landscape and associated instruments are changing. The Industrial Strategy has been replaced by a new Plan for Growth (due to challenges associated with Brexit and post-Covid recovery). In addition, there has been a new Agriculture Act (2020), Energy White Paper (December 2020), Environment Act (2021) and Net Zero Strategy (2021). Our assessment of trade-offs and synergies has needed to align with these changing circumstances to attract interest and engagement with stakeholders. | Recent discussions with officials in government departments and local authorities have highlighted a need for information on the spatial coincidence of RES potential and other ES across regions. This is to help identify strategic opportunities or problems (e.g. where infrastructure investment is required). Decisions regarding RES-ES interactions at the level of the individual project or site are regarded as appropriately handled within the planning system. However, what more problematic are the issues regarding cumulative impacts of increased RES generation and the spatial scale at which these should be assessed. | In the first instance, we need to visualise and quantify the spatial coincidence of potential generation from different RES and other ES. This is needed to help communicate the potential issues to stakeholders. We undertook a GIS analysis using our RES-SOTA results and existing ES databases to generate maps comparing potentials for 1 km grid squares across our East of England study area. Grid cells and administrative units (such as local authorities) were classified on their relative potential for delivery of different RES and other ES. |

| CASE STUDY | FIT-FOR-PURPOSE POLICY DEMAND | KNOWLEDGE NEEDS (SPECIFIED FROM THE ANALYSIS OF THE RELATED POLICY DEMAND) | METHOD FOR ES AND RES TOS&SS |
|---|---|---|---|
| **GERMANY** | ERDF funding can provide marginal support for the energy transition in Germany, for example by supporting generation technologies that are not economically viable on the market but that are particularly compatible with nature. To this end, it is necessary and possible to open up the funding guidelines in order to promote the protection of ecosystem services coupled with innovative generation technologies. For this, the already formulated Lower Saxony strategy with the combination of environmental and climate protection would also have to be reflected in new funding directives. | A future, overarching energy mix for Lower Saxony that is compatible with nature and consists of the interaction of wind, solar or bioenergy should be defined.<br>So far, the energy sources have been considered individually, as the actor networks and the responsibilities in the area of solar energy and wind energy are very different.<br>Since there are few regional energy concepts available, the coordination of potentials and expansion possibilities is not yet part of regional planning. The trade-offs between the different energy sources could be considered even more. | We have chosen an area-based approach and analysed those areas that can be used for the production of renewable energy in an environmentally compatible way in 2050. The focus of the analysis was on the production of electricity with wind energy onshore and solar energy on roofs as well as in open areas. Future developments in nature conservation (e.g. future nature conservation areas) are spatially located. With our data, energy production plants in Lower Saxony can be optimally distributed according to natural potentials (trade-offs and synergies). The analyses can be transferred to the local level. In this way, the overarching goals of the state are to be taken into account at the local level and the community's responsibility to achieve the overall target (Germany's energy demand in 2050) becomes clear. In accordance with the requirements of the German Nature Conservation Act, the impacts of the energy plants on soil, water, landscape, biodiversity and people were taken into account in the analyses. |

| CASE STUDY | FIT-FOR-PURPOSE POLICY DEMAND | KNOWLEDGE NEEDS (SPECIFIED FROM THE ANALYSIS OF THE RELATED POLICY DEMAND) | METHOD FOR ES AND RES TOS&SS |
|---|---|---|---|
| **ROMANIA** | We had specific discussions with National Environmental Protection Agency ntroducing the RES-ES trade-offs and synergies because they have implemented in Romania the MAES. The National Environmental Protection Agency expressed the interest from two point of view, one linked with the use of the results of the MAES project in Romania and the second with the use of an appropriate tool to evaluate the trade-off between RES and between RES and other ES. | An analysis of the Trade-offs & synergies at the regional scale requires the following knowledge:<br>• spatially explicit distribution of ecosystem services<br>• spatially explicit distribution of RES exploitation<br>• design of a participatory meeting and landscape visualization. | In order to identify potential synergies and trade-offs across space and time, participatory methods will be applied. Through active participation, local communities can inform researchers, and reciprocally , about the optimum renewable energy scenarios and local transition. Participatory mapping combines local knowledge from stakeholders with GIS techniques to assess the actual situation and to choose between future development scenarios. In particular, regarding the cultural ecosystem services, the involvement of communities in participatory methods is the most relevant aspect, because participation protects the citizens and stakeholders contribution in defining the spatial distribution of cultural services and their level of supply.<br>The interrelation between RES and ES can be assessed through landscape visualizations, where people can perceive how the landscape will look like according to different levels in the supply of other ES. |

# 3. UK, EAST ANGLIA

BY ANDREW LOVETT, GILLA SUNNENBERG, TRUDIE DOCKERTY AND PAUL BOURGEOIS

First, a table (Table 2) provides a synoptic view of the main elements of the UK case study discussed in this section.
The table addresses four main fields (listed in the headings) discussing: the Policy instrument, the State of the art on mapping/assessment of ES, the RES development and the Socio-economic-environmental context.

### POLICY INSTRUMENT

Responsibility for energy and climate change within the UK government lies with the Department for Business, Energy and Industrial Strategy (BEIS). In 2017 it launched an Industrial Strategy, central to which was the Clean Growth Strategy. At the regional scale, Local Enterprise Partnerships (LEPs) have since developed Local Industrial Strategies and grouped together to produce Local Energy Strategies. In eastern England, three LEPs produced the Local Energy East strategy in 2018 which has shaped local thinking regarding decarbonisation initiatives to deliver a net-zero future.
Our SWOT analysis of these instruments considered the extent to which renewable energy and ecosystem services were assessed in an integrated manner. It highlighted that while there was intent to achieve such integration (especially at a national level), the mechanisms (e.g. funding schemes) and tools for implementation 'on the ground' were lacking.
Since the start of IRENES there have been a number of changes in UK policy instruments. The Industrial Strategy has been replaced by a new Plan for Growth. There has also been a new Agriculture Act (2020), Energy White Paper (December 2020), Environment Act (2021) and Net Zero Strategy (2021). In the UK Action Plan we are now focusing on implementation of the Net Zero Strategy because it is the key current policy that shapes the decarbonisation agenda at national, regional and local levels. However, the same issue of lack of guidance regarding renewable energy deployment and other aspects of land use still exists and so is the focus of the UK case study..

### STATE OF THE ART ON MAPPING/ ASSESSMENT OF ES

The UK has a long history of initiatives on the mapping and analysis of ecosystem services (ES). Examples are the reports of the National Ecosystem Assessment (http://uknea.unep-wcmc.org/) and the Natural Capital Committee (https://www.gov.uk/government/groups/natural-capital-committee). The latter recommended creating a 25 Year Environment Plan (https://www.gov.uk/government/publications/25-year-environment-plan) and since this was published in 2018 it has stimulated the incorporation of ES assessments into a range of policy areas.
There have also been many projects to make spatial data on natural capital and ES widely available. These include work by the UK Centre for Ecology and Hydrology (https://eip.ceh.ac.uk/naturalengland-ncmaps), atlases of data from Natural England (http://publications.naturalengland.org.uk/publication/6672365834731520) and assessment tools such as Natural Environment Valuation Online (https://www.leep.exeter.ac.uk/nevo/). The UEA team have recently completed an Natural Capital Evidence Compendium for two counties of the IRENES study area (http://www.nbis.org.uk/natural-capital-compendium) so we were very familiar with the available data for generating spatial data on ES for a trade-off analysis.

### RES DEVELOPMENT

In 2018 there were over 74,000 renewable energy sites with a capacity of 4,379 MW in the study region. Offshore wind accounted for 50% of this total, with 34% from solar photovoltaics and 8% from onshore wind. Electricity generation from land-based renewables represented 22% of regional consumption in 2018, the proportion rising to 59% if offshore wind is also included.
The potential for increasing generation from renewables was assessed for biomass crops, solar photovoltaics, and onshore wind by mapping a range of physical, regulatory or policy constraints. Results indicated that 28% of the region was not available, 19% possible for one renewable, 27% for two and 25% for all three. This result highlights the importance of considering renewables in combination since assessments in isolation will overstate potential.
Assigning available land to the highest generation potential resulted in a total calculated output of nearly 100 GWh. This was more than five times greater than total electricity consumption in 2018. However, utilising such potential is currently limited by the capacity of the electricity transmission and distribution network, quite apart from the opportunity costs of reducing food production or impairing delivery of other valuable ecosystem services.
More detailed evaluation of trade-offs is therefore needed to make a realistic estimate of potential, as well as identifying key barriers to address through policy instruments or funding mechanisms.

### SOCIO-ECONOMIC-ENVIRONMENTAL CONTEXT

The UK study region focuses on five counties and three unitary authorities in the East of England. Overall, the region accounts for nearly 14% of the land area and 10% of the population of England. It covers nearly 1.8 million hectares (ha) and is relatively flat. Much of the land is used for arable crops, along with pastures (particularly in river valleys), freshwater habitats (e.g. in the Broads National Park) and some woodland cover.
In 2020, the total population was 5.6 million. There are six main urban centres (Cambridge, Chelmsford, Colchester, Peterborough, Norwich and Ipswich), together with more continuous built-up areas in Hertfordshire and Essex (near London) that include settlements such as St Albans, Southend, Stevenage and Watford. The remainder of the region is rural in character, typically with a mixture of villages and market towns. Many of these rural areas lack connection to the gas network and have higher proportions of residents aged at least 65 (e.g. over 30% in northern Norfolk). However, other parts of the region are projected to experience population growth of over 10% by 2040, mainly due to land allocations for new house building close to key transport routes or around existing urban centres.

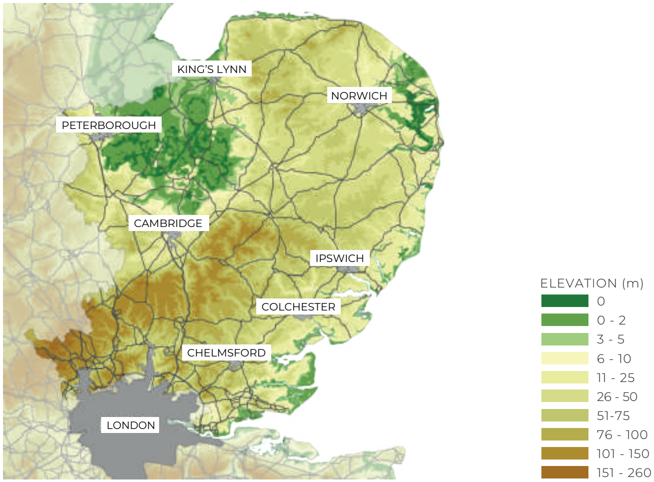
Secondly, the UK team identified and define the methods for their analysis, in order to meet the policy demand and respond to the issues presented in table 1 (section 2 of this work). The spatial analysis by the UK team, led by UEA, focussed on first developing an assessment of the 'state of the art' regarding renewable electricity generation in eastern England and then an examination of trade-offs and synergies between renewable energy potential and other natural assets. The specific study area is the East of England region, shown in **Map UK1**, on the left.

The first steps of the analysis consisted in developing detailed mapping of the electricity generation potentials for three types of renewable energy sources (Solar, Wind and Biomass) and converting them into standardised potentials in the form of power densities. Three GIS layers, one for each energy source type, were generated, as shown in the following maps.

This map **[Map UK2]** was derived data from the Global Solar Atlas, a resource developed by the World Bank Group and funded by the Energy Sector Management Assistance Program (ESMAP).

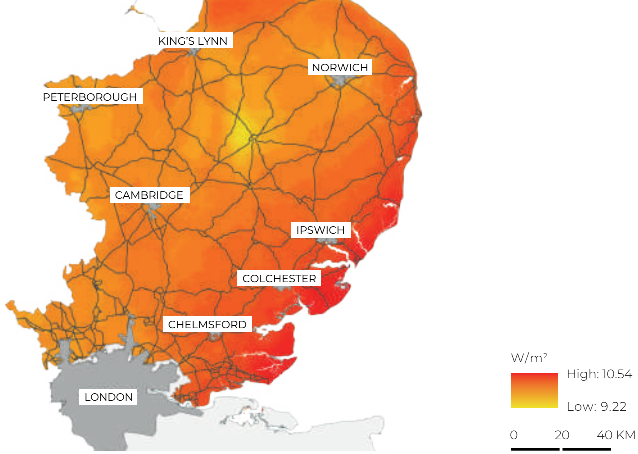
In detail, the map uses a solar radiation model, which takes into account the attenuation factors of solar radiation using data inputs from geostationary satellites and meteorological models[1]. GTI stands for Global Tilted Irradiation, capturing the total radiation received on a surface with defined tilt and azimuth, fixed or sun-tracking. This is the sum of the scattered radiation, direct and reflected. (Source Solargis: https://solargis.com/docs/methodology/solar-radiation-modeling)

**UK1: THE STUDY AREA**




**UK2: SOLAR GTI**

A solar power density map ranging from a low of 9.22 W/m2 to a high level of 10:54 W/m2.



1. First, clear-sky irradiance (values under the assumption of absence of clouds) is calculated using the clear-sky model, which considers the position of the sun at every instant together with the effect of altitude, concentration of aerosols (particles coming from different sources, natural and human), water vapour content, and ozone. Second, the data from geostationary meteorological satellites (from several satellite missions covering different parts of the Earth) is used to quantify the attenuation effect of clouds by means of cloud index calculation. The clear-sky irradiance calculated previously is then coupled with the cloud index to retrieve the all-sky irradiance values. The primary calculated global horizontal irradiance is further post-processed by other models to get direct and diffuse irradiance and global irradiance on tilted surfaces. These values are corrected for shading effects from the surrounding terrain.(Source https://globalsolaratlas.info/support/methodology)

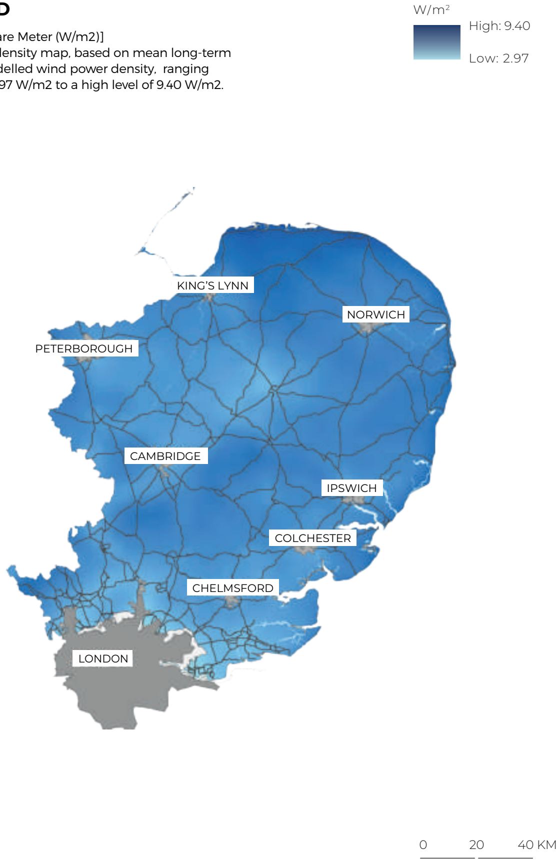
The data for **Map UK3** were obtained from the New European Wind Atlas, a free, web-based application developed, owned and operated by the NEWA Consortium. For additional information see www.neweuropeanwindatlas.eu.

Miscanthus offers a sustainable form of renewable energy. It is a crop that can grow well on more marginal land with poor quality soils. Output from the MiscanFor model (kindly provided by Dr Astley Hasytings, University of Aberdeen) were used to calculate energy densities, **Map UK4** showing values ranging from a low of 0.15 W/m2 to a high level of 0.33 W/m2.

These potential grids were combined with estimates (from the previous RES-SOTA analysis) of land available for the three renewables after hard constraints based on physical or regulatory limits had been excluded. These included buffer zones around roads, railways, rivers, lakes, airfields and residential areas. Other exclusions were steeper slopes and Ministry of Defence sites. The extent of these constraints varied between the three renewables, with the largest exclusion zones for onshore wind turbines and the smallest for biomass crops. Working on 100 m grid cells (i.e. 1 hectare in size) the generation potentials for each renewable were compared, the highest value selected and then summed for each of the 662 Middle Layer Super Output Areas (MSOAs) in the study region. The resulting totals were then divided by the total number of hectares in each MSOA, giving a final renewable electricity generation potential in MWh/Hectare as shown in **Map UK5**.

## UK3: WIND

[Watts Per Square Meter (W/m2)]
A wind power density map, based on mean long-term microscale modelled wind power density, ranging from a low of 2.97 W/m2 to a high level of 9.40 W/m2.



## UK4: MISCANTHUS

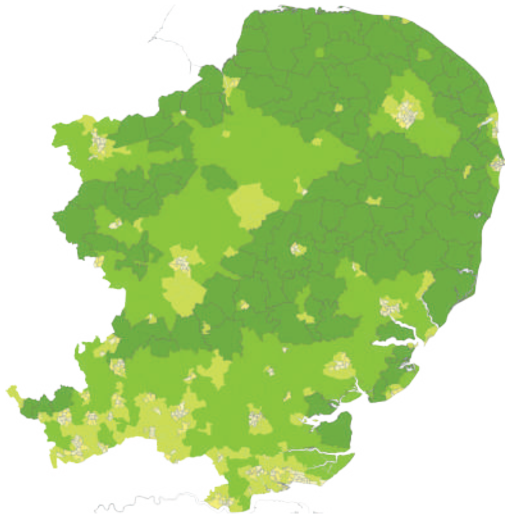
[Watts Per Square Meter (W/m2)]
Miscanthus offers a sustainable form of renewable energy. It is a crop that can grow well on more marginal land with poor quality soils. Output from the MiscanFor model (kindly provided by Dr Astley Hasytings, University of Aberdeen) were used to calculate energy densities, Map UK4 showing values ranging from a low of 0.15 W/m2 to a high level of 0.33 W/m2.

W/m²
High: 0.33
Low: 0.15


0 20 40 KM

## UK5: RENEWABLE ENERGY POTENTIALS IN MWH/HECTARE

MWH / Hectare
- 0.0 - 9.9
- 10.0 - 24.9
- 25.0 - 74.9
- 75.0 - 99.9
- 100.0 - 140.0



0 20 40 KM

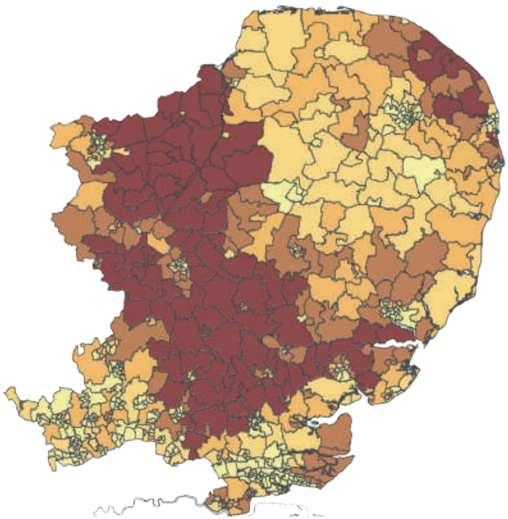
This analysis provided the renewable energy side of the trade-off and was then compared with other aspects of land use that provide a range of ecosystem services benefits. Maps UK6 to UK9 show the four aspects considered, with class intervals in the form of 5 quantiles so there are 20% of the MSOAs in each category.

**Map UK6** is based on information from the Agricultural Land Classification and shows the percentage of each MSOA with land in Grades 1 and 2 which are the best categories for food production.

Recreation potential is considered in **Map UK7** based on information on the distribution of a variety of different types of site.

### UK6: AGRICULTURAL LAND, GRADE 1 AND GRADE 2

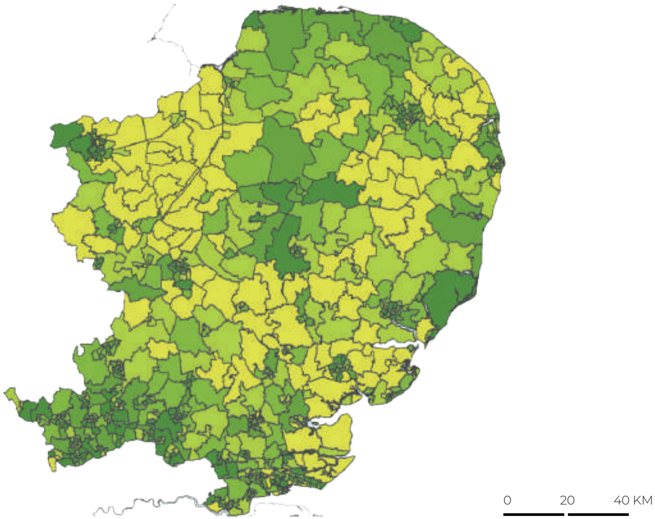
% of Land Area
- 0.0
- 0.1 - 8.9
- 9.0 - 25.5
- 25.6 - 51.6
- 51.7 - 100



### UK7: RECREATIONAL LAND

Historic Parks & Gardens, National Trust open land, National Forest Recreation Areas, Ordinance Survey Green Spaces, National Trails, CRoW (2000) Act land, Public Rights-of-Way (PRoWs.)

% of Land Area
- 0.0 - 2.2
- 2.3 - 4.3
- 4.44 - 7.6
- 7.7 - 12.5
- 12.6 - 54.1

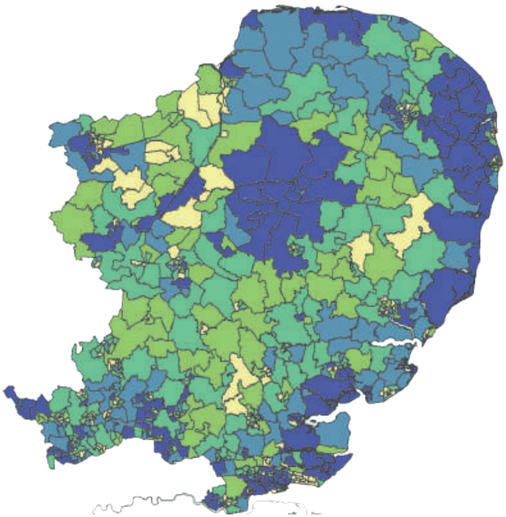


Designations of land for nature conservation or special habitats form the basis of **Map UK8** and woodland resources are shown in **Map UK9**. These four maps were chosen to represent different types of ecosystem services (e.g. provisioning, regulating, cultural and supporting), though we chose to map different types of land asset because this was easier to discuss with stakeholders. It also acknowledges that some types of asset (e.g. woodland) provide multiple services and benefits.

## UK8: PRIORITY HABITATS AND NATURE RESERVES

Priority Habitats Inventory, SPA, SAC, RAMSAR and SSSI designations, RSPB, national and local nature reserves.

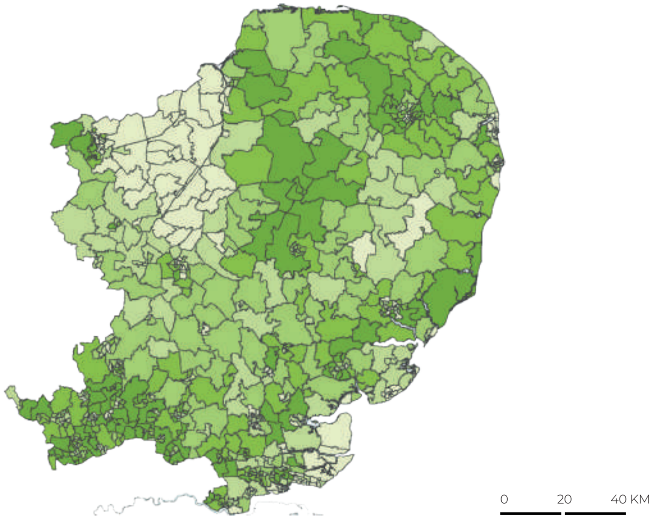
% of Land Area
- 0.0 - 3.3
- 3.4 - 5.7
- 5.8 - 9.6
- 9.7 - 16.1
- 16.2 - 81.6



## UK9: WOODLAND

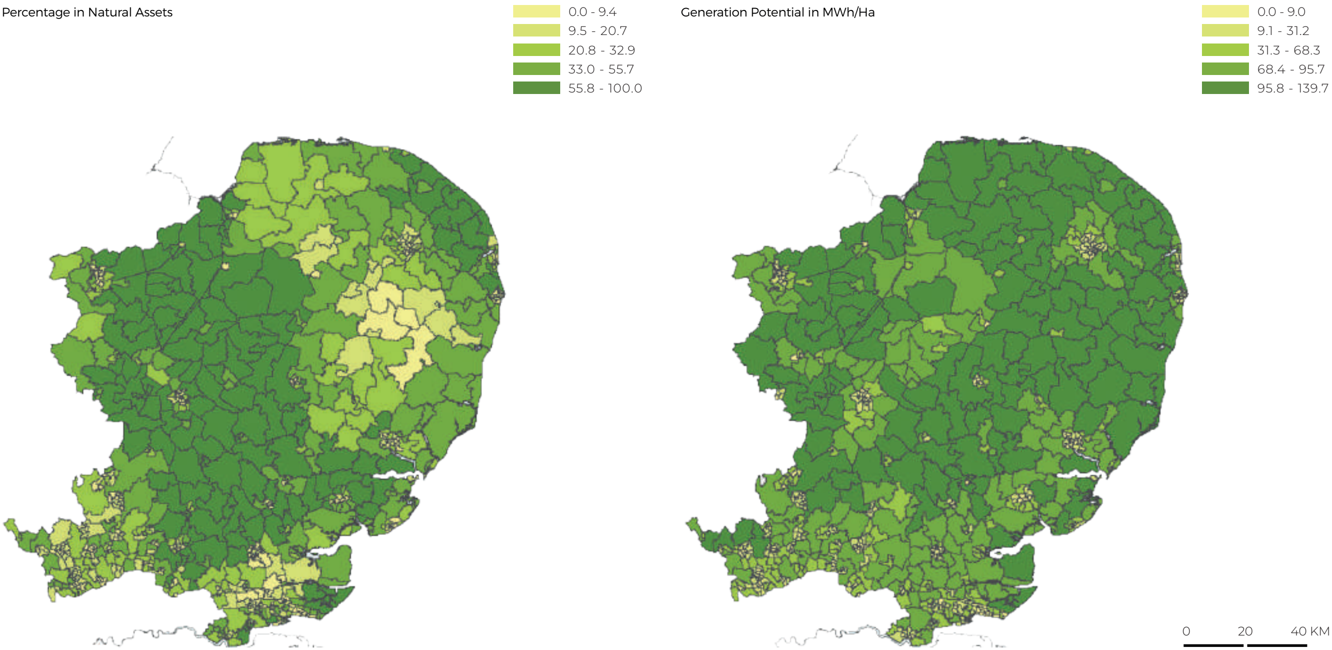
Forestry Commission National Forest Inventory, Ancient Woodland.

% of Land
- 0.0 - 3.4
- 3.5 - 6.6
- 6.7 - 10.0
- 10.1 - 15.3
- 15.4 - 78.4



Areas in one of the four types of asset were then calculated for each MSOA and the percentage totals are shown in the left side of **Map UK 10** (again using five quartiles with 20% of MSOAS in each class). Many MSOAs had at least a third of their land area covered by one or more of the four assets. A similar quartile map for generation potential is shown on the right side of **Map UK10**. Once the two aspects are compared in this way it is evident that there are many MSOAs with relatively high values on both maps (i.e. development of renewables potential will need to consider trade-offs with other natural assets).

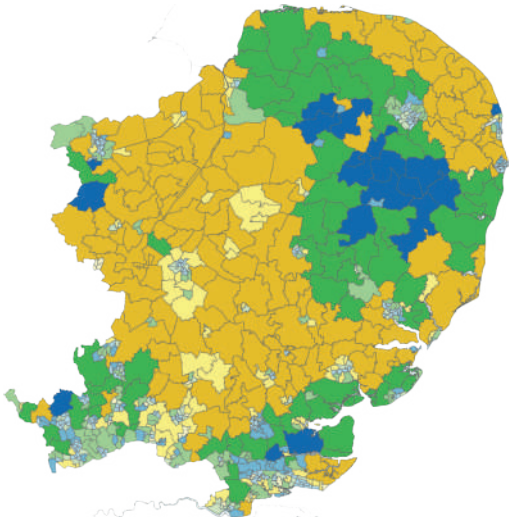
**UK10: EXTENT OF NATURAL ASSETS AND ELECTRICITY GENERATION10POTENTIAL IN MSOAS**



The final step in the spatial analysis sought to make this comparison more explicit. Each MSOA was classified as either low, medium or high in the extent of natural assets, and, again, as low, medium or high in terms of renewable energy generation potential. These categories were then cross tabulated to produce nine classes of MSOAs and mapped using the colour scheme shown in **Map UK11** to provide a spatial representation of trade-offs and synergies in the region.

As one example, the orange symbolisation for Category 9 (in **Map UK 11**), captures the presence of high potential for both indicators, **hence a significant trade-off:** indicating MSOAs with both high renewable potential and high natural assets. These areas are situations where stakeholder consultation and engagement will be needed to identify sensitive strategies for renewables development. Rather differently, areas colour coded in dark blue (Category 7), have a high generation potential but are relatively low on other natural assets. These areas could be prioritised for investment in renewables as the degree of trade-off is likely to be less. Finally, areas in Category 3, colour coded in light yellow, are those with lower renewable energy generation potential and higher extent of natural assets. These would not be good zones for investment in renewables, with potentially higher costs and lower benefits.

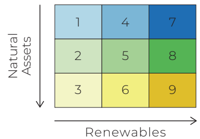
**UK11: EAST OF ENGLAND MAP OF TRADE-OFFS BETWEEN RENEWABLES & NATURAL ASSETS**



MSOAs were categorised into thirds based on their generation potential and their natural asset indicators.

These classifications were then cross-tabulated to derive nine groups.

Category 9 represents high potential on both indicators. Category 7 is high for generation potential but relatively low on other natural assets.



# 4. ESTONIA

BY MIGUEL VILLOSLADA PECINA AND INDREK LAAS

First, a table (Table 3) provides a synoptic view of the main elements of the Estonian case study discussed in this section. The table addresses four main fields (listed in the headings) discussing: the Policy instrument, the State of the art on mapping/assessment of ES, the RES development and the Socio-economic-environmental context.

| POLICY INSTRUMENT | STATE OF THE ART ON MAPPING/ ASSESSMENT OF ES | RES DEVELOPMENT | SOCIO-ECONOMIC-ENVIRONMENTAL CONTEXT |
|---|---|---|---|
| The policy instrument being targeted is the Operational Programme for Cohesion Policy Funds. However, as a results of the SWOT, the SOTA and the ongoing work within IRENES, other instruments are also indirectly targeted. | The MAES process in Estonia has been implemented through the project ELME (Elurikkuse sotsiaal-majanduslikult ja kliimamuutustega seostatud keskkonnaseisundi hindamiseks, prognoosiks ja andmete kättesaadavuse tagamiseks vajalikud töövahendid). ELME has recently been finalized, although additional work will be undertaken in the following months. The objectives of ELME are twofold: Analyse ecosystem condition and assess the supply of ecosystem services (ES) in forests, agricultural land, grasslands and wetlands. A very wide range of ES has been so far assessed, including carbon sequestration, primary production, microclimate regulation and erosion control among other (the full list includes ca 15 services). The supply of ES has been assessed using biophysical models and the outputs are raster maps with a resolution of 10m/pixel. These highly detailed ES maps allow upscaling and can feed in several spatial planning processes. | Based on the general principles of climate policy, the current government is developing Estonian economy into competitive low-carbon economy by the mid-century according to the government's action program Estonia 2035. Currently, renewable energy production in Estonia is mostly focused on primary solid biofuels (mainly fuelwood, although also wood residues, wood pellets), wind energy and solar. Solar photovoltaic has only recently experienced an increase in production, which has doubled between 2018 and 2019. Spatial planning processes in relation to RES are now mostly focused in drafting potential locations for wind energy production, minimizing the impact on natural resources, protected areas and the Green Network. | Estonia is facing changes related to the aging of society. According to estimates, the natural increase of the population in Estonia will remain moderately negative until 2035, due to the fact that the smaller generations born in the 1990s and later have reached the age of starting families. The increase of average life expectancy (78.82) in Estonia is the fastest in the European Union but remains below the average indicator. The healthy life years, however, has not increased within the last ten years (55.9 years). Source: valitsus.ee |

Secondly, the Estonian team identified and define the **methods** for their analysis, in order to meet the policy demand and respond to the issues presented in table 1 (section 2 of this work). The analysis performed in Estonia focussed on comparing the wind energy potential with the supply of other ecosystem services and then combined these data layers to identify regions of possible conflict or trade-off (where both indicators are high) and others where there is more compatibility to expand the use of wind power. There are similarities with the maps generated for the East of England in the UK. In both cases, such maps can help inform planning policies to better integrate considerations of ecosystem services provision and development of renewable energy.

The zonation maps created in Estonia serve as an example of the applicability of the ES hotspots concept in a planning context. By combining ES hotspots with wind speed and potential planning restrictions (e.g. protected areas, green network, etc.), potential wind energy planning areas are unveiled, while avoiding trade-offs with valuable ES, and maximizing win-win situations (synergies).

The ES hotspots analysis was chosen as a tool to convey landscape multifunctionality. In IRENES context, **hotspots can be defined as regions with a high diversity and a high supply of ecosystem services. They are closely related with good ecosystem health and high landscape multifunctionality.** The zonation maps created in Estonia constitute a spatially explicit guidance tool, which should support decision making processes.The structure of the analysis of the trade-offs in Estonia, followed the following steps:

## 1. Identification of key ES

13 ecosystem services from the Estonian MAES assessment have been included in the hotspots assessment (see table1). Four provisioning, three cultural and six regulation and maintenance services have been chosen in order to offer a balanced representation of ES supply in Estonia.

## 2. ES hotspots

The second steps focussed on mapping the spatial distribution of the ES selected in step 1, through hot/cold spots maps. Hotspots were calculated as the rescaled sum of potential ES supply. The methodological steps for calculating intensity hotspots are outlined hereinafter:

### 2.1. Rescaling ES

ES supply layers are represented using different biophysical units; therefore, rescaling is needed before any further operation is undertaken. For this analysis, all ES layers were linearly rescaled from 1 to 5 (minimum to maximum supply) following recommendations of Willemen et al. (2018) and Schröter and Remme (2016), adapted from the common minimum-maximum normalization.

$$x' = \frac{((x - x_{min}) * 4)}{(x_{max} - x_{min})} + 1$$

Where

$X'$ Rescaled ES value

$X$ Original ES value in a pixel

$X_{min}$ Minimum value across the range of values of that particular ES

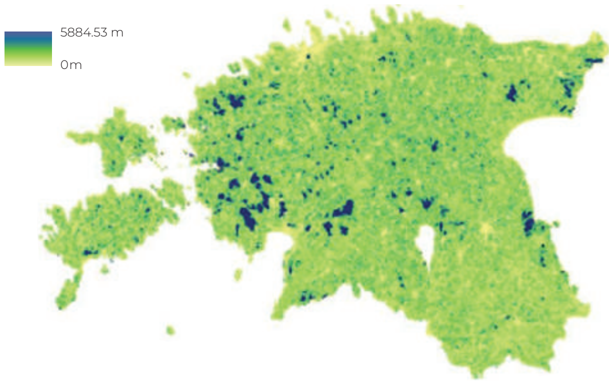
$X_{max}$ Maximum value across the range of values of that particular ES

Normalization and rescaling are however sensitive to maximum and minimum values. In order to avoid biases due to outliers, every ES supply map is windownised before the rescaled sum: so that all values falling beyond the 5–95 percentile are assigned the 5th or 95th value respectively (Willemen et al., 2010).

The figure below provides examples of the original data and the rescaled versions for two specific ES Noise reduction, and Pollination potential, both based on data from the MAES Estonia project (Available online: https://keskkonnaagentuur.ee/elme). And their rescaling into a 1-5 scale, for ease of aggregation in the next step.

### ESTO1: NOISE REDUCTION

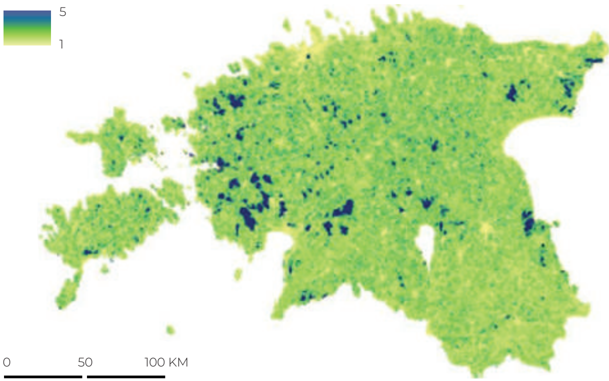
Original data (MAES Estonia): author: Ain Kull



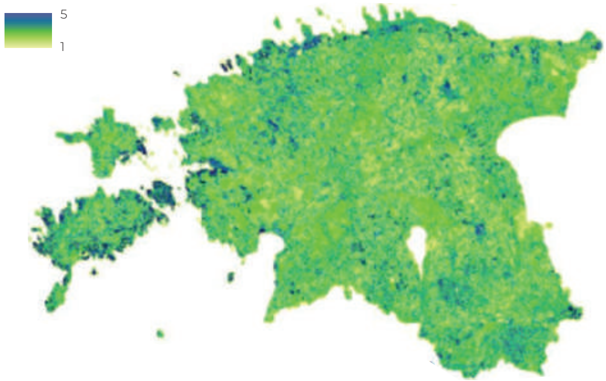

### ESTO3: POLLINATION POTENTIAL

Original data (MAES Estonia): author: Aveliina Helm


### ESTO2: RESCALED




### ESTO4: RESCALED



### 2.2. Rescaled sum of services

In the absence of specific assumptions or planning scenarios, all ecosystem services were then given equal weight and summed up. The resulting layer was then linearly rescaled once again, to be in the 1 and 5 range, where the maximum value of 5 (red-coded) is meant to indicate areas with the highest ES supply (hotspot) while the lowest value of 1 (blue-coded) indicates areas with lowest ES supply (coldspots).

### 2.3. Wind energy potential

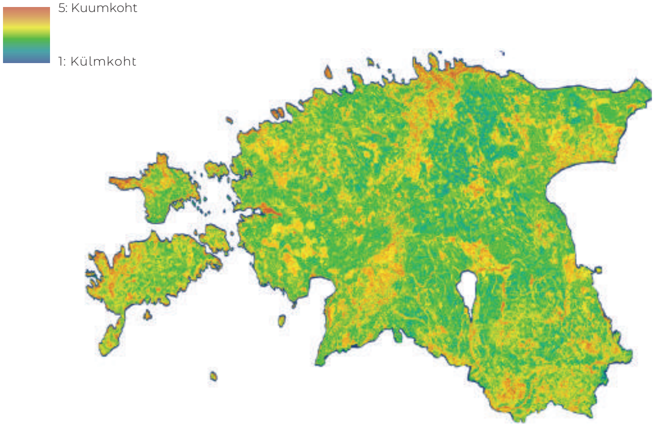
Windspeeds were calculated from the MAES Estonia project wind energy layer. However, ELME wind energy is provided at a height of 10m. In order to provide relevant input for wind energy planning at the regional scale, the 10m height wind speed layer was transformed into windspeed at 100m height, following the log-law outlined by Manwell (2003):

$$v \approx v_{ref} \cdot \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}$$

The final windspeed layer used in **Map ESTO 6**, was based on 10 years' average speed values in m/s. The resolution of the raster layer is 1 km/pixel.

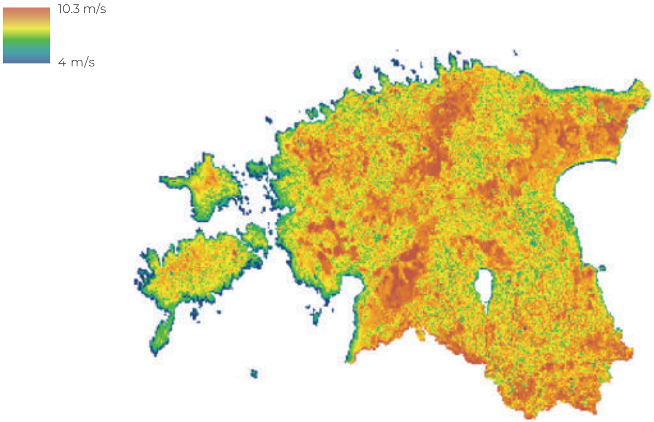
**ESTO5: HOT AND COLD SPOTS MAP**

1 indicates cold spots and 5 indicates hotspots. The scales are unit free.




**ESTO6: AVERAGE WIND SPEEDS (M/S)**

Re-calculated from MAES Estonia project



### 2.4. Zonation and trade-offs

The final step of the methodology followed a simple overlay procedure, used to combine different sets of information. Before proceeding with the overlay process, both the wind speeds layer and the ES hotspots layer were reclassified into discrete categories, two for the wind speed and three for the ES supply, as follows:

| Layer | Value ranges | Label |
|---|---|---|
| Wind speed | 0 - 6 m/s | Low wind speeds |
| | > 6 m/s | High wind speeds |
| Hotspots | 1 - 2 | Very low overall supply of ES |
| | 2 - 3 | Low overall supply of ES |
| | 3 - 5 | High overall supply of ES |

After which, wind speeds and ES hotspots could be recombined into 5 distinct classes, as follows:

- Low wind speeds & Low total ES supply
- Low wind speeds & High total ES supply
- High wind speeds & Low total ES supply (potential synergy areas)
- High wind speeds & Very low total ES supply (potential synergy areas)
- High wind speeds & High total ES supply (potential conflict areas)

**Low wind speeds & High total ES supply**

These areas are characterized by the high supply of ecosystem services (hotspots), but show no significant potential in terms of wind energy production.

**High wind speeds & Low total ES supply (Potential synergy areas)**

Within these areas, the overall supply of ecosystem services in the rescaled sum is below 3. This indicates a low supply of services, corresponding to somewhat simplified landscapes and mostly overlapping agricultural areas. The potential supply of wind energy is high.

**High wind speeds & Very low total ES supply (Potential synergy areas)**

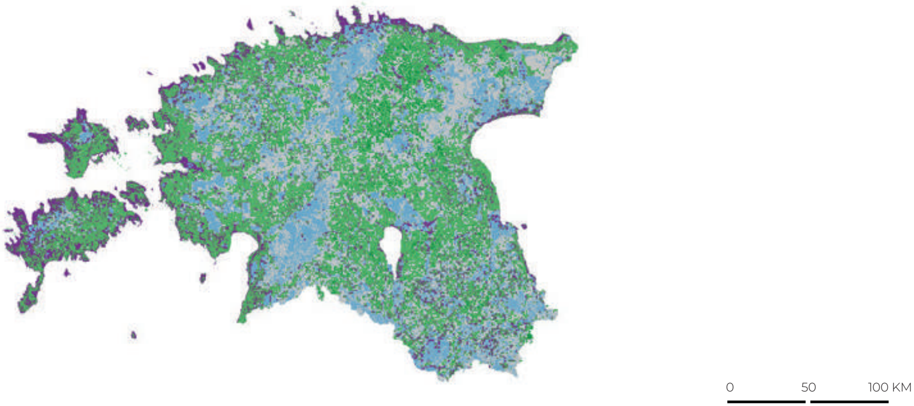
Within these areas, the overall supply of ecosystem services in the rescaled sum is below 2. This indicates a very low supply of services, corresponding to an ecosystem services coldspot. This usually overlaps with highly intensified agricultural areas, or ecologically degraded areas. The potential supply of wind energy is high.

**High wind speeds & High total ES supply (Potential trade off areas)**

These areas are characterized by a high overall supply of ecosystem services, corresponding with high landscape multifunctionality. Simultaneously, the potential supply of wind energy in these areas is high. These overlap constitutes a conflict characterized as a trade-off: Any wind energy development will likely lead to a decrease in the supply of other ecosystem services.

These areas, classified according these five combined classes, are represented in Map ESTO 7, below, indicating the spatial distribution of the key potential synergies and trade-offs, in Estonia, as identified by the Estonian's Team.

## EST07: ECOSYSTEM SERVICES HOTSPOTS AND WIND ENERGY POTENTIAL COMBINED




- Low wind speeds & Low total ES supply
- Low wind speeds & High total ES supply
- High wind speeds & Low total ES supply (potential synergy areas)
- High wind speeds & Very low total ES supply (potential synergy areas)
- High wind speeds & High total ES supply (potential conflict areas)

The Estonian team's study also identified some interesting limitations, necessary for future work. The key one being on the possible trade-offs not between ES and REN but among different ES.

The work done within the project on the extensive literature review indicates the presence of interesting contributions on how to possibly estimate the conflicts among alternative ES use of lands. The interaction between these ES is a clear essential step for policy analysis.

In more detail, the Estonian Group, performed a Principal Component Analysis identifying the following 4 classes. Whereby PC1 including ES: Habitat for forest indicator species, Microclimate regulation & Recreational value, emerged as trade off with Agricultural production. The methodology for the PCA follows the one outlined by Villoslada et al. (2018). The PCA was done using the individual re-scaled maps obtained in step 2.1. The factor loadings were used to discern whether the bundles revealed by the PCA corresponded to a synergy or a trade-off.

| | PC 1 | PC 2 | PC 3 | PC 4 |
|---|---|---|---|---|
| ▲▲ | Habitat for forest indicator species<br>MIcroclimate regulation<br>Recreational value | Habitat for grassland indicator species<br>Habitat for wetland indicator species<br>Grass production (fodder)<br>Pollination | Wild plants for nutrition (bilberries)<br>Wild fungi for nutrition | C storage<br>Tranquillity or seclusion |
| ▼▼ | Agricultural production | | | |

# 5. GERMANY, LOWER SAXONY

BY JULIA WIEHE, OLE BADELT, SYLVIA HERRMANN, CHRISTINA VON HAAREN, FRIEDERIKE STELTER AND EIKE MÜLLER

First, a table (Table 3) provides a synoptic view of the main elements of the German case study discussed in this section. The table addresses four main fields (listed in the headings) discussing: the Policy instrument, the State of the art on mapping/assessment of ES, the RES development and the Socio-economic-environmental context.

| POLICY INSTRUMENT | STATE OF THE ART ON MAPPING/ ASSESSMENT OF ES | RES DEVELOPMENT | SOCIO-ECONOMIC-ENVIRONMENTAL CONTEXT |
|---|---|---|---|
| The SWOT analysis of the Operational Programme and in particular the documents and strategies associated with it shows that this instrument in Germany can only make a limited contribution to an energy transition that is compatible with nature. The main actors of the energy transition are to be found at other levels and in other specialised ministries.<br>Financial support for the energy transition is mainly provided by the Renewable Energy Sources Act (EEG), which applies nationwide. This instrument defines development and expansion targets, differentiated according to the various energy sources. However, it does not make any statements on the spatial management that is compatible with humans and nature, so that the EEG cannot be used to manage the spatial impacts of wind or solar energy.<br>The EEG has a great influence on the feasibility and economic viability of individual energy projects at the municipal level, in that it enables or prevents feed-in, sets the level of subsidies and thus also influences the technologies used. | The concept of ecosystem services is similar to that of German landscape planning, even if the assessment methods differ in detail. Landscape planning has a long tradition in Germany and delivers a large range of basic data on nature and landscape.<br>It includes a systematic and area-wide ecological analysis at different spatial scales (federal state to municipality), with a concrete spatial reference and a defined mandate within the overarching spatial planning.<br>Landscape planning is legally embedded and established in planning and evaluates aggregated by landscape functions statements on soil, water, climate/air, species and habitats as well as the landscape appearance. It presents concrete requirements and measures of nature conservation for the planning area that are necessary to realise its targets and is an important basis for determining the usage potential as well as the economic value of ecosystem services.<br>Integration of the ES concept into landscape planning is currently limited to a few sub-sectors. The challenge for landscape planning is therefore to expand its methodological spectrum, to standardise the data basis accordingly and to balance environmental services to a greater extent and prepare them for monetarisation.<br>As we do not address the relevant stakeholders with the IRENES project, the analysis of trade-offs and synergies is based on the current methodology of landscape planning. | The importance of renewable energies for energy supply is continuously increasing in Lower Saxony. In 2022, the share of renewables in Primary energy consumption (PEC) more than 16 % PEC.<br>In 2019, the share of renewable energy sources in gross electricity generation in Lower Saxony has reached 52 %.<br>Wind power generation (onshore and offshore) in particular increased sharply in Lower Saxony in 2018 and accounted for 69 % of total gross electricity generation from renewable energy sources. The forecast for 2019 expects up to 74 % of renewable electricity from wind energy.<br>The shares of biomass (around 20 percent) and photovoltaics (6.5 percent) regress slightly compared to the previous year. Hydropower plays only a minor role in electricity generation.<br>The planning procedures for each energy source are implemented by different actors and there is no overall concept for energy planning. Spatial planning mainly makes statements on wind energy: potential areas are identified and regional expansion targets are defined.<br>Solar energy is not considered spatially relevant and is therefore not planned by overarching regions but by municipal planning authorities.<br>The use of bioenergy is not regulated by planning at all. The construction of a biogas plant or the cultivation of energy crops is left to the farmers. Only the possibility of feeding electricity into the grid and its remuneration determines the decision, so the incentive is at the federal level and the EEG. | Lower Saxony has the most jobs in the renewable energy sector in Germany, with around 56,500 people. The state can benefit significantly from the expansion of both onshore and offshore wind energy in Germany. Although participation in wind farm manufacturing processes is declining, the state is still deeply involved in the installation and maintenance of offshore farms. Its position in the Germany-wide onshore market remains strong. In the solar energy sector, expansion is below average for both photovoltaics and solar thermal. On the other hand, there is positive stimulus from the industry for geothermal energy. For bioenergy plants - the share of employees is also above average. |

Secondly, the German team identified and define the **methods** for their analysis, in order to meet the policy demand and respond to the issues presented in table 1 (section 2 of this work). For Lower Saxony, a set of maps have been developed, focussing on the trade-offs between potential for solar park development and local vulnerability in terms of territorial perception of ecosystem services.

The approach, similarly, to the others' teams, was articulated focussing on the evaluation of both: the nature compatibility and land use efficiency of renewable energies. Interestingly, Lower Saxony decided to exclude bioenergy, given its major negative impacts on nature and the environment, coupled with a low energy yield per ha. Renewable such as hydropower and geothermal energy were also overlooked since they have very little potential in Lower Saxony. The focus was then on Wind and solar energy potential, considering solar both on roofing and open field installations.

The Analysis started from the identification of the key ecosystem services that would have been affected by the investments on renewables. The focus being on **habitats, recreation, water and soils.** The data on vulnerability were mapped using the following scale:

- **Very high vulnerability:** Areas where the construction of the respective energy plant is prohibited (legal reasons) or is not possible for technical reasons.

- **High vulnerability:** Current legal regulations and legally derived requirements exclude these areas. Their use would not be compatible with humans and nature.

- **Medium vulnerability:** Areas that, with restrictions, offer usable potential that is compatible with humans and nature. The use is possible with proper compensation.

- **Low vulnerability:** Areas with low nature conservation and recreational value, where the energy plant only causes short-term or minimal loss of functionality. The energy plant has only very minor impacts on human being and nature.

The criterion for allocation of energy production areas was to keep only the areas of low and medium vulnerability. The classification was based on the presence of ecosystem services as described, based on current legal regulations and legally derived requirements , in table DE Table 1, below.

The technical side of the area analysis was implemented using a GIS model (ArcMap 10.7.1). The areas of Lower Saxony were assigned to a vulnerability class on the basis of their site sensitivity and their value for nature conservation (see Table in this section). For the areas with low vulnerability, the human and nature-compatible electricity yield potential was then calculated in accordance with the power density (MW/ha) of the reference plant.

In addition to current Habitat Regulations, vulnerability has also been considered in relation to future Habitat Regulations. Hence, areas with the potential for nature conservation, according to the German biodiversity strategy (BMUB 2007), were added according to the vulnerability criteria reported in Table DE1.

## DE TABLE 1: ASSIGNMENT OF THE AREA CATEGORIES TO THE VULNERABILITY CLASSES ACCORDING TO THEIR SENSITIVITY TO A REFERENCE WIND ENERGY POWER PLANT (ACC. (WIEHE ET AL. 2020))

| VULNERABILITY | LAND CATEGORIES | ECOSYSTEM SERVICES CONCERNED |
|---|---|---|
| VERY HIGH VULNERABILITY | • Settlements, Infrastructure (railways, roads, motorways, airports), Buffer zone around settlement and infrastructure areas, calculated according to the height and sound level of the example plant, areas with importance for leisure and recreation | RECREATION |
| | • National parks, Natura 2000 network: FFH areas, bird sanctuaries, Wildlife sanctuaries **Areas with the potential for nature conservation according to the German biodiversity strategy:** Green Belt Germany (national monument along the former inner German border), military training areas & post-mining landscapes wilderness development areas, forest development areas | HABITAT |
| | • Water areas, Water protection areas (zone I), Riparian zone | WATER |
| | • Surfaces with a slope of ≥ 30˚ | |
| HIGH VULNERABILITY | • Landscape with high visual quality rating | RECREATION |
| | • Biotope network: Functional areas forest and semi-open landscape (if no arable land), Occurrence of wind-sensitive bird species outside protected area of category very high plus buffer zones, Ramsar Wetlands, Historical forest locations, Biosphere reserves (core areas), 200m buffer zone around national parks, nature reserves, Natura 2000 areas, | HABITAT |
| MEDIUM VULNERABILITY | • Landscape conservation areas (german cat.), Biosphere reserves (buffer zones and transition areas) | RECREATION<br>RECREATION |
| | • Bird sanctuaries without windenergy-sensitive species, deciduous and mixed forests, Biosphere reserves (buffer zones and transition areas) **Areas with the potential for nature conservation according to the German biodiversity strategy:** Areas and corridors of national importance for the biotope network, Undissected low-traffic areas, Morphological riparian zones | HABITAT |
| LOW VULNERABILITY | • Landscape with low visual quality rating | RECREATION |
| | • Grassland, Coniferous forests | HABITAT |
| | • Arable land | SOIL |

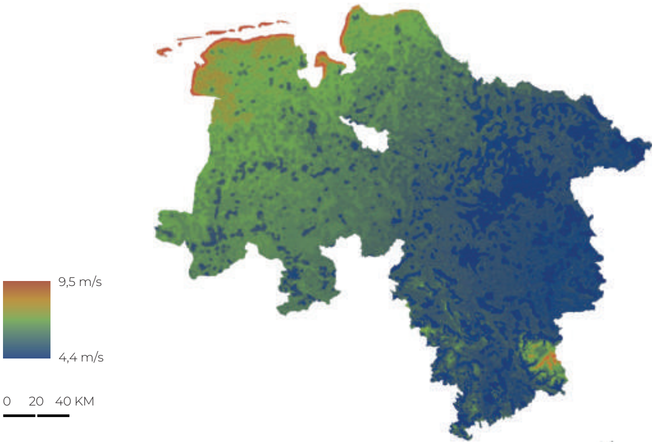
Once considered the vulnerabilities, the next step of the analysis was to map the potential energy generation, both from wind and solar. In detail, DE MAP4 below shows the wind speed in lower saxony in measured in m/s and ranging from a high of 9.5 m/s to lower level of 4.4 m/s.

By considering the vulnerability and potential for wind energy, the study identified and mapped, see **DE MAP 5**: 1.056 km² in the region with low vulnerability and 1.495 km² with medium vulnerability, as areas potentially to be chosen for wind energy. The possible installed capacity in areas with low vulnerability, only, is of 56 GW. To determine the electricity potential, time series with a resolution of 1 h, a time span of one year and a spatial resolution of the Cosmo-DE model were prepared. The historical weather year 2012 forms the basis for the calculation. The placement takes into account minimum distances depending on the wind direction and a use of the areas from the "edge", which ensures an efficient use of the area. The following yield calculation determines the wind energy output for each time step and each weather model pixel. The pixel-, time step- and height-specific wind speed, a correction of the wind speed and plant-specific power curves as well as the hub height are taken into account Thiele et al. 2020)

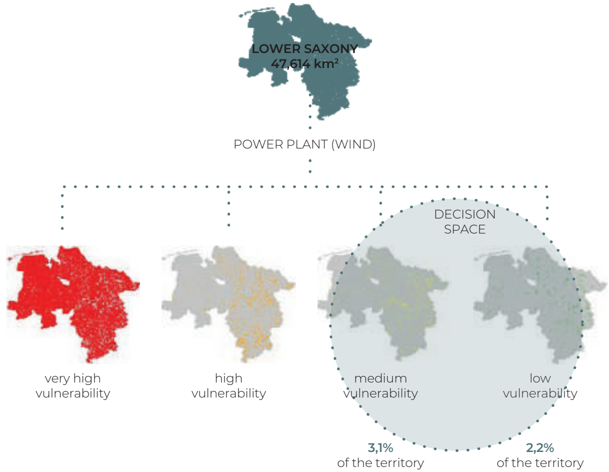
The key technical parameters adopted for this conclusions were for Wind generators: Nominal power: 7.58 MW, Rotor diameter: 127 m, Hub height: 200 m, Max. sound power level: 108.5 dB(A); Safety distance between turbines and the adoption of Shutdown algorithms reduce environmental impact on bats.

### DE1: WIND SPEED

200m x 200m gridded mean of annual wind speeds from 10 m to 100 m (in 10 m steps) above ground an Weibull parameters, for Germany. Version V0.1, 2014. Source DWD Climate Data Center (CDC).




### DE2: VULNERABILITY OF THE TERRITORY IN LOWER SAXONY TO THE STANDARD WIND-ENERGY POWER PLANT



## ASSIGNMENT OF THE AREA CATEGORIES TO THE VULNERABILITY CLASSES ACCORDING TO THEIR SENSITIVITY TO A REFERENCE SOLAR PARK (ACC. (BADELT ET AL. 2020))

| VULNERABILITY | LAND CATEGORIES | ECOSYSTEM SERVICES CONCERNED |
|---|---|---|
| VERY HIGH VULNERABILITY | • Settlements, Infrastructure (railways, roads, motorways, airports) | RECREATION |
| | • National parks, Natura 2000 network: FFH areas, Biosphere reserves: core zone, Forests and woodlands | HABITAT |
| | • Water area, Water protection areas (zone I), Riparian zone | WATER |
| | • Topography (slope inclination and orientation), Shading areas around forests and groves | |
| HIGH VULNERABILITY | • Landscape with high visual quality rating | RECREATION |
| | • Biotope network: Functional areas forest and semi-open landscape (if no arable land), extensive grassland, Occurrence of Solarpark-sensitive bird species outside protected area, resting and feeding areas of wintering nordic guest birds, wild herb areas | HABITAT |
| | • Arable land (high to extremely high soil fertility) | SOIL |
| | • Flood risk areas (HQ100 and HQ frequent - HQ from "High" and flow coefficient Q) | WATER |
| MEDIUM VULNERABILITY | • Landscape conservation areas (german cat.), Historical Cultural Landscapes of Lower Saxony, Landscape with medium visual quality rating, Biosphere reserves (buffer zones and transition areas) | RECREATION |
| | • Bird sanctuaries without PV-FFA sensitive species, arable land with importance for the biotope network | HABITAT |
| | • Water protection areas (Zone II) | WATER |
| LOW VULNERABILITY | • Landscape with low visual quality rating | RECREATION |
| | • Grassland | HABITAT |
| | • Arable land (low-yield soils) | SOIL |
| | • Water protection areas Zone III A and B | WATER |

The second renewable considered in the Lower Saxony study is solar energy. A similar vulnerability analysis was performed, considering however, that vulnerability changes according to the type of renewable used. As a result, 563,279 hectares or about 12% of the state area in Lower Saxony can be classified as having low spatial vulnerability (see Figure ). Large areas in the south-western part of the state in particular are suitable for solar parks.

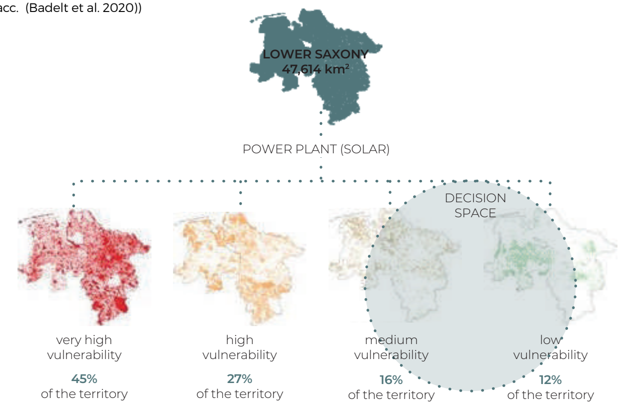
To calculate the electricity potential from solar parks, a reference system was chosen which reflects the current (2020) economically optimal design for open space systems (Badelt et al. 2020). The modules are flat (18° installation angle) and the rows are placed close together. Because in this arrangement more solar modules fit onto the same area, the yield per area increases strongly, even if the yield per individual solar module decreases slightly. At the same time, the costs for cabling and also the required floor space per solar module are reduced. The typical power densities per area of solar parks rise to 1 MW/ha as a result of this development.

Moving on from the vulnerabilities to the solar energy potential, DE MAP5 below shows the global radiation in Lower Saxony ranging from a low of 11,46 kWh/m2 to a higher limit of 17,07 kWh/m2.

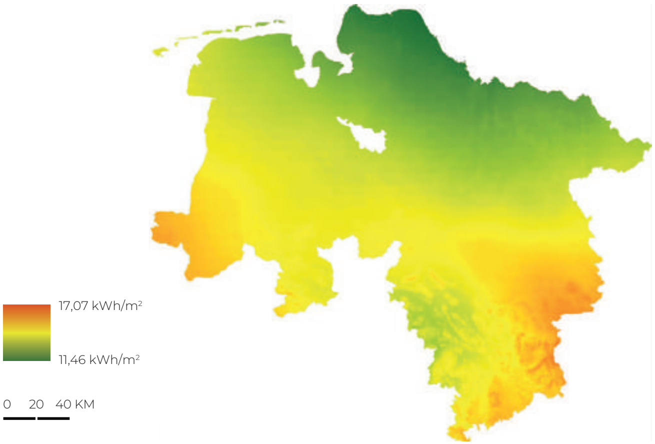
Finally, DE MAP 3 shows the vulnerability of the territory in Lower Saxony to solar park development. The low vulnerability area in the region amounted to: 5,710 km², while the medium vulnerability one to 7,618 km². The estimate of the possible installed capacity in low vulnerability areas was of 109 GW. The key technical parameters underlying these estimates were: 7.5 m distance between solar module rows; 50.6 % coverage of the area, with modules; and an height between 0.5 to 1.56 m for the module fields.

### DE3: VULNERABILITY OF THE TERRITORY IN LOWER SAXONY TO THE STANDARD SOLAR PARK

(acc. (Badelt et al. 2020))




### DE4: SOLAR RADIATION IN LOWER SAXONY



# 6. ROMANIA

BY CHRISTIAN ADAMESCU, TUDOR RACOVICEANU, ELENA PREDA, MAGDA BUCUR, GEORGE GURAN AND MIRELA COSOVAN

First, a table (Table 5) provides a synoptic view of the main elements of the Romanian case study discussed in this section. The table addresses four main fields (listed in the headings) discussing: the Policy instrument, the State of the art on mapping/assessment of ES, the RES development and the Socio-economic-environmental context.

## POLICY INSTRUMENT

The Large Infrastructure Operational Program (POIM). It addresses the development challenges identified at national level in terms of transport infrastructure, sustainable urban transport, environment, energy and risk prevention. The programme will mainly invest in removing the main transport bottlenecks and developing sustainable, efficient and green transport modes in the country. Another strong focus lies on measures to increase energy efficiency and protect natural resources.

## STATE OF THE ART ON MAPPING /ASSESSMENT OF ES

At the country level, the project „Demonstrating and promoting natural values to support decision-making in Romania" implements the MAES process in Romania and has the following aims:
The public policy analysis aims to assess the level of integration of the concept of ecosystems and ecosystem services in public policy for the period 2014-2020 in order to develop recommendations on integrating the results of mapping and biophysical assessments in decision-making processes. The areas of public policies analyzed are: biodiversity, climate change, fishing and aquaculture, agriculture and sustainable development, transport, energy, regional development, tourism, and marine and forest areas. It was made an inventory of the responsible institutions, an institutional map and a questionnaire to identify institutional needs related to the MAES process
Analysis and data management for the MAES process. This is done by taking the following directions: identification of data sources, analysis of the availability, analysis of the representativeness and of the update policies, data integration in the conceptual model and in the physical model of data organization. All these directions are in continuous development both regarding the contribution of the project partners, of the representatives of the Scientific Council and of the contributors to the core national research system
Mapping and biophysical assessment of the priority ecosystems and ecosystem services (the MAES process itself). There were achieved major results regarding:
mapping ecosystems at the national level, achieving "Ecosystems classification in Romania EUNICE 3" (intermediate version) the development of tools for updating this distribution (land field guide to identify the ecosystems, methodological guide for assessing the ecosystem services)
the selection of methods for assessing the ecosystem services that are carried out continuously based on the matrix of indicators and on the comparative analysis of existing methods.

## RES DEVELOPMENT

Within the "Romania's Energy Strategy for period 2007-2020", approved by Government Decision No 1069/2007, the target for consumption of electricity from renewable energy resources represents 33% of the gross domestic consumption of electricity in 2010, 35% in 2015 and 38% in 2020. To promote the production of electricity from renewable sources, Romania uses the system of mandatory quotas coupled with the trading system for green certificates.
Based on this mechanism, suppliers acquire mandatory quotas of green certificates and the electricity is sold separately on the energy market. The acquisition quotas for green certificates are established in correlation with the targets and their values increase every year. The market energy has dispatching mechanisms that give priority to sales of electricity from renewable sources.

## SOCIO-ECONOMIC-ENVIRONMENTAL CONTEXT

Romania has a balanced and diversified primary energy resources mix. Currently, in Romania, approx. 400 crude oil and natural gas deposits are exploited, and for another 39 oil-deposits development-exploitation and exploitation agreements have been concluded with various companies. Coal is the basic primary energy resource in the energy mix, being a strategic fuel in support of national and regional energy security. In extreme weather periods, coal ensures the proper functioning of the National Energy System, covering a third of electricity needs.
Romania has rich and varied resources of renewable energy: biomass, hydropower, geothermal potential, respectively for wind and photovoltaic energy. They are distributed throughout the country and can be exploited on a larger scale as the performance-price ratio of technologies will improve, by developing new generations of equipment and related facilities.
The potential of hydropower is used to a large extent, although there is the possibility to continue the hydropower management of the main watercourses, while respecting good practices for the protection of biodiversity and ecosystems. In recent years, Romania has advanced in the use of an important part of the wind and solar energy potential.

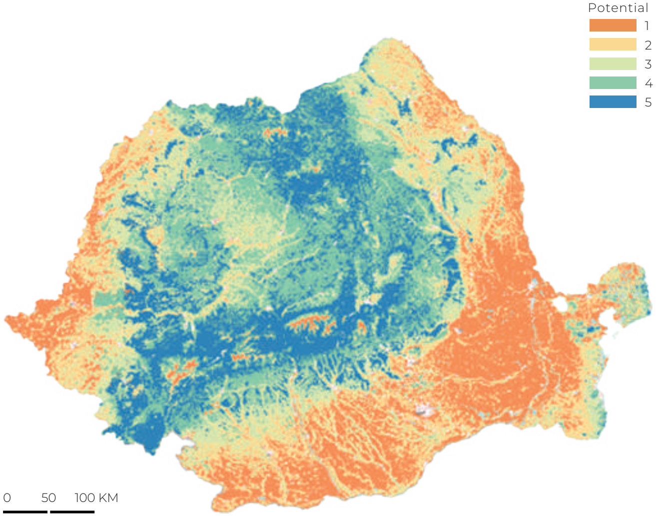
Secondly, the Romanian team identified and define the **methods** for their analysis, in order to meet the policy demand and respond to the issues presented in table 1 (section 2 of this work). The study done by the Romanian's team is based on the EU Ecosystem Type Map (Weiss and Banko, 2018). This was used to identify the key indicators of ecosystem services potential following a matrix approach by Burkhard et al. (2009, 2012)..

The map of the areas with potential for renewable energy were based on Solar and wind atlas data, while Remote sensing data on net primary production was used to map the potential for biomass (Modis MOD17A3H product).

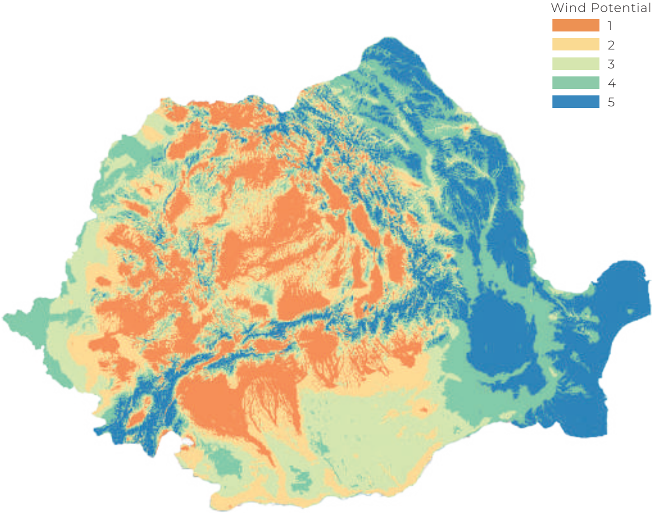
The mapping resulting from these data sources are reported in the three tables below. In detail, **RO Map 1** maps the region's net primary productivity, on a one to five colours' coding scale for Biomass potential, using Remote sensing data.

Similarly, **RO Map 2,** maps the Wind potential, based on wind atlas data according to the same colour coded scale. These data are based on a set of assumptions (See https://globalwindatlas.info/), whereby the default ones are Turbine type: Generic 3.45 MW - IEC Class 2, Rated power (kW): 3450, Rotor diameter (m): 126, Hub heights (m):100, Power control system: Pitch, Design annual average wind speed (m/s): 8.5, Power curve valid for air density (kg/m3):1.225:

**RO1: BIOMASS POTENTIAL NET PRIMARY PRODUCTIVITY**




**RO2: WIND POTENTIAL**

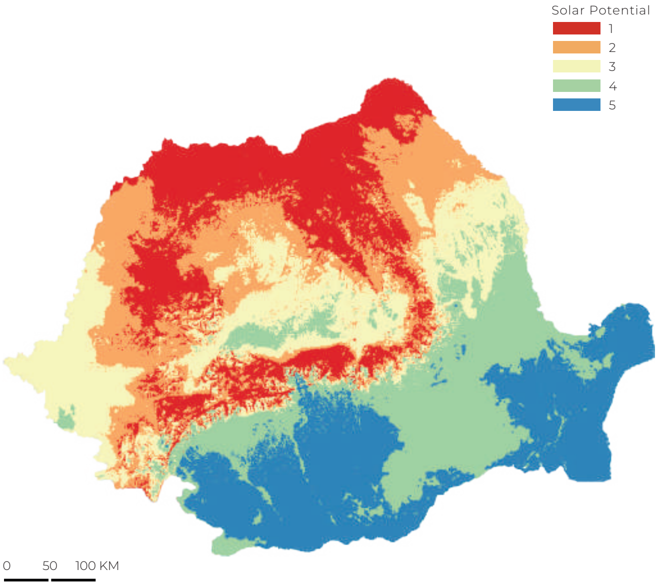


Next, the Solar potential is mapped, according to the same colour coded scale in **RO Map 3**, below. The map data provide the Specific photovoltaic power output (https://globalsolaratlas.info/map?c=45.602509,23.829346,7&s=44.43378,26.05957&m=site)

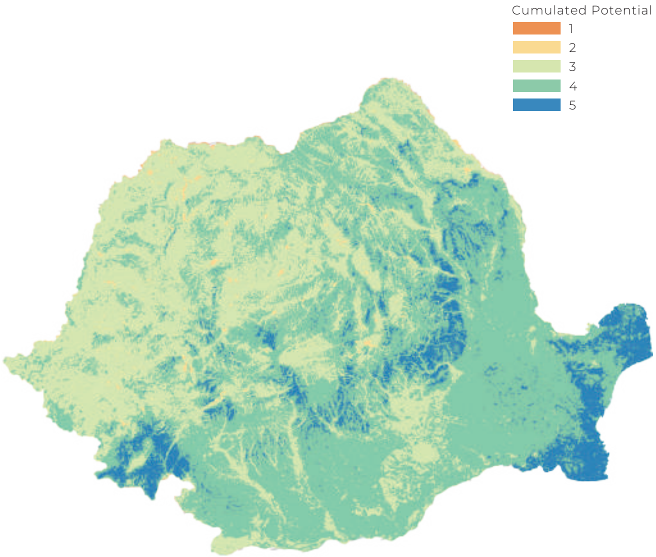
These Potential from alternative renewable sources, were then merged into the integrated **RO Map 4**, providing the Cumulated Energy Potentials.

Moving to the Ecosystems Services, The Romanian's team calculated them using indicators from Burkhard et al. (2009, 2012) and Level 2 Ecosystem types map (2018) data. These were divided into Eco-

**RO3: SOLAR POTENTIAL**



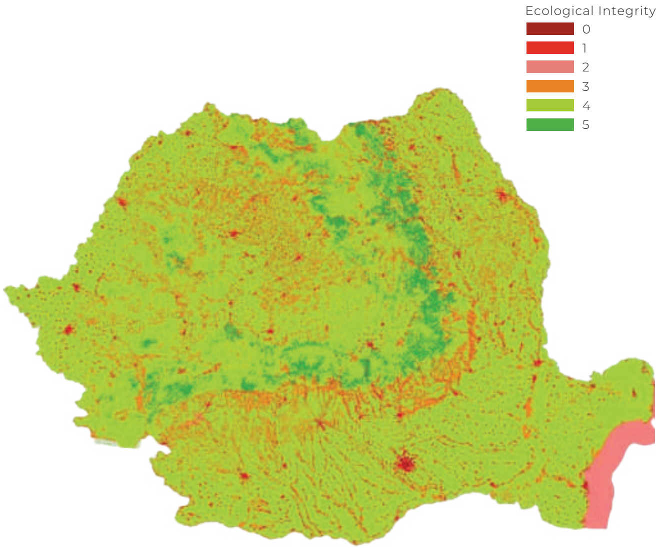

**RO4: CUMULATED ENERGY POTENTIALS**



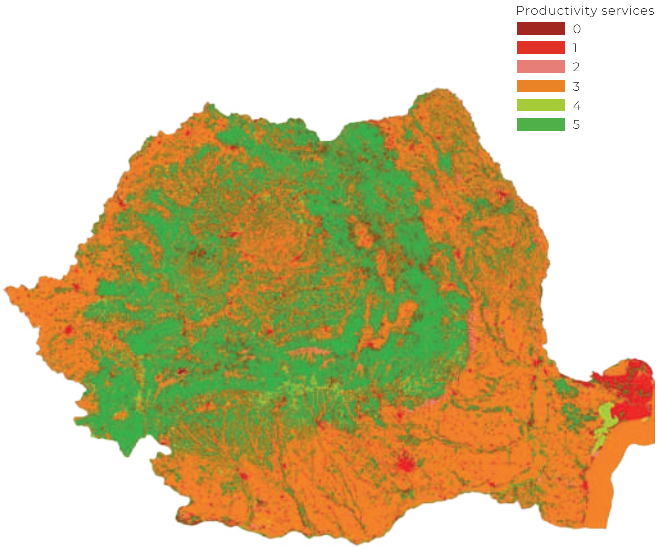
logical integrity (Map 5), Productivity services (Map V5), Regulatory services, (Map V6) and Cultural services **(Map RO 7)**.

Ecological integrity is an overarching concept that integrates multiple properties of ecosystems, including structure, function and resilience to external change (de Juan 2014, Özkundackzi et al.,2014, Burkhard et al., 2011). For the current study we assessed ecological integrity aQnd the services provided by ecosystems using a matrix model matching different types of ecosystems with their potential of producing services ranked in different studies/or by stakeholders (). A five ranking score was used 1 low to 5 high potential (Figures 5 to 8).

**RO5: ECOLOGICAL INTEGRITY**




**RO6: PRODUCTIVITY SERVICES**

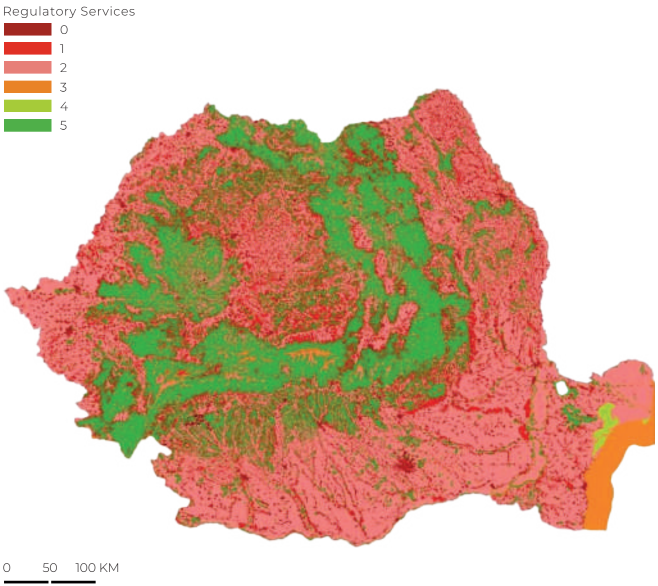


And, finally, Cultural Services were mapped based on the indicators in **Map RO 8** below.

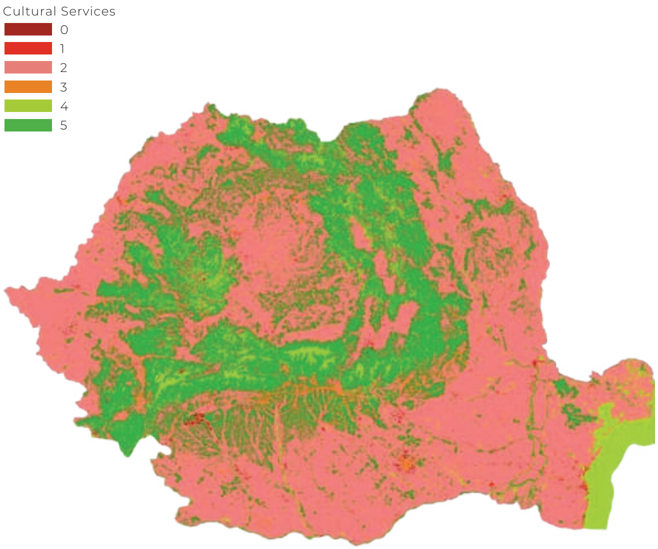
The next step was to represent trade-offs and synergy between Renewable potentials, (mapped according to the five categories of Potential for renewable energy, represented in Map RO 4 Cumulated Energy Potentials) and the and Recreation potential, (Map RO 9). These trade-offs and synergies were based on the tabulation, Table RO 2, showing the average ecosystem services ranks in areas with different potential ranks for renewable energy.

The resulting overlay produced a 25 categories colour coded map, RO Map 10, overlaying information on both Renewables and Natural Assets. Clearly, top right categories 4/5/9 and 10 seem to be indica-

**RO7: REGULATORY SERVICES**



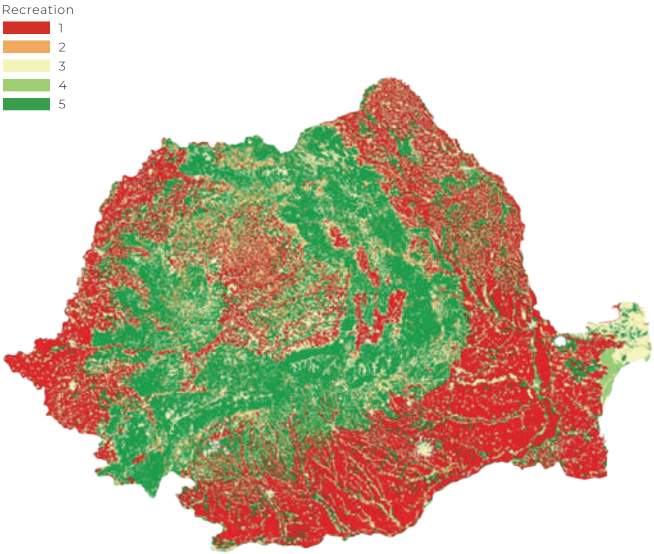

**RO8: CULTURAL SERVICES**



ting the most promising, synergetic areas, with a high energy potential and low recreational value, while the highest trade-offs seem to be in area 19/20/24/25 where both high energy potential and high recreational value. These areas are clearly the most problematic in terms of investment planning decisions.

Finally, the areas with low energy potential and high recreational values, i.e., 16/27/21/22, should preferably left for recreational use and not be targeted for renewable investment, while the areas 1/2/6/7 characterised by both low energy potential and low recreational values, would be the lowest in priority of political debate.

#### RO9: RECREATION POTENTIAL




#### TABLE RO2: AVERAGE ECOSYSTEM SERVICES BY RANKING IN POTENTIAL FOR RENEWABLE ENERGY

| Potential for renewable energy | Ecological integrity | Regulating services | Provisioning services | Cultural services |
|---|---|---|---|---|
| 1 | 3.74 | 2.78 | 3.96 | 3.33 |
| 2 | 3.24 | 2.85 | 3.35 | 2.96 |
| 3 | 3.67 | 3.28 | 3.88 | 3.44 |
| 4 | 3.81 | 3.20 | 4.03 | 3.45 |
| 5 | 3.89 | 3.66 | 4.21 | 3.88 |
| Total territory | 3.73 | 3.30 | 3.96 | 3.49 |

# 7. ITALY, VENETO REGION

BY LINDA ZARDO, MASSIMILIANO GRANCERI BRADASCHIA, FRANCESCO MUSCO, PIERCARLO ROMAGNONI, ELENA GISSI, GIULIO SEGATTO, MARTA EVA KRAKOWIAK, IVAN BOESSO, MARIA SOLE D'ORAZIO AND FRANCESCA MACCATROZZO

First, a table (Table 2) provides a synoptic view of the main elements of the Italian case study discussed in this section. The table addresses four main fields (listed in the headings) discussing: the Policy instrument, the State of the art on mapping/assessment of ES, the RES development and the Socio-economic-environmental context.

| POLICY INSTRUMENT | STATE OF THE ART ON MAPPING/ ASSESSMENT OF ES | RES DEVELOPMENT | SOCIO-ECONOMIC-ENVIRONMENTAL CONTEXT |
| --- | --- | --- | --- |
| The policy instrument considered is the POR-FESR. The analysis (SWOT, the SOTA and the ongoing work within IRENES), focused on the PI for 2014-2020 and other instruments are indirectly targeted. However, the main objective of the work is to make use of the analysis and work undertaken under IRENES to provide useful inputs for the POR-FESR 2020-2027. | In Italy the MAES process has been implemented at national level from several initiatives from the Ministry of the Environment and from ISPRA. The analysis of the state of the ecosystems and of ES is focused on understanding the relationship between ES and land consumption; the study was implemented at national scale and at regional scale.<br>In Veneto Region, the Regional Environmental Agency has supported the analysis of MAES for the part of land consumption and soil ES in the provinces of Vicenza and Rovigo. The results of the analysis were included in the map of soils of the two provinces recently published. Soil ES were mapped and assessed through a system of indicators representing the capacity of different soils to provide ES.<br>A series of research activities and projects on ES have considered the Region of Veneto of parts of it as case study areas. | The Veneto Region met the burden-sharing targets before 2020, however, given the new panorama and need to abate emissions and produce (clean) energy, targets changed and further efforts are needed. The Veneto Region in among the regions consuming the highest amount of energy in Italy (third, after Lombardia and Emilia Romagna), but presents a raking in terms of energy production from renewable resources which is lower than other italian Regions consuming less energy (PER-FER 2017).<br>At present, RES production is led by hydroelectric, followed by energy produced from solar source and biomass. However, at present, the hydroelectric contribution cannot grow further. Hence, to meet the targets derived from burden sharing, the region bets on solar and biomass.<br>For thermal purposes, the Region in its Regional Plan for Energy (2020), bets mainly on biomass (expected to provide RES for 49% on the total target needed)- For electric purposes, the Region bets mainly on biogas and biomass (39% and 21% respectively), while solar is considered only for the 12% (PERFER 2017). | Veneto is one of the richest regions in Italy, with an average monthly household ex penditure between 2500 and 3000 euro. Agricultural and zootechnical activities are still important, and are highly mechanised. There are numerous DOC and DOP products. Industry is mainly present in the western provinces and on the Adriatic coast; small companies specialise in the food, textile, footwear and furniture sectors.<br>The tourism sector is also key, thanks to the presence of valuable landscapes (the Venice lagoon, the Dolomites, etc.) and architectural heritage (e.g. UNESCO sites).<br>The territory is characterised by small to medium-sized urban centres and a highly built-up countryside.<br>Pollution is a key issue. |

Secondly, the Italian team identified and defined the **methods** for their analysis, in order to meet the policy demand and respond to the issues presented in table 1 (section 2 of this work). Based on the above-described premises, the scope of the ES trade-off analysis was defined for the Region. In particular, the goal is to assess and map suitability of areas for agricultural biomass production (from leftovers), and for solar farms, respectively. Then, the idea is to compare them.

The Research question shaping the analysis is **"How much area is considered suitable for agricultural biomass production and, similarly, for solar farms based on trade-offs with other ESs?"**

Figure **IT 1**, below, provides the key trade-offs, separately for agricultural biomass production and solar farms. Following Hastik et al. (2015) the trade-offs were identified for each of the two types of RES, and ranked from 0 to 2, (darker shading indicates greater conflict). In particular, trade-offs identification between RES and ES, include 5 ES (provision of agricultural products, water provisioning and filtering, climate regultation, habitat for flora and fauna, and cultural services). Findings suggest that this approach can help identify greater scope for use of renewables than a simple binary (yes/no) classification of suitable areas. In more detail, we can see that the more serious (light grey in this case) trade-offs with agricultural biomass production, are with: i) **"Water provisioning and filtering"** ES, due to pesticides releases and water eutrophication, linked to intensified agriculture; ii) **"Climate regulation"** ES, due to reduced soil carbon proportion, linked to intensified agriculture; iii) **"Habitat for flora and fauna"** ES, due to habitat loss in case of intensified agriculture, and to the effects of agro-biodiversity; iv) Less serious trade-offs were identified with **"Cultural services"** ES, due to landscape composition impacts possible.No trade-off was identified between Agricultural Biomass production and the: "Provision of agricultural products" ES, since the type biomass considered for this work is obtained by leftovers, not from dedicated crops, hence no conflict will occur with food provisioning.

Concerning solar farms, the Veneto study, identified as the more serious (dark grey in this case) trade-offs are with the: **i)"Provision of agricultural products"** ES, given the coemption for space between solar farms and crops; ii) Less serous trade-offs (light grey) were identified between solar farms and **"habitat for flora and fauna"** ES, where only minor impact is expected, when avoidance of important habitat is required; and with **"Cultural services"** ES, linked to the visual impacts on landscape composition; iii) the least affected trade-offs were identified between solar farms and: **"Water provisioning and filtering"** ES, due to their null or minor impact in the water cycles, and on **"Climate regulation"** ES, only emerging in case of inappropriate land-use change.

| | PROVISION OF AGRICULTURAL PRODUCTS | WATER PROVISION AND FILTERING | CLIMATE REGULATION | HABITAT FOR FLORA AND FAUNA | CULTURAL SERVICES |
|---|---|---|---|---|---|
| AGRICULTURAL BIOMASS | No competition for agricultural products, as biomass will derive from left overs | Pesticide releases and eutrophication with intesified agriculture | Reduced level of soil carbon with intensified agricul-ture | Habit loss with intensified agricul-ture effects on agro-biodiversity | Possibile impacts of landscape composition and with emissions from biogas facilities |
| SOLAR FARMS | Competitiion with agricultural products possibile | No or only minor impacts on the water cycle | impacts in the case of inappropriate land use change | Only minor impacts expected avoidance of important habitat required | Visual Impacts on landscape composition |

The second step of the analysis for the Veneto Region aimed at defining the level of potential of ESs provisioning of different landcover categories. To assign a score of ES production to different types of landcover, another matrix, which builds on the work of Burkhard et al. (2012), was adopted. Burkhard et al. (2012) assigned a score of ES potential provisioning to each landcover type, based on Corine landcover. The scores lied on a range between 0 to 5, where:

- 0 correspond to no ESs provided, and
- 5 correspond to the highest ES supply potential for that specifying landcover type

Only the 5 ESs selected in the first step and presented in figure above were selected from the original matrix of Burkhard et al. (2012). In order to harmonize the two different ranges of scoring for facilitating the coming steps of the methods, the Burkhard et al.'s was normalized (see table below) in the range 0 to 4, where:

- 0 corresponds to the non-provisioning of ES, and
- 4 correspond to a high provisioning of the ES).

Third step combined the identification and quantification of trade-offs (obtained from step 1 adopting the findings from Hastik et al. 2015) with ESs supply scores based on landcover (obtained from step 2 adopting the findings from Burkhard et al. 2012). Specific objective this step was to assign a level of RES production non-suitability. For getting these non-suitability scores, for each ES, the trade-offs score with to either solar or biomass production was multiplied with the potential of land-cover type to produce that specific ES. Making a long story short, by multiplying the trade-off's score by the ES supply's score, we obtain a level of negative impact of specific RES provisioning on a specific ES provisioning, which determines a non-suitability. All results were normalized in a scale from 0 to 4, where 0 corresponds to no impact of the RES on other ES provisioning, (hence suitability of the area for RES production), and 4 corresponds to the highest negative impact of the RES on other ES provisioning, (hence non-suitability of the area for RES production) (see table below). In particular, values under the column "average" represent average values for non-suitability, calculating first the average values given from the 5 ES values for each Res from non-normalized values, and then normalizing results to get values from 0 to 4.

These tables were used to produce through GIS maps that assign the level of non-suitability (or "risk") to each land cover type, for solar farms and agricultural biomass respectively. Disaggregated maps, one per ES for each RES, presenting non-suitability of areas (where the score 0 indicates suitable areas for RES production, and score 4 indicates the highest level of non-suitability for RES production). In this way, a set of 5 maps (one per ES) was obtained for each of the two RES. Then, two maps (one per RES) were also produced considering the average scores for level of non-suitability, and one final map overlaying average non-suitability map for agricultural biomass, with average non-suitability map for solar farms. To produce credible results, the layer of "protected areas" was added, in order to also exclude them from the list of "suitable areas for RES production" emerging from the GIS ES trade-offs analysis.

## LEVEL OF POTENTIAL ES PROVISIONING, BASED ON CORINE LAND COVER (LEVEL 2)

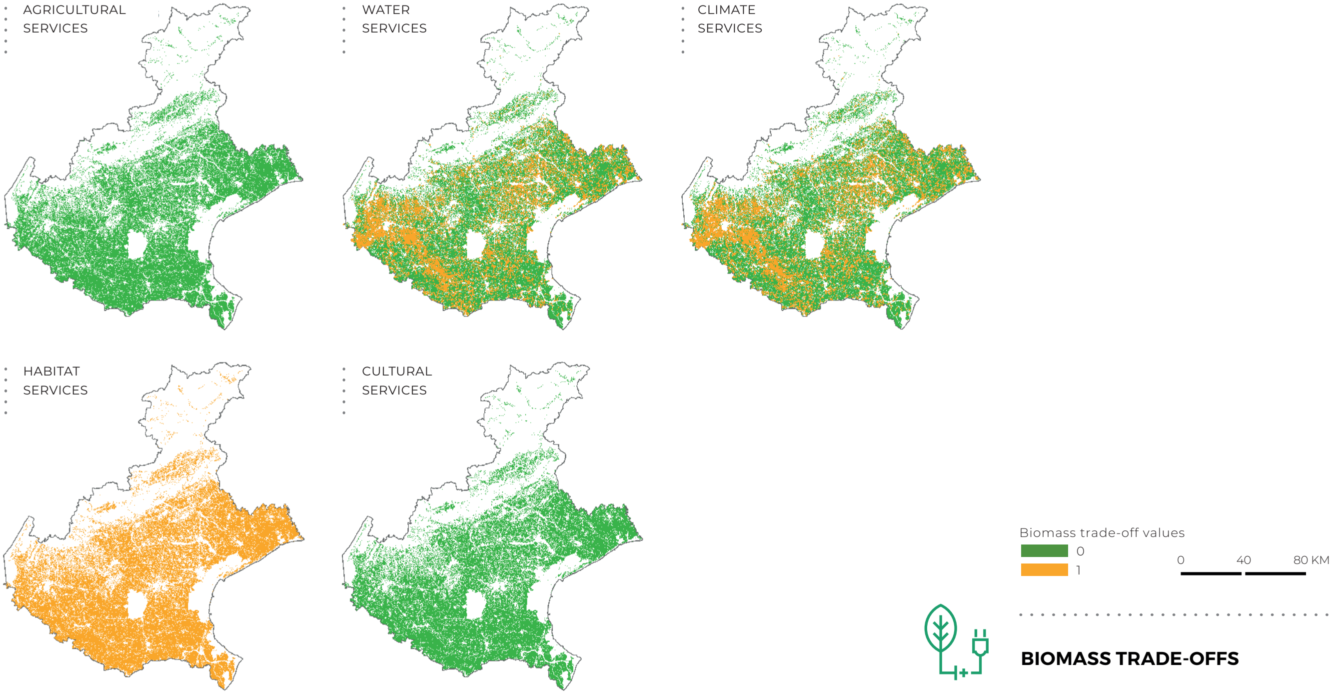
| CLC_liv III | DESCRIPTION | PROVISION OF AGRICULTURAL PRODUCTS (CROPS) | WATER PROVISION AND FILTERING | CLIMATE REGULATION (GLOBAL) | HABITAT FOR FLORA E FAUNA | CULTURAL SERVICES (RECREATIONAL AND AESTHETIC VALUE) |
|---|---|---|---|---|---|---|
| **211** | Non-irrigated arable land | 0 | 0 | 0 | 1 | 0 |
| **212** | Permanently irrigated land | 0 | 0 | 0 | 1 | 0 |
| **213** | Rice fields | 0 | 0 | 0 | 1 | 0 |
| **221** | Vineyards | 0 | 0 | 0 | 1 | 0 |
| **222** | Fruit trees and berry plantations | 0 | 1 | 1 | 1 | 0 |
| **223** | Olive groves | 0 | 0 | 0 | 1 | 0 |
| **224** | Other permanent crops | 0 | 1 | 1 | 1 | 0 |
| **231** | Pastures | 0 | 0 | 0 | 1 | 0 |
| **232** | Other pastures | 0 | 0 | 0 | 1 | 0 |
| **241** | Annual crops associated with permanent crops | 0 | 0 | 0 | 1 | 0 |
| **242** | Complex cultivation patterns | 0 | 0 | 0 | 1 | 0 |

## NON-SUITABILITY SCORES FOR (AGRICULTURAL) BIOMASS

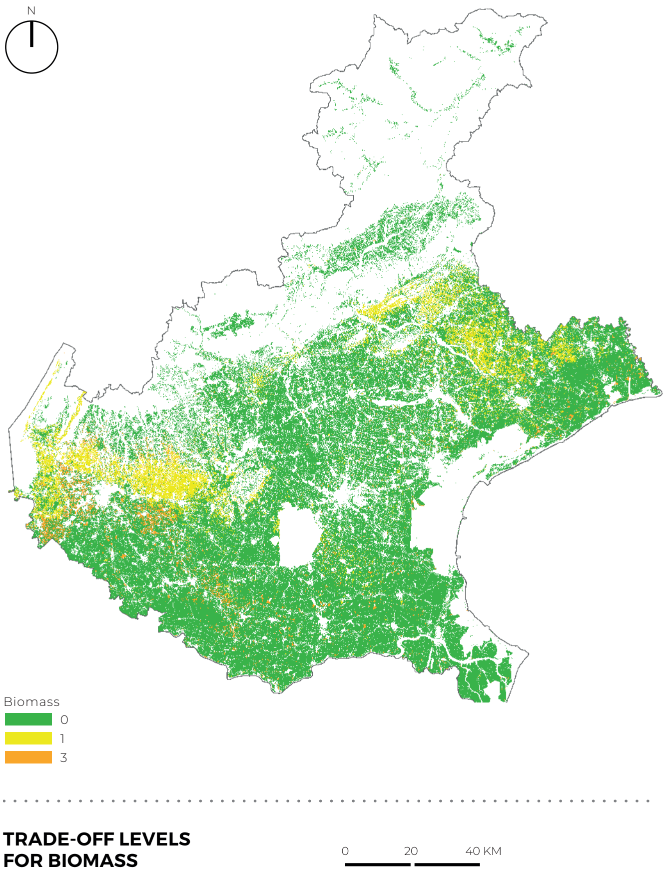
| CLC_liv III | DESCRIPTION | PROVISION OF AGRICULTURAL PRODUCTS (CROPS) | WATER PROVISION AND FILTERING | CLIMATE REGULATION | HABITAT FOR FLORA E FAUNA | CULTURAL SERVICES | AVERAGE |
|---|---|---|---|---|---|---|---|
| **211** | Non-irrigated arable land | 4 | 0 | 0 | 1 | 0 | 1 |
| **212** | Permanently irrigated land | 4 | 0 | 0 | 1 | 0 | 1 |
| **213** | Rice fields | 4 | 0 | 0 | 1 | 0 | 1 |
| **221** | Vineyards | 4 | 0 | 0 | 1 | 1 | 2 |
| **222** | Fruit trees and berry plantations | 4 | 0 | 0 | 1 | 1 | 4 |
| **223** | Olive groves | 4 | 0 | 0 | 1 | 1 | 2 |
| **224** | Other permanent crops | 4 | 0 | 0 | 1 | 1 | 4 |
| **231** | Pastures | 0 | 0 | 0 | 1 | 1 | 0 |
| **232** | Other pastures | 0 | 0 | 0 | 1 | 1 | 0 |
| **241** | Annual crops associated with permanent crops | 4 | 0 | 0 | 1 | 0 | 1 |
| **242** | Complex cultivation patterns | 4 | 0 | 0 | 1 | 0 | 1 |

By applying the methods above described, a set of maps and figures to provide technical support to decision-makers were obtained.

The first set of 5 maps presents results disaggregated by ES, where it is visible that the highest level of non-suitability (which is still low and correspond to level 1) is given by trade-offs between the provisioning of habitat services and the provisioning of agricultural biomass. Intermediate situations can be seen for water services and climate service, while no trade-offs (hence, 0 level of non-suitability) can be seen for agricultural services and cultural services.




**BIOMASS TRADE-OFFS**



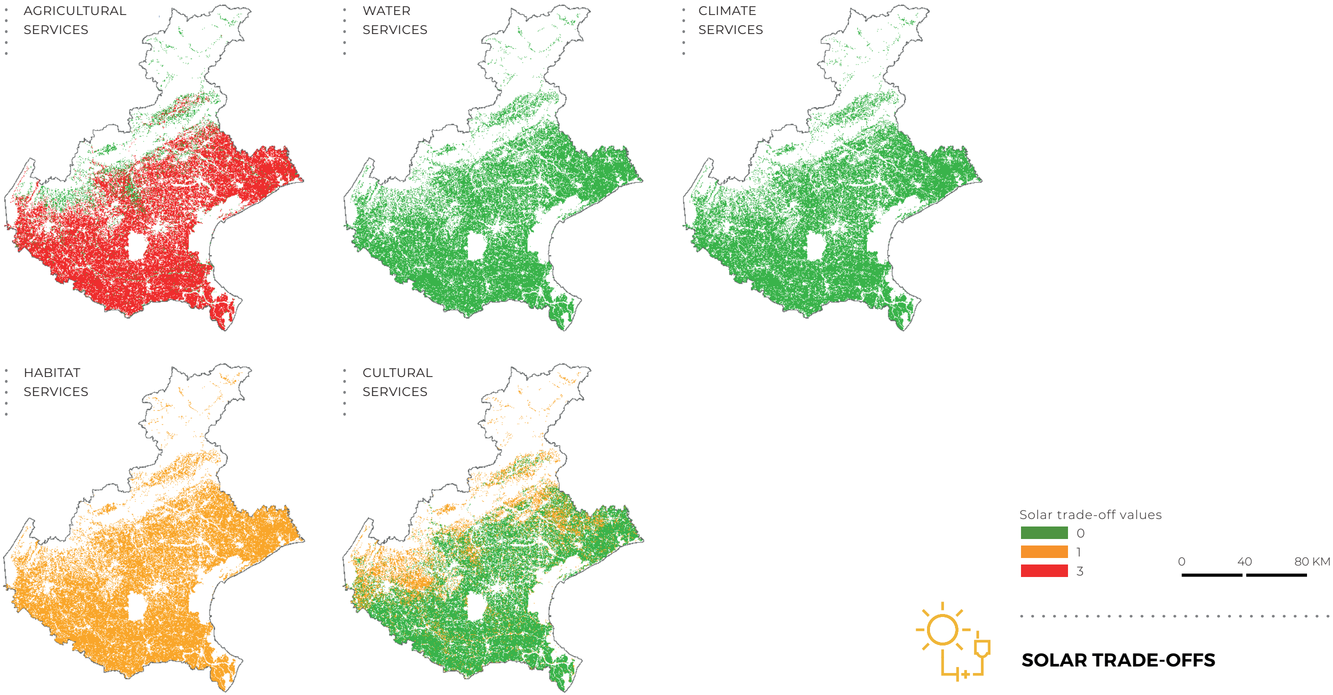

The map below presents average values combining all 5 ES. Considering average values, 86% of the total agricultural land (corine level 2), excluding protected areas, is suitable (level 0 of non-suitability) for agricultural biomass production from left-overs. Which means a total surface of 763298,15 hectares. Then, 10% of the surface present level 1 of non-suitability, which corresponds to 86638,27 hectares, no land presents level 2, approx. 4% presents level 2, which corresponds to 33292,69 hectares, and no land presents level 4.


**TRADE-OFF LEVELS FOR BIOMASS**

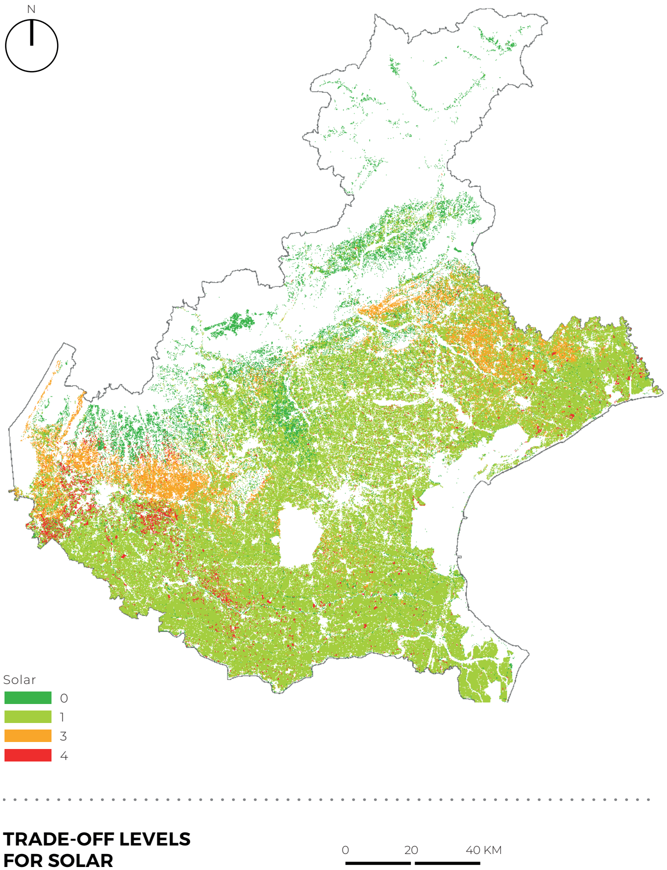
**NON-SUITABILITY FOR BIOMASS**

The set of five maps below presents results disaggregated by ES under the trade-off analysis regarding solar farms. It is visible that the highest level of non-suitability (level 4) is given by trade-offs between agricultural production and the provisioning of energy through solar farms. Intermediate situations can be seen for habitat services and cultural services, while no trade-offs (hence, 0 level of non-suitability) can be seen for water services and climate services.

The map below presents average values combining non-suitability deriving from ES trade-off analysis of all 5 ES for solar farms production. Considering average values, 73% of the total agricultural land



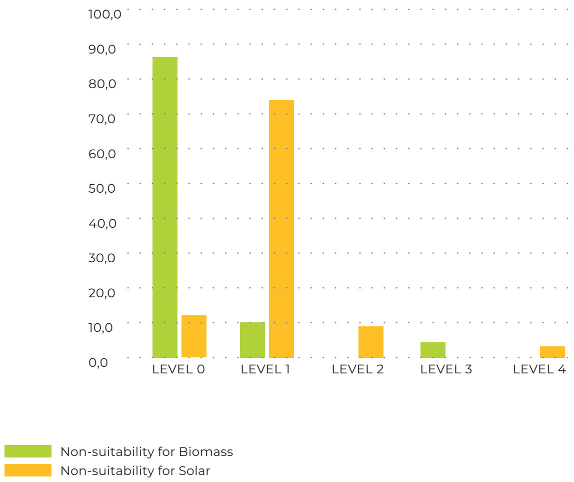
(corine level 2), excluding protected areas, presents a level 1 of non-suitability. Which means a total surface of 653765,13 hectares. Then, 13% of the surface present level 0 of non-suitability, which corresponds to 109533,02 hectares, and 10% presents level 2 of non-suitability , which corresponds to 86638,27 hectares. No surface presents a level 3, while 4% present a level 4 of non-suitability (33292,69 hectares). Still, it is key to remember that even where average values present level 0 of non-suitability, it does not mean the absolute absence of trade-offs (for example, trade-off with agricultural production is always present).

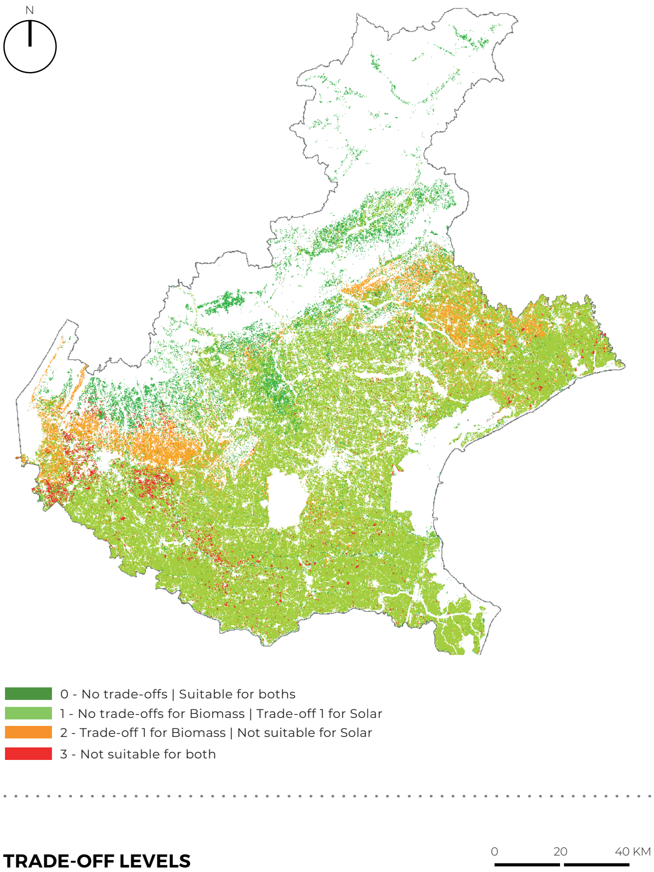



**TRADE-OFF LEVELS FOR SOLAR**


**NON-SUITABILITY FOR SOLAR**

The graph below compares results presented by maps produced from agricultural biomass, and by maps produced for solar farms. On the y axis, values indicate the percentage of the total agricultural land (corine level 2, excluding protected areas) falling under level 0, level 1, level 2, level 3 and level 4 of non-suitabilility. Figure 6 shows that the majority of land present 0 non-suitability level (hence, it is suitable) for agricultural production from left-overs. Regarding solar farms, the majority of land present non-suitability level 1, due to important trade-offs with the agricultural production and cultural services.




**NON-SUITABILITY LEVELS FOR BIOMASS AND SOLAR COMPARED**

**TRADE-OFF LEVELS**

The last map here below combines results from trade-off analysis for agricultural biomass and solar farms (average values), and assigns 0 level of non-suitability to land where both agricultural biomass and solar farms presents no-trade-offs (level 0 of non-suitability). Such type of areas corresponds to the 13% (113227,24 hectares) of the total. Level 1 of overall non-suitability is assigned in the map where agricultural biomass presents 0 level of non-suitability and solar farms presents level 1 of non-suitability. Such type of areas corresponds to 74% (650070,91 hectares).

There are no cases of land with level 1 of non-suitability for agricultural biomass and 0 level of non-suitability for solar farms. Level 2 in the map is assigned to land with level 1 of non-suitability for agricultural biomass and non-suitability (from level 2 above) for solar farms. Which corresponds to 10% (86638,27 hectares) of total land. Level 3 in the map is assigned to land which is non-suitable (non-suitability levels from 2 above) for both types of RES, which corresponds to 4% (33292,69 hectares) of total land.

Then preliminary conclusions from the Veneto's team suggest that 13% of total land is suitable for both types of RES, 74% of land suitable for agricultural biomass and solar farms can be considered if measures to minimize impacts on agricultural production and cultural services are taken. The 10% of land is suitable for agricultural biomass if measures to minimize impacts on habitat, water and climate services are taken, while it is not suitable for solar farms. The remaining 4 % of land is not suitable for either of the two RES production.

More in detail, it is possible to state that:

- Trade-offs analysis considers agricultural biomass from leftovers to be much less impactful than ground-based solar farm.
- In the region, production of energy from agricultural biomass has high potential to negatively impact on habitat services, followed by water-related and clmate-related services.
- In the region, production of energy from solar farms has high potential to negatively impact in agricultural production, followed by habitat services and then cultural services.
- Overall, the trade-offs analysis seems to detect a low risk of trade-offs. This is due to the aggregation of the results for the individual services into an average value. The disaggregated values help a more critical reading of results.

The key implications suggest that:

- Where non-suitability level scores from 2 above, we discourage the RES production, unless careful EIA and mitigation measures are put in place to ensure that ES provisioning is protected and ensured
- Even when average non-suitability level scores 0, there is need to double check the provisioning of ES that presents higher score of trade-offs with that specific RES
- Present indications from the Regional Energy Plan (PER, 2017) set very similar constrains to produce energy from biomass and for solar farms, as if the negative impacts they trigger are almost the same. Based on the present analysis, it would be interesting to further analyze the present policy constrains for energy production from RES, to better understand whether and how they can be updated and adjusted.
- The interlinkage provided by the presented methodology between CORINeland-cover types, and non-suitability for Res production, can , support land use-related policies. For example, the tables above show that land cover types 2.2. tend to be more impacted by both agricultural biomass provisioning and solar farms installation.

# 8. OVERALL PICTURE OF KEY ASPECTS FROM THE CASES

In this section, a summary from each case study's experience is provided. In particular, subsection 8.1. introduces **Policy demands and Policy instruments across the regions and RES development; subsection 8.2 discusses the Knowledge needs and State of the art across the different case studies, while subsection 8.3 presents the Methods for ES and RES Trade-offs and Synergies (TOs&Ss) used.**

## 8.1. POLICY DEMANDS AND POLICY INSTRUMENTS ACROSS THE REGIONS AND RES DEVELOPMENT

Each region was characterised by the presence of different policy demands. In the **UK**, the interaction between renewable energy and other ecosystem services is recognised as an important issue at a national level, but the policy landscape and associated instruments have changed appreciably in the past three years. The Industrial Strategy has been replaced by a new Plan for Growth (due to challenges associated with Brexit and post-Covid recovery). In addition, there has been a new Agriculture Act (2020), Energy White Paper (December 2020), Environment Act (2021) and Net Zero Strategy (2021). The UK Action Plan now focuses on implementation of the Net Zero Strategy because it is the key current policy that shapes the decarbonisation agenda at national, regional and local levels. However, the same issue of lack of guidance regarding renewable energy deployment and other aspects of land use still exists.

In **Estonia**, according to the action program Estonia 2035, the current government is developing the economy into a competitive low-carbon one by the mid-century and the IKA's representatives involved in the case study were especially keen on using trade-offs assessments for their RES-related spatial planning processes. The Ministry of Finance alongside regional and local planners were encountering difficulties in achieving balanced planning solutions, in the context of wind and solar energy development. The trade-offs and synergies maps produced by the Estonian team were therefore expected to be utilised to guide spatial planning processes for RES, at spatial scales relevant to local planning processes. Using these tools, the IKAs expected to overcome the current lack of information and guidance in **spatial planning for RES**, and eventually achieve policy change applications. The policy instrument being targeted is the Operational Programme for Cohesion Policy Funds. However, as a results of the SWOT, the SOTA and the ongoing work within IRENES, other instruments were also indirectly targeted. The Mapping and Assessment of Ecosystem Services (MAES) in Estonia has been implemented through the project ELME[2]. Concerning the current state of RES, renewable energy production in Estonia is mostly focused on primary solid biofuels (mainly fuelwood, although also wood residues, wood pellets), wind energy and solar. Solar photovoltaic has only recently experienced an increase in production, having doubled betwe-

2. Elurikkuse sotsiaal-majanduslikult ja kliimamuutustega seostatud keskkonnaseisundi hindamiseks, prognoosiks ja andmete kättesaadavuse tagamiseks vajalikud töövahendid

en 2018 and 2019. Spatial planning processes in relation to RES are now mostly focused in drafting potential locations for wind energy production, minimising their impact on natural resources, protected areas and the Green Network.

In **GERMANY**, the ERDF funding can provide marginal support for the energy transition, for example by supporting generation technologies that are not economically viable on the market but that are particularly compatible with nature. To this end, it is necessary and possible to open up the funding guidelines in order to promote the protection of ecosystem services coupled with innovative generation technologies. For this, it is important that the Lower Saxony strategy with the combination of environmental and climate protection is reflected in new funding directives. Financial support for the energy transition is mainly provided by the Renewable Energy Sources Act (EEG), which applies nationwide. This instrument defines development and expansion targets, differentiated according to the various energy sources. However, it does not make any statements on the spatial management that is compatible with humans and nature, so that the EEG cannot be used to manage the spatial impacts of wind or solar energy. The EEG has a great influence on the feasibility and economic viability of individual energy projects at the municipal level, in that it enables or prevents feed-in, sets the level of subsidies and thus also influences the technologies used. The planning procedures for each energy source are implemented by different actors and there is no overall concept for energy planning. Spatial planning mainly makes statements on wind energy: potential areas are identified and regional expansion targets are defined. Solar energy is not considered spatially relevant and is therefore not planned by overarching regions but by municipal planning authorities. The use of bioenergy is not regulated by planning. The construction of a biogas plant or the cultivation of energy crops is left to the farmers. Only the possibility of feeding electricity into the grid and its remuneration determines the individual decisions, so that incentive is at the federal level and the EEG. **Concerning the state of the RES in Lower Saxony,** in 2022, the share of renewables in Primary energy consumption (PEC) reached more than 16 % PEC. In 2019, the share of renewable energy sources in gross electricity generation in Lower Saxony has reached 52 %. Wind power generation (onshore and offshore) in particular increased sharply in Lower Saxony in 2018 and accounted for 69 % of total gross electricity generation from renewable energy sources. The forecast for 2019 expects up to 74 % of renewable electricity from wind energy. The shares of biomass (around 20 percent) and photovoltaics (6.5 percent) regress slightly compared to the previous year. Hydropower plays only a minor role in electricity generation.

In **ROMANIA**, the National Environmental Protection Agency have implemented the MAES process (Mapping and Assessment of Ecosystems and their Services) under the N4D Project ( Nature for Decision-making or Nature in Public Decisions) the purpose of which is to carry-out the biophysical mapping and assessment of ecosystems and of services they provide to the society, at national level.. The NEPA expressed the interest from two points of view, one linked to the use of the results of the MAES project in Romania and the second with the use of an appropriate tool to evaluate the trade-off between RES and between RES and other ES. The development challenges identified at national level in terms of transport infrastructure, sustainable urban transport, environment, energy and risk prevention are addressed by the Large Infrastructure Operational Program (POIM). The programme will mainly invest in removing the main transport bottlenecks and developing sustainable, efficient and green transport modes in the country and introduce measures to increase energy efficiency and protect natural resources. To promote the production of electricity from renewable sources, Romania uses the system of mandatory quotas coupled with the trading system for green certificates. Based on this mechanism, suppliers acquire mandatory quotas of green certificates and the electricity is sold separately on the energy market. The acquisition quotas for green certificates are established in correlation with the targets and their values increase every year. The market energy has dispatching mechanisms that give priority to sales of electricity from renewable sources. **Concerning the state of the RES, in Romania**, the target for consumption of electricity from renewable energy resources represents 33% of the gross domestic consumption of electricity in 2010, 35% in 2015 and 38% in 2020. (See the "Romania's Energy Strategy for period 2007-2020", approved by Government Decision No 1069/2007 ).

Finally, in **ITALY**, policy makers have shown interest in understanding potential trade-offs and synergies about strategies and projects implementing RES production from solar energy. There is also a policy interest on agricultural biomass, and on considering its potential trade-offs with food production. The analysis of Veneto's team focused on the Programma Operativo Regionale- Fondo Europeo di Sviluppo Regionale(POR-FESR 2014-2020), while other instruments were indirectly targeted. However, the main objective of the work is to make use of the analysis and work undertaken under IRENES to provide useful inputs for the POR-FESR 2020-2027. Concerning the current state of RES, the Veneto Region met the burden-sharing targets before 2020, however, given the new panorama and the need to abate emissions and produce (clean) energy targets changed. In detail, the Veneto Region is one of the regions consuming the highest amount of energy in Italy, while ranking lower in terms of energy production from renewable resources than other Italian regions which are consuming less energy (PER-FER, 2017). At present, Veneto's RES production is led by hydroelectricity, followed by energy produced from solar and biomass. However, the hydroelectric contribution has reached its limits and cannot grow further. Hence, to meet the new targets derived from burden sharing, the region is betting on solar and biomass. For thermal purposes, the Regional Plan for Energy (2020), focuses mainly on biomass (expected to provide RES for 49% on the total target needed)- For electricity purposes, the Region mainly emphasises biogas and biomass (39% and 21% respectively), while solar is considered only for the 12% (PERFER 2017).

## 8.2 KNOWLEDGE NEEDS AND STATE OF THE ART ACROSS THE DIFFERENT CASE STUDIES

In the **UK**, recent discussions with officials in government departments and local authorities have highlighted a need for information on the spatial coincidence of RES potential and other ES across regions. This is to help identify strategic opportunities or problems (e.g. where infrastructure investment is required). Decisions regarding RES-ES interactions at the level of the individual project or site are regarded as appropriately handled within the planning system. However, somewhat more problematic are the issues regarding cumulative impacts of increased RES generation and the spatial scale at which these should be assessed. The UK has a long history of initiatives on the mapping and analysis of ecosystem services (ES). Examples of such initiatives are found in the reports of the National Ecosystem Assessment and the Natural Capital Committee. The latter recommended creating a 25 Year Environment Plan and,since this was published in 2018, it has stimulated the incorporation of ES assessments into a range of policy areas. Among the many projects to make spatial data on natural capital and ES widely available there is the work by the UK Centre for Ecology and Hydrology, atlases of data from Natural England and assessment tools such as Natural Environment Valuation Online.

In **ESTONIA**, there is a manifested need to access spatial data on the supply of ES, their hotspots and trade-offs among them. Data is needed at a local scale, so that it can serve as an input to ongoing spatial planning processes. Also needed are spatial data on the potential supply of RES, at the local scale, so that it can be combined with the ES one and jointly used in spatial planning processes. The objectives of the ELME project are twofold: to analyse ecosystem conditions and to assess the supply of ecosystem services (ES) in forests, agricultural land, grasslands and wetlands. A wide range of ES has been assessed, including carbon sequestration, primary production, microclimate regulation and erosion control among others. The supply of ES has been assessed using biophysical models and the outputs are raster maps with a resolution of 10m/pixel. These highly detailed ES maps allow upscaling and can feed in several spatial planning processes.

The key knowledge need for **LOWER SAXONY** is in defining an overarching energy mix that is compatible with nature and consists of the interaction of wind, solar or bioenergy. So far, the energy sources have been considered individually, as the actor networks and the responsibilities in the area of solar energy and wind energy are very different. Since there are few regional energy concepts available, the coordination of potentials and expansion possibilities is not yet part of regional planning.

The concept of ecosystem services is similar to that of German landscape planning, even if the assessment methods differ in detail. Landscape planning has a long tradition in Germany and delivers a large range of basic data on nature and landscape. It includes a systematic and area-wide ecological analysis at different spatial scales (federal state to municipality), with a concrete spatial reference and a defined mandate within the overarching spatial planning. Landscape planning is legally embedded and established in planning. It evaluates landscape statements on soil, water, climate/air, species and habitats as well as the landscape appearance. It presents concrete requirements and measures of nature conservation for the planning area that are necessary to realise its targets and is an important basis for determining the usage potential as well as the economic value of ecosystem services. Integration of the ES concept into landscape planning is currently limited to a few sub-sectors.

The challenge for landscape planning is therefore to expand its methodological spectrum, to standardise the data basis accordingly and to balance environmental services to a greater extent and prepare them for monetization.

In **ROMANIA** the identified knowledge requirements were to obtain: a spatially explicit distribution of ecosystem services, a spatially explicit distribution of RES exploitation and a plan for participatory meeting and landscape visualisation. At country level, the project “Demonstrating and promoting natural values to support decision-making in Romania” implements the MAES process in Romania and has the  public policy aims to assess the level of integration of the concept of ecosystems and ecosystem services in public policy for the period 2014-2020 in order to develop recommendations on integrating the results of mapping and biophysical assessments in decision-making processes.

The areas of public policies analysed are: biodiversity, climate change, fishing and aquaculture, agriculture and sustainable development, transport, energy, regional development, tourism, and marine and forest areas.An inventory of the responsible institutions, an institutional map and a questionnaire to identify institutional needs related to the MAES process were made. This is done by taking the following directions: identification of data sources, analysis of the availability, analysis of the representativeness and of the update policies, data integration in the conceptual model and in the physical model of data organization. There were achieved major results regarding: mapping ecosystems at the national level, achieving "Ecosystems classification in Romania EUNICE 3" (intermediate version) the development of tools for updating this distribution (land field guide to identify the ecosystems, methodological guide for assessing the ecosystem services) and the selection of methods for assessing the ecosystem services that are carried out continuously based on the matrix of indicators and on the comparative analysis of existing methods.

Finally, in **ITALY**, based on the present state of policy instruments and energy strategy (PER, 2017), there is interest by the Managing Authority (MA) to further identify suitable areas and identify trade-offs related to the production of energy from solar farms and from agricultural biomass from left-overs (in order to choose among the two and/or identify combinations of solutions).

The largest source of RES in Veneto is currently derived from hydropower. Water represents a precious resource in the Region for energy production, however, the MA recommended not to increase the production of energy through hydropower. Wind speed does not comply with Eolic plants requirement in most of the region's areas: hence, there is no room to increase energy production through windmills either. Geothermal looks promising but needs further time and costly investigations. Biomass from woodlands provides a viable  option for mountainous areas, but the Region needs strategies to face the energy demand of urban and industrialised areas located in the plains. Hence, given the urgent need to produce increasing amounts of energy from renewables, the MA' key knowledge's need is in understanding whether promoting either solar or biomass, without creating trade-offs with agricultural production, and possibly without compromising the landscape, with its negative effects on tourism.

In Italy, the MAES process has been implemented at national level from several initiatives from the Ministry of the Environment and from the Italian National Institute for Environmental Protection and Research ISPRA. The analysis of the state of the ecosystems and of ES is focused on understanding the relationship between ES and land consumption; the study was implemented at national scale and at regional scale.

In Veneto, the Regional Environmental Agency has supported the analysis of MAES on land consumption and soil ES in the provinces of Vicenza and Rovigo. Soil ES were mapped and assessed through a system of indicators representing the capacity of different soils to provide ES.

### 8.3 METHOD FOR ES AND RES TRADE-OFFS AND SYNERGIES (TOS&SS) USED

As mentioned in the introductory sections of the work, each case study selected its methods, based on the policy demand and needs, on the state of the art, data available, capacity and general constrains (budget, time, ...).

In the **UK**, the **RES** included Biomass crops, ground solar PV and onshore wind, while the **ES included** Food production, Timber production, Recreation & Habitat. The focus was on visualising and quantifying the spatial coincidence of potential generation from different RES and other ES. This was done through a GIS analysis using the RES-SOTA results and existing ES databases, leading to the generation of maps comparing potentials for 1 km grid squares across the East of England study area. Grid cells and administrative units (such as local authorities) were then classified on their relative potential for delivery of different RES and other ES. The UK Study included **Policy- regulatory constraints** considering the buffers around roads, rail, rivers, lakes, airfields, defence sites and residential areas.

In the **ESTONIA**'s case study, the only **included RES** was wind, while there was a fine diversification of the **ESs considered**: - Fodder/bioenergy from grasslands, Edible mushrooms, Bilberries production, Agricultural yield, Spiritual value, Passive recreation, Active recreation, Microclimate regulation, Global climate regulation, Pollination, Genetic resources in grasslands, Genetic resources in mires, & Genetic resources in forests. A stepwise methodology was followed: first focussing on these ES hotspots and then bundling them performing a Principal component analysis.

The Trade-offs and Synergies were then identified using a Production frontier across a range of ecosystem conditions. The **Estonia** case study included **Policy- regulatory constraints** focusing on those for the protected areas.

In **LOWER SAXONY** the **RES** included Wind & Solar energy, while the **ES** included Cultural services, Habitat, Water provisioning, Soil provisioning. **Lower Saxony followed** an area-based approach, analysing those areas that can be used for the production of renewable energy in an environmentally compatible way by 2050. The focus of the analysis was on the production of electricity with wind energy onshore and solar energy on roofs as well as in open areas. With the data obtained, energy production plants in Lower Saxony can be optimally distributed according to natural potentials (trade-offs and synergies).The analyses can be transferred to the local level. In this way, the overarching goals of the state are to be considered at the local level and the community's responsibility to achieve the overall target (Germany's energy demand in 2050) becomes clear. In accordance with the requirements of the German Nature Conservation Act, the impacts of the energy plants on soil, water, landscape, biodiversity and people were considered in the analysis.

The **Lower Saxony** Study included **Policy- regulatory constraints** considering both legal regulations and legally derived requirement (Federal Nature Conservation Act; National Biodiversity Strategy).

Finally in **ROMANIA**, the RES included were: Wind energy, Solar Energy and Biomass energy, while the key ES were, Provisioning services and Cultural services. Policy and regulatory constraints included from protected areas.The analysis provides clear insights in terms of quantity and locations of suitable areas for solar, wind and biomass, setting the basis for policy design. Participatory methods were applied to identify potential synergies and trade-offs across space and time. Through active participation, local communities can inform researchers, and reciprocally , about the optimum renewable energy scenarios and local transition. Participatory mapping combines local knowledge from stakeholders with GIS techniques to assess the actual situation and to choose between future development scenarios. In particular regarding the cultural ecosystem services, the involvement of communities in participatory methods is the most relevant aspect, because participation protects the citizens and stakeholders contribution in defining the spatial distribution of cultural services and their level of supply.The interrelation between RES and ES was assessed through landscape visualisations, where people can perceive how the landscape will look according to different levels in the supply of other ES.

In the **VENETO** region, the **RES included** were: Agricultural Biomass and Solar farms , while the **ES included** were Water regulation, Habitat, Global Climate regulation, Food production & Aesthetic values . Also in the **Veneto**, a stepwise methodology is followed. It consisted in first mapping suitable areas based on ES trade-offs analysis for agricultural biomass from leftovers. Second, mapping suitable areas based on ES trade-offs analysis for solar farms, and finally in comparing mismatches and common highlights. The Veneto study included **Policy- regulatory constraints** for biomass and solar production from the Regional Energy Plan (PER 2017) - these were discussed with stakeholders throughout the process.

# 9. TAKE AWAY FROM COMPARING THE CASES AND CONCLUSIONS

3. Elurikkuse sotsiaal-majanduslikult ja kliimamuutustega seostatud keskkonnaseisundi hindamiseks, prognoosiks ja andmete kättesaadavuse tagamiseks vajalikud töövahendid

Under the principles of knowledge sharing and mutual learning, throughout the processes, the teams from the five countries and case studies met and exchanged their findings, challenges, lessons learned. Similarities and differences between the individual case studies emerged. This final section collects some general findings from this process, looking at all the work presented in this technical report at a glance.

Looking at the outputs provided, the **UK** team provided maps and tables comparing electricity generation outputs for renewables (including siting constraints) with percentages of land in different natural assets. These were compared to classify areas based on their generation potential and natural assert indicators. In **Estonia**, the type of output for the trade-offs analysis were maps representing overlaps between various degrees of overall supply of ES (represented as hot and cold spots) and two categories of wind-speeds. According to the resulting categories, areas of potential trade-offs and synergies are highlighted. The **German team** produced maps of the vulnerability of the landscape (based on environmental protection and policy constrains more that strict ES provisioning indicators) for wind and solar energy (four classes). The **Romanian team** produced maps representing overlaps between various supplies of ES (the 4 main categories: supporting, regulating, provisioning, and cultural) and different types of RES.

Overall, we can say that only Estonia focused on one RES, while other countries addressed and compared a set of RES. This is due to a different state of the art and policy demand. Thus, while Estonia was already wind-energy oriented, other countries were more interested in comparing alternatives or identified a possible set of solutions to combine.

Regarding the types of ES addressed, while Romania addressed all ES, organizing them in the four categories, all other countries target only ES of interest for their contexts. Regarding the indicators and proxies for ES, instead, while Estonia, Romani and Italy adopted indicators for ES mapping from the ES literature, Germany and UK also adopted information and data for environmental protection, resources mapping and other policy-related categories as proxies for Es provisioning. On one hand, the choice of the UK and Germany makes information more decision-makers friendly, while triggering the risk of providing lower accuracy, while Estonia, Romania, and Italy, adopt data which are not already familiar to planners and decision-makers, but ensure a higher level of accuracy.

Bringing together results from the five analysis, **THE RES-ES MATRIX (here below)** presents a snapshot of trade-offs between RES and ES analysed in this work. The **RES-ES Matrix** considers the Renewable Energy sources analysed, RES, as columns, and the Ecosystem Services, ES, as rows, placing each region into the cell matching the specific combinations of RES/ES used in the region's case study. The **RES-ES Matrix** offers a synthetic comparison of the case studies along

| RES<br>ES | SOLAR | ONSHORE WIND | BIOMASS |
|---|---|---|---|
| **Habitat** | Lower saxony (DE), Veneto (IT), East Anglia (UK) | Lower saxony (DE), East Anglia (UK) | Veneto (IT), East Anglia (UK) |
| **Soil provisioning Provisioning Services** | Lower saxony (DE), Romania | Lower saxony (DE), Romania | Romania |
| **Spiritual value Cultural services** | Lower saxony (DE), Romania | Estonia, Lower saxony (DE), Romania | Romania |
| **Fodder/bioenergy from grasslands** | | Estonia | |
| **Agriculture, Food Production in general (including Edible mushrooms and Bilberries production)** | Veneto (IT), East Anglia (UK) | Estonia (Including Edible mushrooms, Bilberries production) | Veneto (IT) |
| **Water regulation Water Provisioning** | Veneto (IT), Lower saxony (DE) | Lower saxony (DE) | Veneto (IT) |
| **Aesthetic values** | Veneto (IT) | | Veneto (IT) |
| **Timber production** | East Anglia (UK) | East Anglia (UK) | East Anglia (UK) |
| **Passive recreation, Active recreation** | East Anglia (UK) | Estonia, East Anglia (UK) | East Angla (UK) |
| **Microclimate regulation, Global climate regulation,** | Veneto (IT) | Estonia | Veneto (IT) |
| **Pollination** | | Estonia | |
| **Genetic resources in grasslands, Genetic resources in mires, Genetic resources in forests** | | Estonia | |

these two RES/ES dimensions and providing an opportunity for further collaborative learning from partners' activities. The **RES-ES Matrix** also represents a first step for future work, aiming at exploring similar Matrices, and associated regional mappings within them, according to different combinations of the relevant dimensions. In this way, the REM provides an opportunity to go beyond simplistic Geographical mapping exercises, moving towards conceptual maps, whose dimensionalities represent concepts rather than geographic coordinates, and where geographies are mapped into these concept spaces. In these conclusions the REM also included as a third dimension, whether a case study also accounted for policy and legal constraints. This third dimension, being summarised by a yes or no binary variable, was initially introduced by adding colour coding to the entries of the REM. However, since all case studies accounted for policy and legal constraints, there was no variability along this dimension, hence all entries remained in one colour only.

RES-ES Matrix (REM) considers the Renewable Energy sources analysed, RES, as columns, and the Ecosystem Services, ES, as rows, placing each region into the cell matching the specific combinations of RES/ES used in the region's case study. All entries are in black colour since all case studies accounted for policy and legal constraints.

Overall, strengths from the results relate to: i) quantification of suitable land for RES(s) (Italy and Romania); ii) Combination of multiple ES in one map, highlighting multi-functionality of landscapes (all the five cases); iii) technical information that match needs and language of the policy-making (Estonia, Germany, and Italy); Comparison of impacts by different types of RES (UK, Germany, Italy, and Romania); very fine resolution of maps (Estonia); specific target on the local scale (UK); and alignment with supra-local objectives of nature conservation, which can thus be more easily incorporated into decision-making at the local level (Germany).

Similarly, limitations relates to: i) adoption of some not yet validated models for trade-off analysis (Estonia); ES maps representing one static point in time (all the five cases); the use of proxies such as assets providing ES rather than the actual ES themselves (UK and Germany); the use of nation-wide geodata (Germany and Romania); final maps presenting average trade-off values (average among all ES considered) that may lead to choices that trigger serious trade-offs with one specific ES (Italy and Romania).

To conclude, the work opens up to future research (based on limitations and missed opportunities to further investigate), but also brings to some policy recommendations. Among these, the whole consortium agrees in stating that other uses of land, and benefits arising from them, need to be recognised when considering the potential for renewable generation. The application of an ES approach and the adoption of ES-related analysis, represent promising tool for pursuing such goal. The ES trade-off maps produced and presented in this report, do not simply aim at highlighting vulnerable areas to safeguard from RES development. Thus, maps also highlight areas where renewable generation could be prioritised, and potential synergies to (between RES and ES) to promote. In addition, when comparison among different RES occur, it is not a matter of setting overall preferability of a specific type of RES. Hence, they can be combined and make it possible to integrate the expansion of the two energy sources wind and solar energy in a regional concept. Different types of RES can be developed together and complement each other according to the natural yield potential of a region.

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**ANALYSIS AND MAPPING OF TRADE-OFFS BETWEEN RENEWABLE ENERGY AND ECOSYSTEM SERVICES**

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FIVE CASES FROM THE IRENES INTERREG PROJECT

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Challenging times and decisions to take for decision-makers involved in the design of energy strategy and plans. A team of researchers and technicians mapped similarities and differences among five different contexts, to choose an assessment method, apply it to the policy needs, and provide action-oriented information about renewable energy production and possible impact on other ecosystem services. Results for each context are presented and compared, to support decision makers towards sustainable energy production and valuable territories.

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