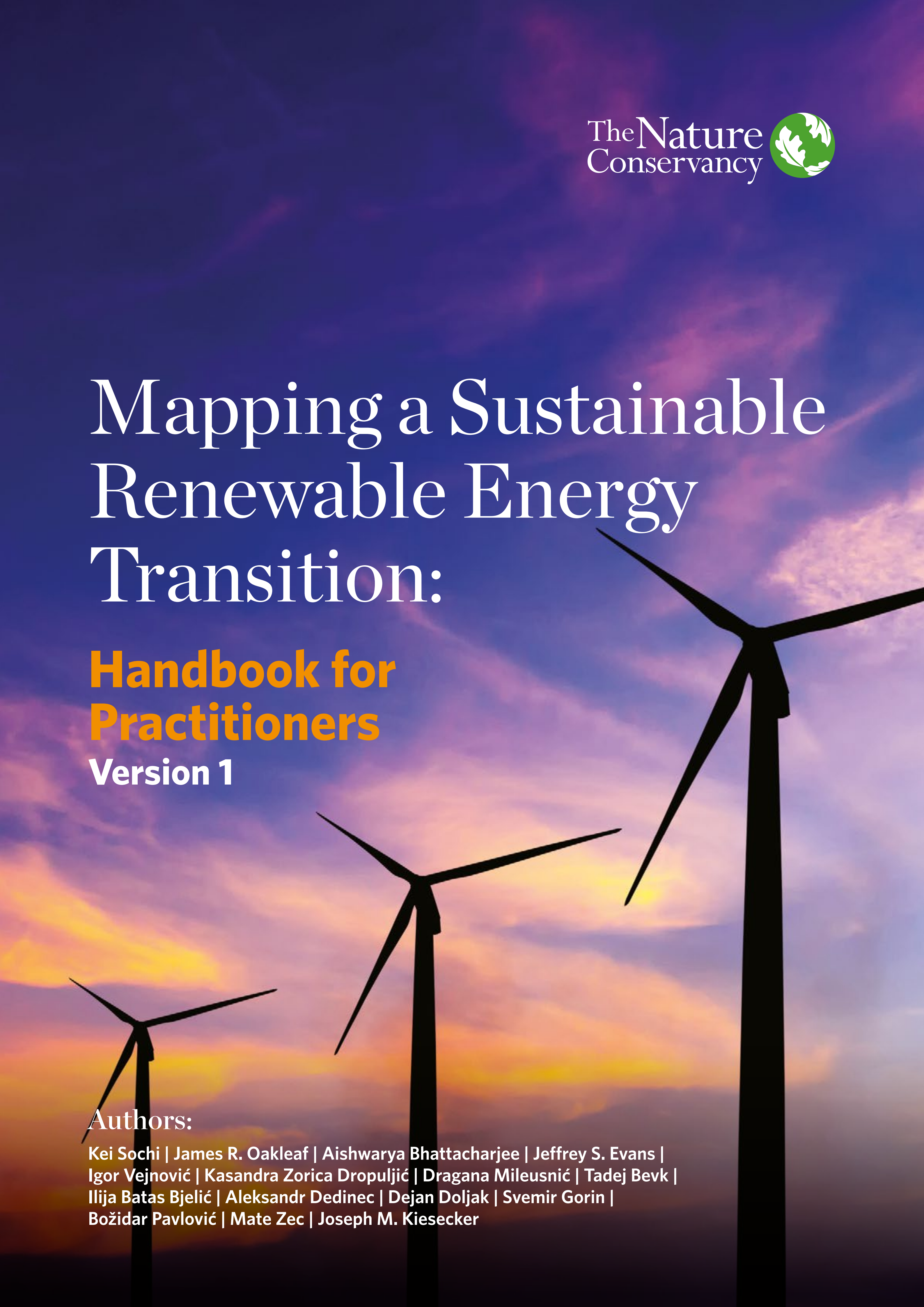

The Nature Conservancy

Mapping a Sustainable Renewable Energy Transition:

Handbook for Practitioners

Version 1

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1. Introduction

Renewable energy is widely acknowledged as the critical pathway needed to reduce emissions and limit global warming to 1.5 degrees Celsius. However, land use conflicts pose a challenge to building the necessary infrastructure for renewable energy. While Europe is already a global leader in scaling up renewable energy that will be needed to replace fossil fuels – renewable capacity expansion must surpass the previous rate within the next five years.

During 2022-2027, renewables will need to add the same amount of installed capacity as over the last 20 years. That's an 85% acceleration from the previous five years (International Energy Agency (IEA) 2023). It is evident that a new approach is needed to accelerate the build-out of renewable energy. With Russia's invasion of Ukraine, European leaders are pushing for a more rapid transition to renewables as part of a strategy to end dependence on Russian fossil fuels. While renewable energy is the logical solution to Europe's need for cheap, homegrown energy that also delivers climate change mitigation benefits, its deployment faces socio-ecological risks and negative land use impacts.

In order to address the issue of climate change and enhance the European Union's (EU) energy independence, there must be a rapid acceleration of the deployment of renewable energy sources, particularly wind and solar power, while also reducing energy consumption. The 'REPowerEU' plan put forth by the Commission in 2022, which led to the revision of the EU Renewable Energy Directive (EU RED), comes at an appropriate time and offers a promising course forward, particularly the increase in the renewable energy target for 2030 to 42.5% and the designation of "Renewables Acceleration Areas".

This legislation will also significantly influence the energy policies of the EU's neighboring countries through the Energy Community Treaty and the transposition of the amended EU RED into the national legislation of the Contracting Parties in the coming years.

Identifying "**Renewables Acceleration Areas**" (as Member States are required to do by the new EU RED) which have a special designation that accelerates the deployment of wind and solar by establishing stricter deadlines for project approvals, should be carried out based on careful consideration of important environmental and social criteria and dependable spatial planning.

There are several key socio-ecological challenges that Europe faces in meeting its 2030 renewable energy targets. These challenges include:

1. **Land use and biodiversity impacts:** Scaling up renewable energy production may require significant land use changes, such as building large solar arrays or wind farms. This can potentially impact critical biodiversity, natural habitats, and agricultural lands. A recent study by The Nature Conservancy suggests that meeting the EU's renewable energy targets set for 2030 would lead to significant land impacts if development patterns focus solely on maximizing development potential. Solar development could potentially impact approximately 1,400 km2 of natural and agricultural lands while wind development could impact roughly 23,000-43,000 km2. The top 5 GHG emitting countries would experience more than half of this land loss (Kiesecker et al. In prep). However, the same assessment suggests that low-conflict converted landcover types have the potential to generate 5.5 million GWh of solar and 2.7 million GWh for wind across Europe – which equals roughly 7-28 times total solar renewable targets and 3 times total wind energy targets. To achieve this potential, careful planning and site selection must be employed to minimize the impact on sensitive areas and to ensure proper environmental assessments are conducted.

2. **Social acceptance and local engagement:** Social acceptance and local engagement are crucial for the successful implementation of renewable energy projects. Opposition from local communities due to concerns related to environmental impacts, aesthetics, noise, or changes in local landscapes can delay or hinder the development of renewable energy projects.
3. **Social and environmental justice:** The deployment of renewable energy infrastructure can have social and environmental justice implications, including those concerning land rights, access to energy, and the distribution of benefits. It is important to ensure that renewable energy projects are developed in a way that respects the rights and needs of local communities, including vulnerable and marginalized populations. This will involve engaging in meaningful public consultation and participation with local stakeholders during impact assessment efforts, and ensuring fair and equitable benefit-sharing mechanisms are in place.
4. **Regulatory and policy framework:** Regulatory and policy frameworks play a critical role in facilitating or hindering the deployment of renewable energy. Uncertain or inconsistent policies, complex permitting processes, and administrative barriers such as insufficient capacity to process permitting requests can create uncertainties for investors and developers, impacting the pace and scale of renewable energy deployment.

In summary, meeting Europe's 2030 renewable energy targets and having increased renewable energy visions as part of countries' National Energy and Climate Plans will require careful planning, stakeholder engagement, sustainable practices, good knowledge of biodiversity hotspots, and robust policies to address potential environmental challenges. A holistic approach that considers the interplay between renewable energy production, environmental conservation, social justice, and sustainability can help mitigate these challenges and pave the way for more rapid and sustainable deployment of wind and solar. Governments, policymakers, industry stakeholders, and local communities need to work together to identify and implement solutions that foster the transition to a low-carbon, renewable energy future while protecting the environment and ensuring social inclusiveness.

Additionally, continued research, innovation, and technological advancements will also assist in overcoming these challenges and achieving higher renewable energy targets for European countries by 2030. Collaboration among countries, knowledge sharing, and international cooperation will also play a vital role in addressing these challenges on a regional and global scale. In short, a multifaceted approach is needed to tackle the environmental challenges associated with meeting Europe's 2030 renewable energy targets. With proper planning, coordination, and implementation of sustainable practices, Europe can make significant progress toward a more sustainable energy future centered around renewable energy.

1.1 Target Audience and Purpose for the Handbook for Practitioners

Welcome to the **"Mapping a Sustainable Renewable Energy Transition" Handbook for Practitioners** for planning renewable energy deployment. Given the twin crises of climate change and energy shortages, the need for sustainable and renewable energy sources has become increasingly critical. As we face the challenges, the deployment of renewable energy has emerged as a key solution to reducing greenhouse gas emissions, mitigating environmental impacts, and fostering energy independence. This guide is designed to provide practical guidance and insights for practitioners involved in planning for renewable energy deployment.

We acknowledge that there will be interest in the guidance from policymakers, financiers of renewable energy, project developers, and community leaders; however, our primary audience is practitioners directly involved in planning for renewable energy deployment. This includes energy and spatial modelers, GIS specialists, and experts on environmental and social impacts from energy development.

This guide is meant to equip practitioners with the knowledge and tools needed to effectively navigate the complex landscape of low-conflict renewable energy planning. From understanding the fundamentals of renewable energy technologies to analyzing site-specific considerations, mapping potential environmental, biodiversity, and social/cultural land use conflicts, and elucidating how different energy development patterns overlap those conflicts, this guide covers the key aspects of identifying areas that are suitable for energy development while lowering avoidable conflicts with important environmental and social values. Through case studies, best practices, and actionable recommendations, we aim to empower practitioners to make informed decisions, optimize outcomes, and contribute to the global transition towards a more sustainable energy future. Join us on this exciting journey to unlock the full potential of renewable energy and make a positive impact on our planet and communities.

1.2 The Critical Steps

Experience has shown that poorly sited solar and wind projects can have significant impacts on wildlife and habitats, as well as severely affect rural communities that are highly dependent on lands for livelihoods (Beck and Nesmith 2001, Santangeli et al. 2016, Kiesecker and Naugle 2017, Lakhanpal and Chhatre 2018, Rehbein et al. 2020) These socio-ecological impacts can lead to conflicts which delay and increase project costs, thereby slowing Europe's transition to a low-carbon energy future (Worsdell and Sambhav 2020). To minimize delays and costs, siting considerations must be evaluated early in the project development process and with consideration of existing development planning efforts (e.g., national strategic plans, action plans, territorial just transition plans or national energy and climate plans) to guide development to areas of lower impacts for people and nature.

Many sources of information already exist to support planning for lower impact solar and wind development. These include national wildlife and natural resource agencies, energy departments, science-based civil society organizations, and academic institutions. The challenge is to harness this wealth of data and information to help identify areas characterized by high development potential and low conflict for ecological and social/cultural values.

The primary goal of this practitioners' handbook is to help facilitate the transition to renewable energy by supporting the building of onshore wind and solar through the identification of renewable energy acceleration areas. These areas are defined as being particularly suitable for the development of renewable energy projects and where deployment is not expected to have significant environmental or social impacts.

The following are the critical steps to mapping and identifying potential low-conflict areas for siting renewable energy (RE) projects (see also, Figure 1):

1. **RE suitability and priority mapping:** Anticipating where future renewable development may occur first requires identifying those lands suitable for wind or solar development. Often labeled as **constraint mapping**, lands are excluded from development based on **economic** (e.g., low winds, limited sunshine, large distances from transmission or distribution network), **administrative** (e.g., zoning restrictions, protected area regulations), and/or **biophysical factors** (e.g., steep slopes, rocky ground). Once unsuitable lands are excluded, the next step is to examine how the different criteria influence RE development and use these to rank the remaining suitable lands. As a general rule for site selection, areas with lower impacts on biodiversity should be considered first, namely degraded habitats, parking lots, industrial areas, etc;
2. **Identify and map environmental or biological conservation values in the region:** We identify and map ecological or cultural/social values (in step 3) as part of creating a **conflicts map**. Understanding what and where critical ecological values are in a region is vital to proactively consider additional landscape conflicts, clarify tradeoffs, and strategize how to guide emerging energy development towards a more low-impact future. This requires identifying and synthesizing those critical values in a spatially explicit manner. As a first step, we consider sensitivity of existing land use and land cover classes to development and include additional critical environmental and biological values (e.g., habitats) as necessary;
3. **Identify and map cultural/social values in the region:** Given a wide range of cultural and geographical diversity, the types of social dimensions to prioritize can vary by region due to social conditions at a local and/or national level (e.g., political, economic, demographic, cultural). In this section, we present some broad thematic categories, which can aid in identifying preferential areas that meet the criteria of lower social impact risks and suggest corresponding data types to consider for renewable energy siting. This step requires engagement with local stakeholders to understand what cultural/social values are important and identifying how these values can be

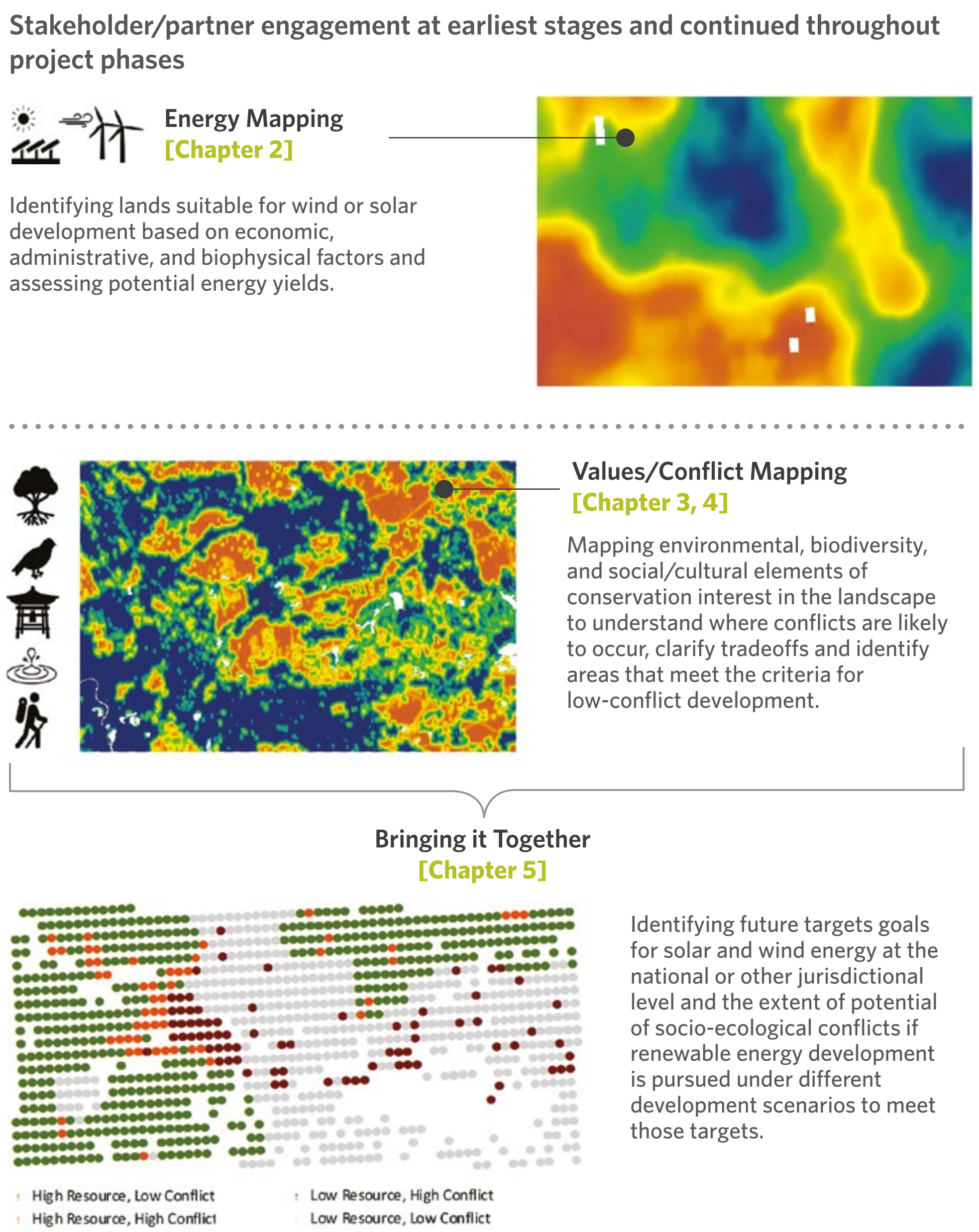
used to provide informative data to avoid RE siting conflicts; and

4. **Bring it together: Understanding pathways to meet future energy goals and finding low-conflict lands with high development potential:** In the final step, future energy goals, possible development scenarios, and estimated land requirements are identified. This is vital to establish whether development targets can be met on low-conflict areas and where they cannot, to understand the scale and tradeoffs in potential impacts to important environmental and social/cultural values represented by different development scenarios.

The order in which these first three steps (i.e., Steps 1, 2, and 3) are tackled is likely to be heavily context-dependent, and the list above is not meant to imply a prescriptive sequence. In actual practice, these components are often conducted on parallel tracks or as an iterative process as insights on additional constraints and conflicts or new data surfaces.

There are important decisions to be made too about whether to incorporate different data inputs as constraints or conflicts. We treat **constraints** here primarily within the energy modeling as areas to be excluded due to administrative and biophysical factors or local policies and regulations on environmental and social assets. **Conflicts** are those values that are not rigidly restricted, yet nonetheless represent important ecological or social/cultural functions or assets in a region. Conflicts can help identify and rank suitable sites from low to high potential risk of conflict. In cases where mapped values are considered irreplaceably important, they can be incorporated into the constraints layer (i.e., excluded from the energy modeling) or considered separately in an **avoid** or **'no-go'** class where development should be avoided.

Figure 1. Assessment components



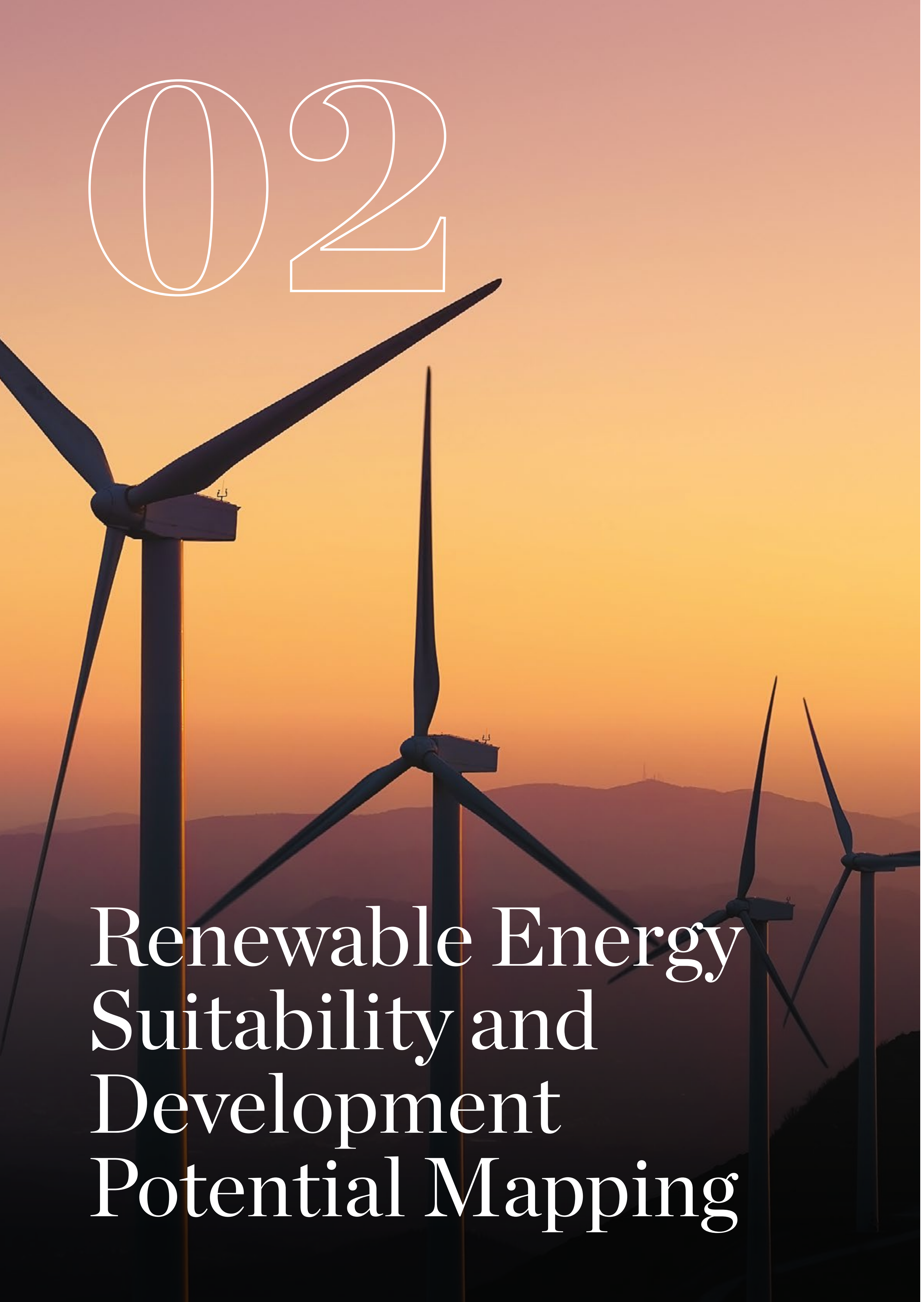
Although this is not a focus of this technical guide, we consider **stakeholder and partner engagement and collaboration** as a fundamental feature that is woven into each step of the assessment. Stakeholders and partners can contribute valuable data, insights, capacities and other resources at every step in the assessment and likely vary with each step. Early engagement with stakeholders allows for opportunities to co-create assessments that reflect partner priorities and consider partner planning needs. Consequently, this delivers products that better support existing policies or decision-making processes and reduces the likelihood of project delays or cost overruns. Engagement, directly or through a variety of forums (e.g., focus groups, surveys) with a broad suite of stakeholders is also critical to define and identify values that need to be spatially represented (Reed 2008, Sochi et al. 2021). Such engagement and collaboration takes time to build (Reed 2008), but is vital to ensure a common understanding and, ultimately, buy-in for the data inputs, analyses, outputs and recommendations.

Another fundamental element of an analysis for low-conflict renewable energy siting that we do not include in the handbook is a **policy gap assessment**. Such assessments serve several important purposes. They can clarify and set the analysis within the relevant policy context, align it with current strategic planning efforts, identify opportunities and constraints arising from those policies and plans, document strategies to implement a low-conflict development vision, and ultimately, identify legislative, regulatory, and funding gaps that require attention.

1.3 Navigating the Handbook Sections

Within this practitioners' guide, there is a unit for each recommended step that includes the following sections where appropriate and links to additional resources:

- **Rationale:** understanding why we undertake this step;
- **Recommended products:** products generated by this step to be used in the final analysis;
- **Guidance:** provides additional background on conceptual issues that often arise, suggested methods, and best practices;
- **Examples:** there are often many ways of arriving at the same analysis product, and here we consider examples of how other projects have approached the chapter-specific analysis;
- **Tools and Resources:** selection of useful analytical tools, data, and applications.



2. Renewable Energy Suitability and Development Potential Mapping

2.1 Rationale

Anticipating where future renewable development may occur first requires identifying those lands suitable for wind or solar development. Often labeled as constraint mapping, lands are excluded from development based of economic thresholds (e.g., low winds, limited sunshine, high development costs), administrative/legally designated lands with development restrictions (e.g., zoning restrictions, protected area regulations), and/or biophysical factors (e.g., steep slopes, rocky ground, sandy soils). Additionally, other environmental and social constraints may reduce the available land but require stakeholder “buy-in” to identify such constraints (see Sections 3 -5). After producing a suitability map, the next step is to identify, create and combine different criteria (e.g., proximity to transmission and distribution lines and substations) which may influence RE development to rank the development potential of suitable lands.

2.2 Recommended products

- Maps identifying land suitability for wind and solar farm siting based on economic, administrative land use classes with restrictions, and biophysical factors.
- Maps which take the land suitability maps filtered through a set of criteria (e.g., proximity to transmission systems) to identify areas likely to be developed or future wind and solar development.

2.3 Guidance

Creating a suitability (or, constraint) map: As an important step in creating a final potential energy development map (Appendix 3), we limit the analysis to areas suitable for future PV solar and wind development (Oakleaf et al. 2019). To do so, we restrict the analysis by considering important resource thresholds (e.g., solar irradiance, wind speeds), land use characteristics (e.g., urban areas for wind, areas with already operating plants), and biophysical parameters (e.g., slope, elevation). See Table 5 (in Appendix 1) for a list of typical constraints and recommendations on how they are spatially represented.

Once all selected constraints are created and mapped, these are combined to produce a binary dataset identifying RE suitability (i.e., 0-unsuitable and 1-suitable) for each resource being modelled (e.g., wind, photovoltaic solar). To do so, any pixel within the study area that overlaps with any of the selected constraints is given a value of 0 (unsuitable) while any pixel not overlapping a constraint is assigned a 1 (suitable). This suitability layer serves as a mask used to restrict the development potential map to areas that meet resource and biophysical thresholds for development.

Model integration – ranking development potential: To produce a final ranking of RE development potential across the study area (e.g., Figure 3, Figure 4), criteria data need to be created. Criteria data rank (e.g, 0-1) pixels by the relative suitability for development per each criteria (e.g., distance from transmission lines, see Table 5 in Appendix 1 for a list of common criteria used in RE sitting). Often these criteria directly relate to the costs of building a site or costs of transporting the power produced from the site to users.

Once a spatial database of important criteria is created, there are often two methods applied to rank overall land suitability for wind and solar development. The first uses a **spatial multi-criteria decision analysis** (GIS-MCDA) and the second involves using locations of current wind and solar facilities to develop **predictive models.** If current locational data for either wind turbines and/or solar farms are available across the landscape being modelled, we recommend using the latter approach. Sometimes, however, these data are lacking, or little to no development, has occurred within the study area which then dictates a GIS-MCDA approach be applied. Below we discuss each of these approaches.

2.3.1 Estimating Energy Futures with spatial multi-criteria decision analysis

Spatial multi-criteria decision analysis (MCDA) used in RE sitting follows four general steps: constraint mapping, criteria mapping and scaling, criteria weighting, and finally the combination of weighted criteria (Malczewski and Rinner 2015, Oakleaf et al. 2019).

First, sector-specific land constraints expected to restrict development are mapped (see previous discussion and Table 5). Second, spatially explicit, independent criteria that enhance the suitability of RE development are mapped. These criteria often include measures of potential (wind speed, Global Horizontal Irradiance (GHI), and/or spatially explicit capacity factors) and development feasibility (e.g., transmission lines, substations, power plants, demand centers, major roads, and/or railroads)(see Table 5). These criteria are then limited to suitable development areas identified in the constraint mapping and scaled to comparable units (e.g., 0–1, 0-100).

Depending on the data distribution and/or skewness of these criteria values, continuous data are often compressed to limit influences of outliers and/or transformed prior to scaling. For example, Oakleaf et al. (2019) approximated normally distributed values ranging from 0–1 by : (1) reassigning values of cells that were within the top one percentile outliers to the 99th percentile value of the distribution, (2) applied transformation based on the skewness (s) of the yield value distribution as follows: no transformation if $s < 0.5$, square-root transformation for $0.5 \leq s \leq 1.0$, and log-transformation if $s >> 1.0$, and (3) scaled data into a 0–1 range using min-max normalization. For categorical data, classes can be assigned values ranging from the scale applied.

Once criteria have been selected and scaled, each are assigned a weight based on the sitting importance of that criteria. Most weights are created by applying one of three methods: ranking, rating, or pairwise comparisons. All weights are typically between 0 to 1 and sum to 1. These weights are often determined through expert input and/or through a literature review.

The final step in the spatial MCDA is to combine the criteria and their assigned weights to produce a ranking of suitability. Most often the weighted linear combination (WLC) technique is applied which is a simple additive method. Important within this method is that all criteria need to be independent of each other to avoid redundancy. To examine redundancy, a Spearman Rank correlation can be applied to all scaled criteria. If any two criteria have correlations greater than 0.6 then it is likely best to stick with the highest weighted criteria between the two. Other combination techniques are available to mitigate correlation of variables without having to limit criteria but can be more complex and difficult to use.

Figure 2. Development Potential from Oakleaf et al. 2019; dark orange identifies highest rated areas for photovoltaic (PV).

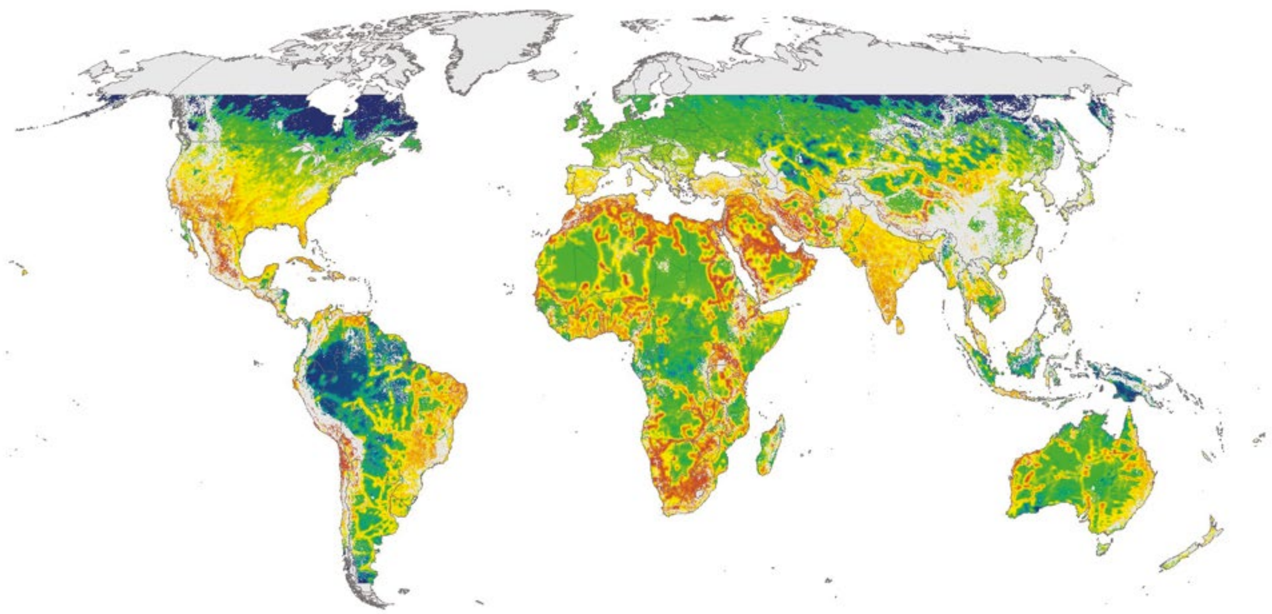
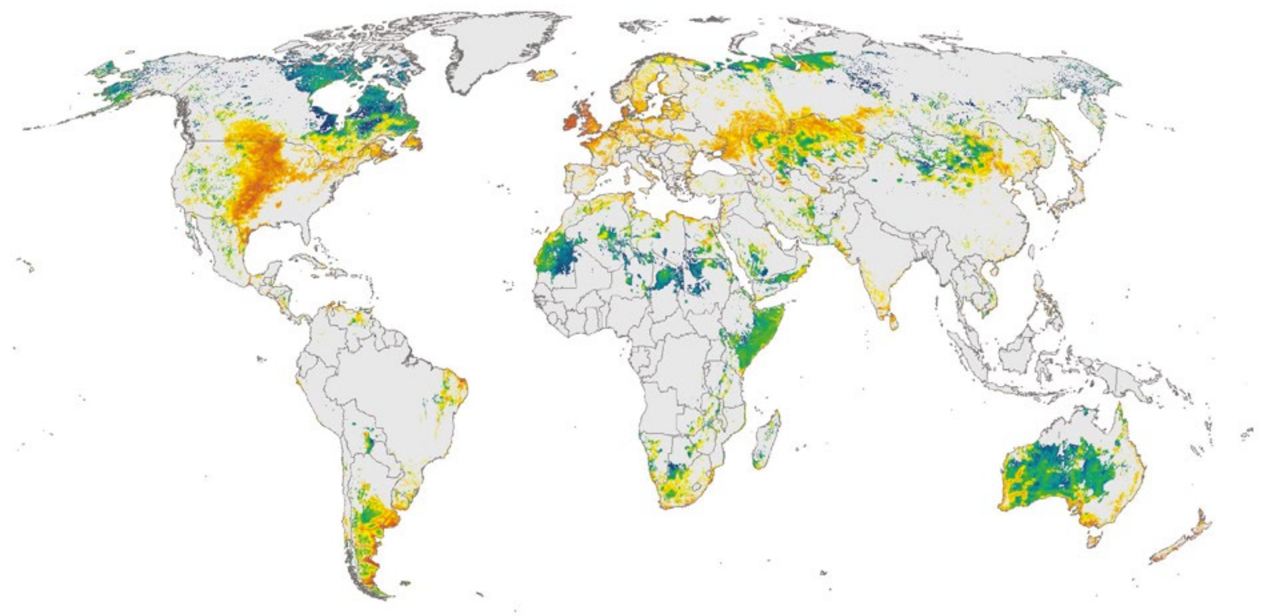


Figure 3. Global Wind Development Potential from Oakleaf et al. 2019; dark orange identifies the highest rated areas for wind development.



2.3.2 Estimating Energy Futures with Statistically Derived Predictive Models

Probabilistic classification models of wind and solar development potential can also be created to facilitate landscape-scale analysis. Based on current patterns of development these analyses can be used to inform planners and decision-makers about where wind and solar development is anticipated.

Probabilistic classification models require spatial locations of current wind turbines and solar arrays, and often use a series of topographic, infrastructure and geophysical predictor variables to generate a spatially explicit prediction map. These data inputs can mimic those criteria used in an MCDA. More recently with the advancement of machine learning and artificial intelligence, nonparametric classification algorithms such as Random Forest are becoming ideal for modelling these complex, non-linear relationships between predictors. Developed to address statistical issues related to over-fit and parameter sensitivity in Classification and Regression Trees (CART) models, Random Forest is a reliable and proven predictive model often used to produce continuous measure of the probability of future resource development based on a suite of categorical or continuous predictor variables (Copeland et al. 2009, Evans and Kiesecker 2014, Vorkapić et al. 2021).

Prior to running a model like Random Forest, several steps are necessary. First, the presence data (i.e., wind turbine or solar farm locations) must be assessed to ensure there are enough locations to not only inform the model but also test the model. Commonly 10% of the known locations are randomly selected and removed from the existing development data to allow for model validation. Next, a set of randomly generated null observations (i.e., locations without development) needs to be produced. A more informed way to generate these null observations can be applied by producing an isotropic kernel density map from the actual locations and then applying this map as a weighting mechanism when producing the random sample (Evans and Kiesecker 2014).

Next, similar to the criteria mapping with MCDA, model parameters (i.e., covariates) are created. Before deriving these data, the original mapped features (e.g., transmission lines, roads) are assessed for consistency and completeness across the landscape being modelled. These features are then, if necessary, transformed using spatial analysis tools into usable model parameters (e.g., proximity to roads, rail, and transmission lines). All parameters are initially used during model runs but are often limited to key parameters via model selection methods. Once completed, the final predictive model provides a probable measure 0 (extremely unlikely) – 1 (extremely likely) for all pixels across landscape based on the functional relationships of all selected parameters with regards to past development.

Since building predictive models are dependent on having up to date and reliable data on current wind and solar installations which can be a challenge in many countries, The Nature Conservancy in a partnership with Microsoft and Planet developed Global Renewables Watch (GReW). The goal of this effort is to map and measure all solar and wind installations on Earth using artificial intelligence (AI): https://www.globalrenewableswatch.org/. Data from this tool will be publicly available in mid 2023 and can be used as an input for the modelling work described here (for additional details see: Ortiz et al. 2022).

2.4 Examples

- Copeland, H. E., K. E. Doherty, D. E. Naugle, A. Pocewicz, and J. M. Kiesecker. 2009. Mapping oil and gas development potential in the US Intermountain West and estimating impacts to species. PloS one 4:e7400.
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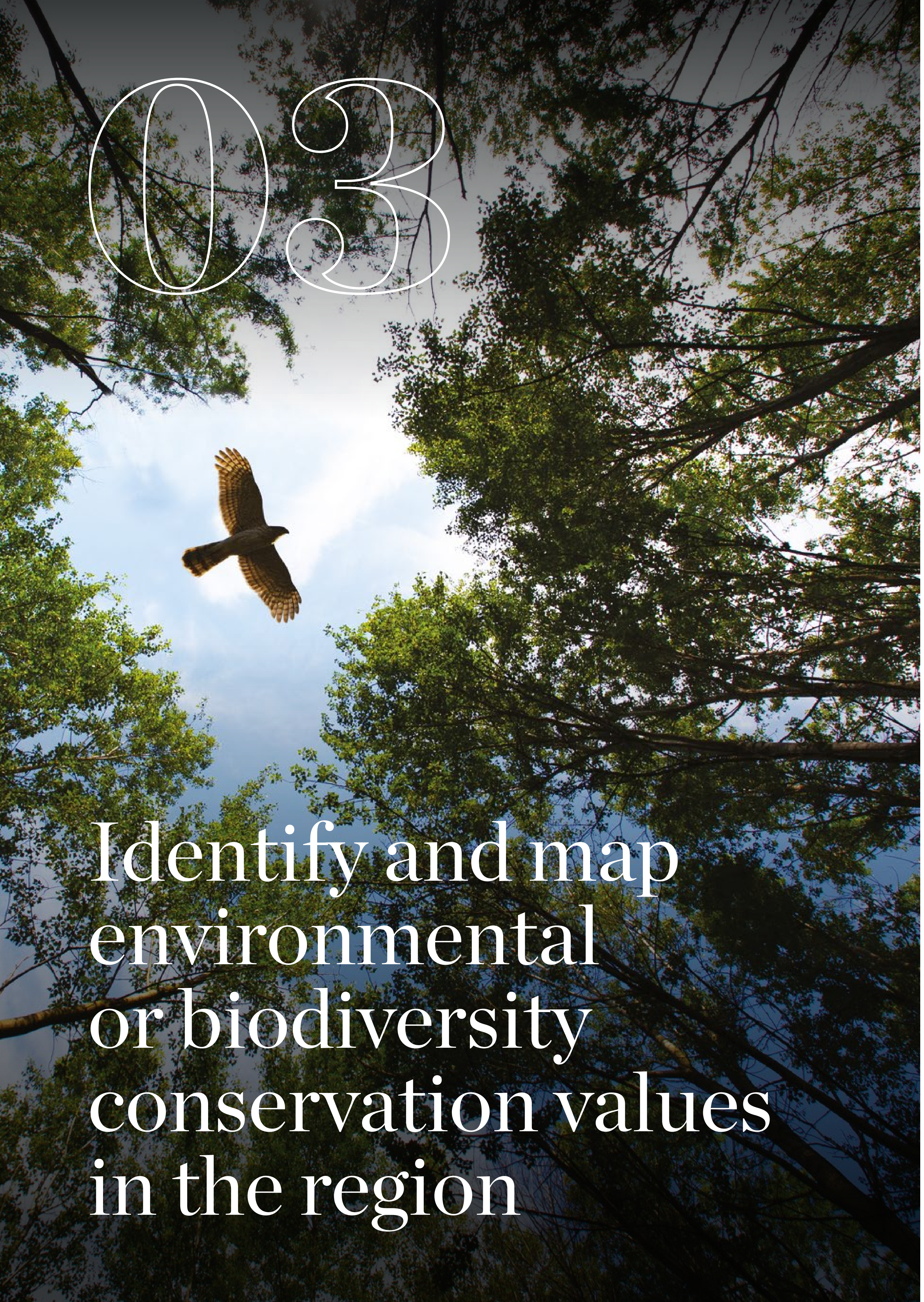
- Von Krauland, A.-K., F.-H. Permien, P. Enevoldsen, and M. Z. Jacobson. 2021. Onshore wind energy atlas for the United States accounting for land use restrictions and wind speed thresholds. Smart Energy 3:100046.
- Oakleaf, J. R., C. M. Kennedy, S. Baruch-Mordo, J. S. Gerber, P. C. West, J. A. Johnson, and J. Kiesecker. 2019. Mapping global development potential for renewable energy, fossil fuels, mining and agriculture sectors. Scientific Data 6:1–17.
- Ryberg, D. S., M. Robinius, and D. Stolten. 2018. Evaluating Land Eligibility Constraints of Renewable Energy Sources in Europe. Energies 11:1246.
- Ryberg, D. S., Z. Tulemat, D. Stolten, and M. Robinius. 2020. Uniformly constrained land eligibility for onshore European wind power. Renewable Energy 146:921–931.
- Vorkapić, V., Ž. Fištrek, A. Kojaković, and S. Knežević. 2021. Integrated Renewable Energy Planning in Southeast Europe Pilot Project: Integrated Wind and Solar Planning in Zatar County. Page 62. Energy Institute Hrvoje Požar, Zagreb, Croatia.

2.5 Tools and Resources

Table 1. Open Source data used in RE assessments with potential application for country/state-level use.

Source	Potential RE siting data	Data Resolution
Global Wind Atlas	Wind speeds (various hub heights) and wind capacity factors (IEC class I, II, & III)	250 m
Global Solar Atlas	Global Horizonal Irradiance (GHI) and PV capacity factors	250 m (GHI & DNI) 1 km (PV cf)
Global Renewables Watch	Solar arrays and wind turbine locations (available 2023)	na
Dunnett et al. 2020	Harmonised global datasets of wind and solar farm locations and power	na
Kruitwagen et al 2021	A global inventory of photovoltaic solar energy generating units	na
Global human settlements	Built-up and settlements	30 m (built up) 1 km (settlements)
OpenStreetMap	Roads, railway, transmission/power lines, substations, power plants, airports, industrial and mining areas,	na
ESA CCI land cover	Forest, wetlands, permanent water bodies, cropland, snow/ice, built-up	300 m
Global Land cover	Forest, wetlands, permanent water bodies, cropland, snow/ice, built-up	100 m
ESA WorldCover 2020	Forest, wetlands, permanent water bodies, cropland, snow/ice, built-up	10 m
Suttle Radar Topography Mission (STRM)	Elevation, slope, aspect	30 m
World Database of Protected Areas	Protected areas	na



3. Identify and map environmental or biodiversity conservation values in the region

3.1 Rationale

Identifying and mapping important landscape values are critical first steps to understanding and addressing the tradeoffs of future energy development (Kiesecker et al. 2010, Heiner et al. 2019). Understanding what those critical values are and where they reside is vital to guide emerging energy development towards a more low-impact future. In this section, we consider environmental and biodiversity values of conservation interest in a region and how they might be represented spatially. In the next section we focus on social and cultural values, and in section 5, we suggest ways to summarize these values in a way that would facilitate understanding the potential conflicts and risks associated with different energy development patterns.

3.2 Recommended products

- List and attributes of key environmental and biodiversity elements.
- Spatially explicit mapping of environmental and biodiversity elements that can be used as inputs into a conflicts layer – these can include land cover maps, ecological integrity maps, species distribution maps, area of habitat maps, and corridor or migratory path/flights.
- Post hoc evaluation of overlap between suitable lands identified and select environmental or biodiversity values, including visualizations of co-occurrence (e.g., proportion of co-occurrence with "high" biodiversity values, relative frequency graphs).

*Post hoc evaluations can serve as a subsequent analysis to suitability mapping, which has already accounted for "**constraints**" (i.e., lands are necessarily excluded due to economic, administrative, biophysical factors, or local policies on environmental or social restrictions). After the required RE suitability and priority mapping have already restricted for "constraints", select social values that are "**conflicts**" (yet not restricted) can be used to further inform the planning. In this case, while the suitability and priority mapping can first identify suitable sites, "**conflicts**" may help further identify and rank or categorize suitable sites from low to high potential risk.*

3.3 Guidance

Environmental and biodiversity targets are the species, communities, and ecological systems that we focus our assessments on in order to capture the broad range of biodiversity of conservation interest or importance in a study area. Targets are a subset of the full range of biodiversity of a place (i.e., a region, country), since it would be costly and time-consuming to assess each environmental or biodiversity value individually regardless of the level of information and data. A manageable list of targets can be arrived at through a screening process that is informed by stakeholder and expert inputs, the regulatory context and further refined by other tools, such as Leopold matrices that consider vulnerability to potential impacts (Josimović et al. 2014).

A "Coarse-filter/fine-filter" approach: We commonly use a coarse-filter/ fine-filter approach to identify environmental and biodiversity targets and thus map potential conflicts with renewable energy development (Groves 2003, Groves and Game 2015). **Coarse-filter** targets are often represented as ecosystems or land cover classes as opposed to species. As coarse filter targets, ecosystems can often be mapped with available and public spatial data. This alone helps to fill a potentially significant information and knowledge gap. Moreover, a coarse-filter approach captures the broad-level environmental processes that are needed to maintain populations of important species over the long-term and thus serves as a good proxy to represent those specific biodiversity elements in a study area. This is necessary since our knowledge regarding species occurrence, range or habitat needs will always be incomplete. This approach also has practical advantages of making use of more commonly available data to represent the full range of representative biodiversity with a practical number of targets.

Coarse-filter elements: Coarse filter elements can often be derived or adapted from already available land use-landcover maps. Where land cover maps are not readily available, coarse-filter units have been defined using environmental information, such as elevation, geology, and landforms (e.g., see Ecological Land Units). However, the growing use of remote sensing imagery and tools has made land cover maps more likely to be available, current, and accessible in most regions.

Practitioners can refine how they incorporate these land cover maps by considering characteristics of different ecosystem classes, such as intactness, connectedness, irreplaceability or condition (Grill et al. 2019, Grantham et al. 2020, Brennan et al. 2022, Noon et al. 2022). Teams may also wish to pay special attention to classes that are rare, irrecoverable, or of outsized importance given the landscape context. For example, riparian or wetlands areas may be of critical focus in arid regions or intact grasslands or forests in regions where they have experienced high degrees of conversion or loss.

Fine-filter elements: There are several criteria that can be used to select fine-filter targets for special attention. These include:

- **Imperiled species:** For example, species meeting IUCN RedList criteria for Critically Endangered (CR), Endangered (EN), or Vulnerable (VU) designations (IUCN Species Survival Commission 2001) or other regional designation (e.g., the EU Birds and Habitats Directives and the Bern Convention);
- **Species of special concern:** species not considered Critically Endangered, Endangered, or Vulnerable according to IUCN RedList criteria may warrant consideration based on additional criteria, such as
  - ***Declining species*** that are exhibiting significant, long-term or localized declines in habitat and/or population numbers and are facing continued high levels of threats;
  - ***Endemic species*** that are restricted to specific places and therefore may be more vulnerable to disturbances than species more broadly distributed;
  - ***Disjunct species*** that have populations that are geographically isolated from its primary range;
  - ***Wide-ranging species*** that typically depend on large areas but may not be well-captured by coarse-filter targets because they tend to range across multiple coarse-filter types. For example, teams may want to especially consider important corridor or migratory path and fly-ways (e.g., BirdLife International fly-ways), and important habitat areas for large mammals (e.g., bears, wolves, lynx); and
  - ***Species aggregation areas*** such as migratory stopover sites that contain significant numbers of migratory individuals of any species.

Fine-filter elements can be spatially represented as points, lines, or polygons and thus map occurrences, movement data, or ranges. These in turn can be refined into area of habitat or species distribution maps.

Summarizing important environmental or biodiversity elements: The challenge, of course, is to summarize or represent these environmental or biodiversity elements in a way that make them easy to incorporate into decision-making or to facilitate an understanding of the trade-off decisions in a particular place. It is easy to imagine for a moment a simple landscape of 3 predominant landcover types hosting a dozen species of concern of which a mere 2-3 are highly mobile and have critical seasonal or large habitat needs. How can we represent these handful of ecological values together and/or separately in a way that facilitates decision-making? The complexity around how we characterize the values in even the seemingly most straightforward of landscapes can quickly grow.

We consider some ways in **Appendix 2** to approach this complexity in depicting environmental or biodiversity elements in ways that are simple to increasingly complex. In all cases, decisions are best made through discussion and consultation with technical experts and stakeholders and the rationale behind decisions should be documented. See Appendix 2 for a more in-depth guide to combining values into a single index or categorical classes as these same issues arise for social and cultural values.

In practice, it is likely that options we consider in Appendix 2, to create an index (continuous or categorical) or to deploy conflicts individually, are used together. For example, there may be a subset of elements that are considered separately as individual layers (e.g., as in an 'avoid' layer) while the remaining are combined in an index to highlight areas of overlapping values. Alternatively, teams may choose to focus on an index option with potential conflicts with individual values on the side – to enable decision-makers to consider places according to the richness of elements alongside the specific contribution or concern (e.g., vulnerability, rarity, irreplaceability) of any one of these elements.

3.4 Examples

- Hise, C., Obermeyer, B., Ahlering, M., Wilkinson, J. and Fargione, J., 2022. Site wind right: Identifying low-impact wind development areas in the Central United States. Land, 11(4), p.462.
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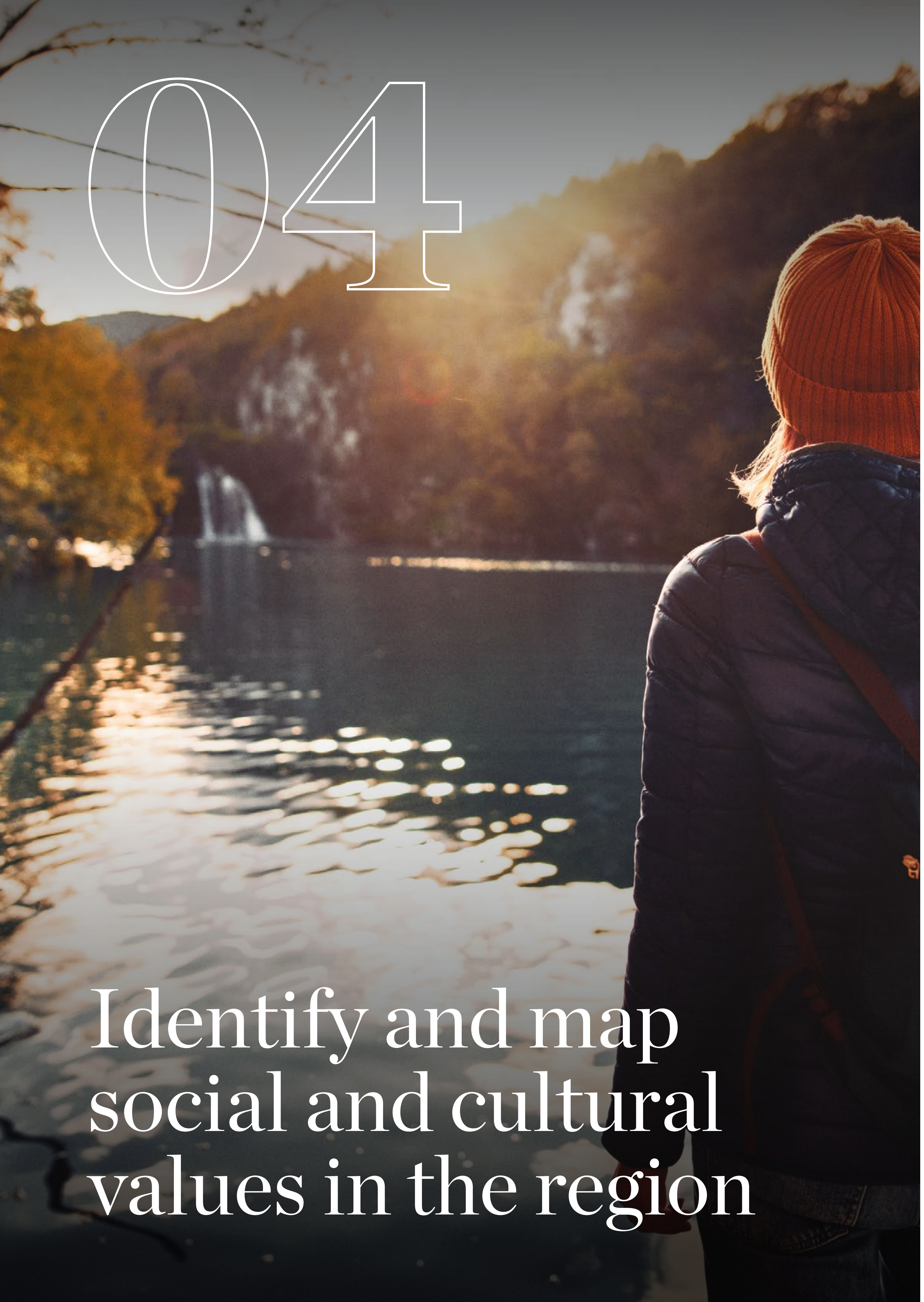
- Wu, G.C., Jones, R.A., Leslie, E., Williams, J.H., Pascale, A., Brand, E., Parker, S.S., Cohen, B.S., Fargione, J.E., Souder, J. and Batres, M., 2023. Minimizing habitat conflicts in meeting net-zero energy targets in the western United States. Proceedings of the National Academy of Sciences, 120(4), p.e2204098120. (See also link: https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/).

3.5 Tools and Resources

Table 2. Common publicly available data for ecological values (regional or global) where relevant local data are unavailable.

Descriptions	Source
Corine Land Cover	https://land.copernicus.eu/pan-european/corine-land-cover
IUCN RedList Species ranges	https://www.iucnredlist.org/resources/spatial-data-download
Natura 2000 species lists and network data	https://ec.europa.eu/environment/nature/natura2000/index_en.htm
Global Hydrology Network	https://globalhydrology.nl/
World Database on Protected Areas	https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
Key Biodiversity Areas (KBA)	https://www.keybiodiversityareas.org/
Important Bird Areas (IBA) and other important bird ranges, flyways	http://datazone.birdlife.org/site/ibacriteria



4. Identify and map social and cultural values in the region

4.1 Rationale

Installations of solar and wind infrastructure often require large expanses of land, which can lead to conflict over change in land-use and access to resources. Traditionally, local communities may hold relationships with land due to the **social values or nature's contributions to people** (NCPs), including **ecosystem services**, that are attributed to certain areas. Failure to consider these values can result in project delays and increased costs when renewable energy is proposed in areas with a greater risk of negative social impacts.

Challenges might include delays in licensing by national, regional, or local authorities or public opposition when selected sites are near features of high ecosystem value to surrounding communities. These values may be characterized by some of the ecosystem service types, including 1) **provisioning** (e.g., freshwater quality and access, agricultural production), 2) **regulating** (e.g., land-use change impacts on ecosystem integrity), or 3) **cultural** (e.g., landscape values associated with aesthetics or recreational benefits) services.

To this end, the use of spatial planning that integrates information on social values will facilitate a successful and informed 'green transition' for greater renewable energy capacity while mitigating potential conflicts. Ensuring a planning process that considers social conditions, including the relationship between landscapes and their inhabitants, can help further foster social acceptance and citizen support (Segreto et al. 2020). Beyond this, proactive assessments of social impacts on areas identified with higher renewable energy potential help inform future development strategies by identifying preferential sites with lower social pressures.

4.2 Recommended products

- List and attributes of the key social and cultural values, including relevant ecosystem services that can serve as indicators.
- Spatially explicit mapping of social and cultural values (see examples in Table 3).
- Post hoc evaluation of overlap (or, conflicts) between suitable lands identified and select social/cultural values, including visualizations of co-occurrence (e.g., proportion of co-occurrence with "high" social values, relative frequency graphs).

*Post hoc evaluations can serve as a subsequent analysis to suitability mapping, which has already accounted for "**constraints**" (i.e., lands are necessarily excluded due to economic, administrative, biophysical factors, or local policies on environmental or social restrictions). After the required RE suitability and priority mapping have already restricted for "**constraints**", select social values that are "**conflicts**" (yet not restricted) can be used to further inform the planning. In this case, while the suitability and priority mapping can first identify suitable sites, "**conflicts**" may help further identify and rank or categorize suitable sites from low to high potential risk.*

4.3 Guidance

Given the wide range of cultural and geographical diversity in Europe, the types of social dimensions to prioritize can vary by region due to social conditions at a local and national level (e.g., political, economic, demographic, cultural). Still, a regional framework for selecting suitable renewable energy sites - one which accommodates potential social pressures - can consider a fundamental set of relevant factors. We present some broad thematic areas, which can aid in identifying preferential areas that meet the criteria of lower social impact risks.

1. Cultural

Communities and individuals often ascribe value to their surroundings and certain landscapes based on personal connections to a place and its contributions. These values (i.e., landscape values) may play an important role in shaping individual identities and perceptions or enhance people's quality of life (e.g., improving mental health and well-being). The importance placed on landscape attributes can depend on recreational benefits and services derived from specific sites, the significance of important historical and cultural locations, locations connected to spiritual or religious beliefs, and visual aesthetics or scenery (e.g., viewsheds and vistas). Consequently, renewable energy development can have a greater social impact when sites are situated in or near places that hold significant cultural value to local communities or larger society. For example, while mountainous areas are often identified as suitable sites given a higher renewable energy potential, certain sites are also highly valued for their recreational benefits, scenic vistas, and supporting biodiversity (Hastik et al. 2015).

2. Economic and demographic

Due to the relatively large land footprint required for renewable energy expansion, common development challenges may involve issues with people's rights and access to land. Economic and demographic factors provide information on the social values associated with given areas (e.g., a particular communities' spiritual or cultural connection to land or place-based values), as well as the relative security of a community's land and resource rights that might indicate greater potential for conflict over development. Examples of data that illustrate the concentration of under-resourced communities and presence of energy demand or accessibility include household income, monthly energy-specific household expenditures, population density, and accessibility measures such as roads and distance to population centers. Additionally, data on tourism attractions or zones, and livestock grazing or hunting areas can highlight areas of greater economic importance to communities. This information can aid development plans by enabling site selection that considers socioeconomic inequalities and energy demands.

In addition, the consideration of economic and demographic attributes can also highlight areas where there is a particular need to ensure societal inclusion via community engagement and participatory planning processes.

Populations of vulnerable, historically marginalized, or under resourced communities can be disproportionately impacted by commodity-driven land pressures. Other demographic data that provides an important indicator of vulnerability includes georeferenced information on Indigenous and community conserved areas (ICCAs), which are lands collectively held, managed, and used by Indigenous Peoples and Local Communities (IPLCs). A recent study determined that nearly a quarter of all Indigenous lands are under high industrial development pressure, with over 22% having current ecological conditions considered highly threatened and 37% as moderately threatened (Kennedy et al. 2022).

Similarly, a technical review on the state of IPLCs lands and territories found that over 25% of IPLC global lands are at risk of high potential development pressure in the future. Moreover, 80% of these overlapping areas retain moderate to good ecological conditions that further highlight their environmental and conservation value (WWF et al. 2021). By proactively identifying areas of greater vulnerability based on economic and demographic factors, appropriate guidelines and steps can be taken to ensure processes such as Free, Prior, and Informed Consent (FPIC), as well as community consultations and consent more broadly.

3. Ecosystem services

The beneficial contributions of nature that people derive from their surrounding landscapes are important to consider when minimizing the social impacts of energy development. Land use change and associated environmental impacts are closely linked to social conflicts, as ecosystem degradation and competition for access to lands can impact the quality and accessibility of natural resources that people rely on. Data on important ecosystem service areas, including distribution of freshwater systems, agricultural land, and protected areas, can identify places where people benefit from access to and maintenance of freshwater, arable land for agricultural production, and land with high ecological integrity that sustain important resources such as wood or sources of food. In addition, where available, spatial data representing ecosystem service indices can be a useful tool to provide insight on multiple benefits at a larger scale (Vysna et al. 2021).

In Table 3, we provide a summary of relevant social values and some corresponding data types to consider for renewable energy siting. We also include examples of available datasets with information on where to access them. Within these broad categories, teams may first consider the local context and priority concerns of community members and other stakeholders to guide their selection of suitable indicators. Additionally, certain indicators (e.g., cultural heritage sites, agricultural or croplands) may be deemed **conflicts** that rise to becoming "**avoid layers**" and are accordingly taken out from consideration, whereas other **conflicts** may be used as "**considerations**" that provide measures of impact or risk to proactively identify low-conflict areas that coincide with already identified suitable lands (see Appendix 1 for further details on common datasets and how they may be classified and used for suitability mapping or subsequent analysis).

Table 3. A summary of three broad social value categories, including types of data to consider and examples of available datasets.

Rationale	Types of data sources	Examples and data availability
THEME: CULTURAL		
People and communities have connections to places and their contributions or meaning. The cultural values associated with certain landscapes can play an important role in shaping their identities, perceptions, and quality of life.	■ Historical/cultural sites ■ Areas connected to spiritual or religious beliefs ■ Visually aesthetic landscapes ■ Recreational areas ■ Tourist zones ■ Nature parks	**World Database of Protected Areas (WDPA)** A global database of protected areas (marine and terrestrial) from UNEP-WCMC, which is updated monthly. The data also includes locations of UNESCO World Heritage sites. The WDPA data can be accessed and downloaded via the Protected Planet website. www.protectedplanet.net **Cultural Gems** An interactive web platform to monitor cultural and creative sites in European cities, produced by the European Commission's Joint Research Center. The dataset compiles community data on locations in Europe that are deemed "cultural and creative spaces" sourced from individuals, universities, public and private organizations, as well as OpenStreetMaps. The data can be downloaded using an application programming interface (API). There is one specific API for map data - general information on locations and designated categories, and another for city data – information on cultural sites/points of interest for each city with details such as location and category. Download information is provided in their Terms and Conditions. https://culturalgems.jrc.ec.europa.eu/terms-conditions#2.%20Cultural%20gems%20is%20open%20data **Social Media Content** Analyzing social media content can provide information on the importance of specific places and landscapes. For example, the concentration of photos at specific locations may be further filtered with keywords to identify places of greater aesthetic or recreational value. These data can be downloaded using the relevant APIs for corresponding social media platforms. The documentation for each API will provide instructions for how to download the desired data and must be modified to meet users requirements. One example includes the publication of a continental-scale dataset for Europe on landscape values, based on the concentration of filtered photos from FlickR, Instagram, or Panoramia for a given time span. The data availability and download information is provided in the manuscript (Van Zanten et al. 2016).

THEME: ECONOMIC and DEMOGRAPHIC		
Demand for large amounts of land for renewable energy expansion can put people's land rights and their access to resources at risk. Economic conditions and demographic distribution provide insight on areas with vulnerable populations and potential risks related to land and resource rights.	■ Employment rates ■ Household income ■ Population density ■ Proximity to population centers ■ Accessibility, roads ■ IPLC lands ■ ICCA lands	**Population Density** Estimated population density (at 5 years intervals between 2000-2020) representing the number of persons per square kilometer. The data can also be transformed to consider population The data is available to download from NASA's Socioeconomic Data and Applications Center website. https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11 The European Commission also makes similar data available through their website on the Global Human Settlement layer. Specifically, this comprises a spatial raster dataset on the distribution of residential populations (number of people/cell). https://ghsl.jrc.ec.europa.eu/ghs_pop2022.php **Roads** Global data set of roads between settlements, with information of road networks from 1980-2010 (varying by country). The data is available to download from NASA's Socioeconomic Data and Applications Center website. https://sedac.ciesin.columbia.edu/data/collection/groads **Probability of Urban Expansion** Forecasted probability of urban expansion by 2030 (Seto et al. 2012), at a resolution of 2.5 arc minutes) at a global scale, representing urban land cover change between 2000 to 2030. The data is available to download from NASA's Socioeconomic Data and Applications Center website. https://sedac.ciesin.columbia.edu/data/set/lulc-global-grid-prob-urban-expansion-2030 **IPLC lands** Data published on the geographical extent of IPLC lands (i.e., IPLC managed and/or controlled) that is aggregated at a global scale, using publicly available resources (Garnett et al. 2018). While the dataset is not openly available to download online, the manuscript states that derived maps are available upon request from the primary author.

THEME: ECOLOGICAL		
People often rely on resources from their surrounding environment, through provisioning (i.e., material benefits extracted) and regulating (i.e., material, and non-material benefits from ecosystem processes) ecosystem services.	■ Forest cover ■ Freshwater systems ■ Agricultural land, cropland, food security ■ Protected areas (i.e., measures of ecological integrity)	**Forest condition** Global data on a continuous 'Forest Integrity Index' that represents forest condition based on observed and inferred human pressures and forest connectivity loss(Grantham et al. 2020). The data is available to download at their website. www.forestlandscapeintegrity.com **Freshwater systems** Published data on the global river network, including the distribution of rivers of varying conditions: free-flowing rivers, good connectivity (contiguous river stretches), and reduced connectivity (impacted rivers) (Grill et al. 2019). The data is published and available to download from an open access repository (link provided in their manuscript). **Food security** Global Food Security-Support Analysis Data (GFSAD30) from a NASA-funded project that is available for 2015 at a 30-meter resolution provides cropland extent, including permanent plantations, lands cultivated and harvested for food, feed, and fiber at least once in a year, and fallows. The data set also includes crop types (8 globally predominant types), irrigated versus rainfed cropland, cropping intensity, and change in cropland between 2000-2025. GFSAD30 is available to download via NASA's Land Processes Distributed Active Archive Center website. https://lpdaac.usgs.gov/news/release-of-gfsad-30-meter-cropland-extent-products/ **Ecosystem Service Indices** Co$tingNature (a collaboration between King's College London, AmbioTEK and UNEP-WCMC) is a web-based tool with several spatial datasets documenting natural capital and ecosystem services. The web-tool also includes an aggregated map of a "relative total realized bundled services index" that is accessible at a regional scale and a 1-km resolution, which considers 16 ecosystem services (e.g., domestic and commercial timber, non-wood forest products, water provisioning, aesthetic quality services, wildlife services and dis-services). The data is not openly available to download for external/offline analysis purpose and currently requires the use of the webtool (https://www.policysupport.org/costingnature). **NATURA 2000 – Site types: SCIs and SACs** Information on protected sites in the European Union designated under the Habitats Directive – Sites of Community Importance (SCIs), and Special Areas of Conservation (SACs). While focused on ecological diversity and conservation, SCI and SAC site types represent areas that hold significance to the maintenance of regional biodiversity. Considering the extent and conservation of these habitats has implications to the benefits people derive from wildlife and ecosystem function. The NATURA 2000 data can be downloaded at the European Environment Agency website. https://www.eea.europa.eu/data-and-maps/data/natura-14

In addition to open-access data sets, social value measures can also be derived from censuses or household surveys that are conducted by administrative institutions (e.g., government ministries/ departments at local, district, and state levels) to monitor and assess social, demographic, and economic trends. In certain instances, such data sources may already be published for a given time range or can be accessed upon request to the relevant institutional bodies. Depending on time constraints and project scope, measures for relevant social values can also be collected through a participatory design process that involves discussions and consultations with the public and stakeholders, and participatory mapping with local communities (Brown and Raymond 2014).

Summarizing multiple indicators: The use of a summary measure that aggregates a set of social value indicators can serve as a broad tool to gauge impact (e.g., conflict risk, vulnerability, land dependence) on potentially suitable lands. Combining pertinent social values for a given area, informed by stakeholder/ expert consultations and context-dependent social concerns, an index or classification system can be computed following an analogous approach used for environmental and biodiversity elements (see Appendix 2). For example, data from each of the three social value categories listed in Table 3 can be merged into a comprehensive measure across categories that encompasses cultural, economic, demographic, and socioecological attributes.

4.4 Examples

- Heiner, M., Hinchley, D., Fitzsimons, J., Weisenberger, F., Bergmann, W., McMahon, T., Milgin, J., Nardea, L., Oakleaf, J., Parriman, D., Poelina, A., Watson, H., Watson, K., and J. Kiesecker. 2019. Moving from reactive to proactive development planning to conserve Indigenous community and biodiversity values. Environmental Impact Assessment Review, 74, 1-13.
- Pocewicz, A. and Nielsen-Pincus, M., 2013. Preferences of Wyoming residents for siting of energy and residential development. Applied Geography, 43, pp.45-55.
- Sochi, K., J. P. Pierre, L. Harveson, P. M. Harveson, D. Ianelli, J. Karges, B. Tarrant, M. Taylor, M. Young, and J. Kiesecker. 2021. Development by Design in West Texas: Mitigating energy sprawl through cooperative landscape planning. Respect Big Bend, Texas: https://bri.sulross.edu/land-stewardship/respect-big-bend/
- Vorkapić, V., Ž. Fištrek, A. Kojaković, and S. Kneževi. 2021. Integrated Renewable Energy Planning in Southeast Europe Pilot Project: Integrated Wind and Solar Planning in Zadar County. Page 62. Energy Institute Hrvoje Požar, Zagreb, Croatia.

4.5 Tools and Resources

- See Table 3 for suggested data sets
- Natural Capital Project (https://naturalcapitalproject.stanford.edu/)
- Critical Natural Assets (https://osf.io/r5xz7/)

5. Bring it together: Identify low-conflict lands with high potential for energy development

5.1 Rationale

The 'green transition' across Europe focuses on advancing and increasing renewable energy targets and helps alleviate societal hardships imposed by the rising costs of fossil fuel-dependent energy. While the expansion of renewable energy systems, such as solar and wind, has the potential to facilitate energy justice (i.e., affordability and accessibility) amidst dynamic sociopolitical and socioeconomic conditions, it is also important that planning and implementation take measures to avoid or minimize latent environmental, social, and cultural conflicts (Paravantis and Kontoulis 2020).

The European Commission's 'REPowerEU' plan and the new EU Renewable Energy Directive are therefore timely and contain useful additions, notably an increase in the 2030 renewable energy target to 42.5% and aiming for 45% (European Commission 2022). Central to 'REPowerEU' and the EU RED are the identification of 'Renewables Acceleration Areas' for renewable energy. However, the new Directive also brings simplifications to the environmental permitting process in Renewables Acceleration Areas, creating a need for a robust and transparent process for designating those zones.

This handbook was created in response to the need for a robust spatial planning process for the identification of these 'acceleration areas' that proactively considers potential conflicts of development pathways with critical environmental and social and cultural values. The focus of this section is on bringing together maps of economically viable wind and solar development with important environmental and social values.

We examine the potential development of wind and solar through scenarios that examine consequences of unplanned development alongside a development pathway that prioritizes low-conflict areas. Comparison of these scenarios can help us understand the costs, consequences and tradeoffs that may exist when development follows one of these trajectories.

Scenario analyses have become a widespread approach in understanding sustainable development options. However, they are used infrequently, at least in any formal way, for assessing environmental impacts. This is surprising because the environmental impact assessment (EIA) process is designed specifically to examine options for less environmentally damaging futures.

Scenario modeling techniques have also been leveraged in land cover change projection studies, but comparable techniques are rarely used to model anticipated energy development and to use those forecasts to proactively quantify environmental impacts (see Evans and Kiesecker 2014, Kiesecker et al. 2020 for exceptions). Scenarios offer tangible, holistic representations of the future and can be instrumental to understanding future system dynamics. It is important to examine a comprehensive build-out scenario for potential impacts associated with both wind and solar as a regular part of renewable energy planning at the country level (Kiesecker and Naugle 2017).

In this section, we bring together maps of renewable energy potential and the suite of environmental and social values taken together in a conflict index to assess through scenarios whether energy targets can be met on low-conflict areas and to visualize the frequency of conflicts and where they occur.

5.2 Recommended products

- Renewable energy development targets (e.g., production goals).

- Creation of scenarios for how RE goals may be met (e.g., a Disturbed Lands or a Business-as-Usual vs Low-Conflict approach).
- Spatially explicit **conflict index** that combines critical environmental and/or social values to identify low-conflict lands.
- Analysis of overlap between lands with high energy development potential with low-conflict lands as identified through a **conflict index** that combines select environmental and social/cultural values, including visualizations of co-occurrence and tradeoffs between different development scenarios (e.g., proportion of co-occurrence with "high" social values, relative frequency graphs).

5.3 Guidance

To understand the extent of potential socio-ecological conflicts from forecasted renewable energy development, we:

1. Identify renewable energy target goals (i.e., production or energy);
2. Develop scenarios for how those targets may be met (here, we focus on a Business-As-Usual (BAU) vs Low-Conflict development scenario. In some assessment, stakeholders may choose to focus on a set of specific low-conflict land cover types, such as former mine sites, as a starting point);
3. Create a map of low-conflict lands building on the environmental and social/cultural values mapped; and
4. Visualize the overlap between lands with high development potential and low-conflict with critical environmental and social/cultural values and summarize tradeoffs associated with scenarios.

Identify renewable energy target goals and articulate development scenarios to meet targets: To develop scenarios, we need to know the renewable energy development goals a region is seeking to meet. These projected growth targets can be gleaned from national plans, policy targets, energy infrastructure plans (such as EU Ten Year Network Development Plans which determine key projects and infrastructure (transmission/distribution) needs in line with EU targets) and market outlooks produced by industry associations, among others.

These goals are a starting point for determining the gap between current production/capacity and future production/capacity needs, where they might be met, and the potential social-environmental conflicts that exist under different development patterns. These targets can be expressed in the form of a range, across different target years and/or across different potential development pathways. For one example of energy targets, see the 2022 Ember report calculating potential growth for Europe's onshore wind fleet and solar plants under three modelled pathways to a clean power system compatible with the Paris Agreement's climate goals (1.5°C)(Rosslowe et al. 2022).

Once energy targets are known, we develop potential scenarios on meeting those targets. We typically consider the following two scenarios:

1. **Business-As-Usual (BAU):** BAU scenarios assume areas of highs development or production potential (areas high in resource yield) are more likely to be developed than areas with low resource yield.
2. **Low-conflict:** In Low-conflict scenarios, we aim to minimize conflicts with potential environmental and social values.

Comparing the results of the BAU and Low-conflict scenarios is a way to understand the viability of a low-conflict development pathway and any trade-offs of impacts to different environmental and social/cultural values. Teams may choose to consider additional development scenarios and compare relative impacts to values across them. For example, teams may consider a more focused assessment prioritizing former mine sites as a first step (see for example, The Nature Conservancy's Mining the Sun Initiative; also Kanevce et al. 2022. Mert 2019) https://www.nature.org/en-us/about-us/where-we-work/united-states/nevada/stories-in-nevada/solar-energy-at-former-mines/.

Mapping low-conflict lands: There are multiple ways to map low-conflict lands that range from a simple approach focused on land cover-land use compatibility to conflict indexes that combine multiple environmental and social cultural values in a region.

Land Cover – Land Use compatibility: Although land cover – land use data is commonly used as an input in more complex representations of low-conflict areas, there are cases when land cover -land use data alone may be sufficient. This simplified and broad approach is particularly useful for rapid or less-detailed analyses across large geographic regions.

Here, we map low-conflict lands in its more basic form by classifying land cover classes into conflict (=1) or non-conflict (=0) based on how compatible they are with potential solar and wind development (see as an example, Table 4). Conflicts are assigned on a per-class basis and are characterized by land uses that have historically not facilitated multiple-use development patterns or may be environmentally or socially sensitive. Teams may choose to use weights instead of a binary 0/1 to differentiate degrees of conflict. If not already removed as a constraint, land uses considered high conflict might also include protected areas with the highest levels of protection for wildlife and natural resources.

Conflict index: Typically, we combine important environmental or social/cultural values into a continuous or categorical index to identify areas along a gradient of potential conflict. These indices can increase in complexity as the number and of environmental and social assets grows. As complexity grows, assessments of what is 'low-conflict' can become less intuitive and more difficult to effectively use as an important decision-making input. We describe several options for creating a conflict index in an expanded discussion that can be found in Appendix 2.

Table 4. A subset of CORINE Land Cover classes and sample conflict scores for compatibility with solar and wind development where 1 = high conflict and 0 = low-conflict. Conflict values may differ across geographies.

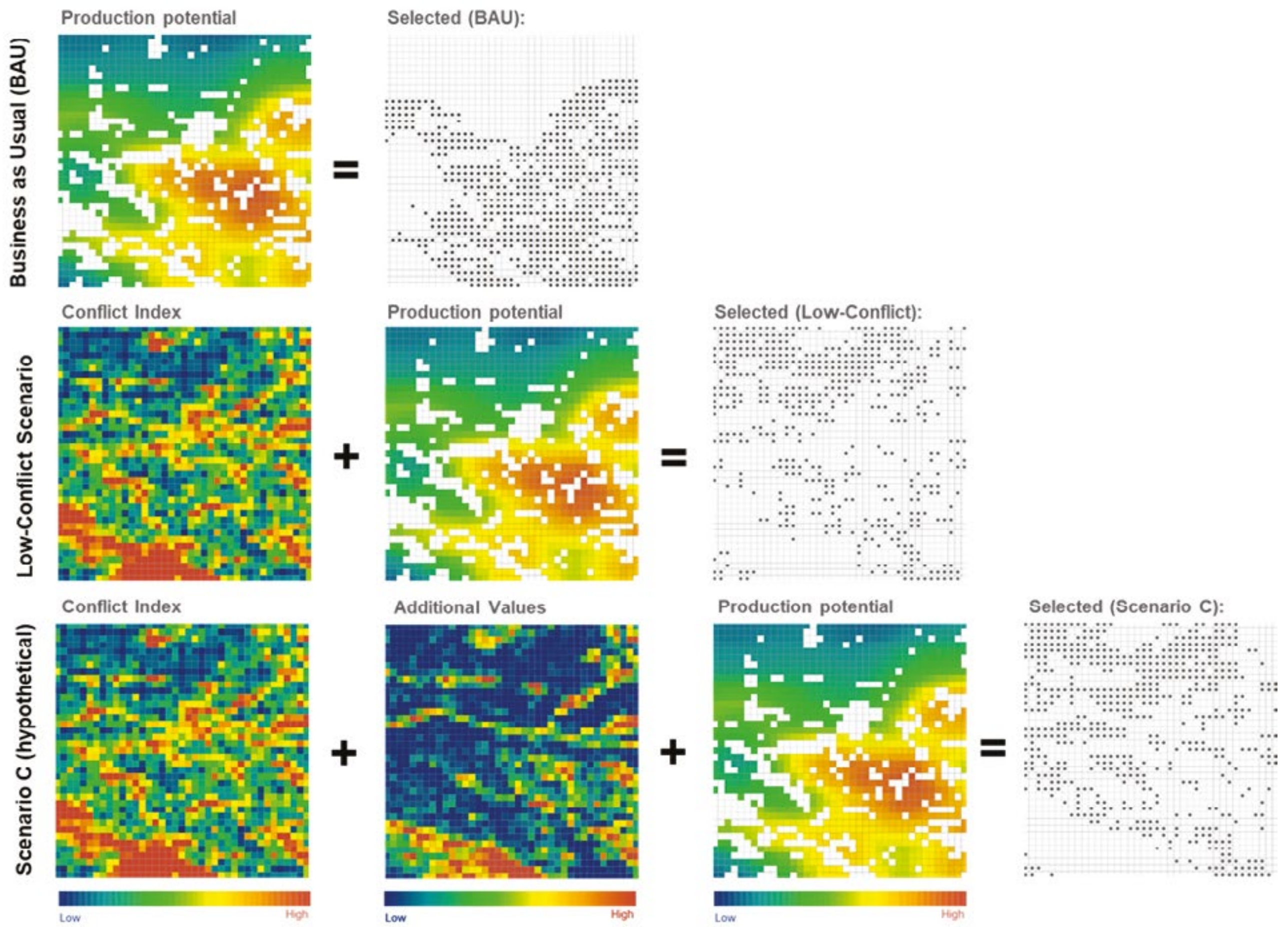
Level 2 CLASS name:	Level 3 CLASS name:	Solar Conflict	Wind Conflict
GLOBAL WIND ATLAS			
1.1 Urban fabric	111 – Continuous urban fabric	0	1
	112 – Discontinuous urban fabric	0	1
1.2 Industrial commercial and transport units	121 – Industrial or commercial units	0	1
	122 – Road and rail networks and associated land	0	1
1.3 Mine dump and construction sites	131 – Mineral extraction sites	0	0
	132 – Dump sites	0	1
	133 – Construction sites	0	0
1.4 Artificial non-agricultural vegetated areas	141 – Green urban areas	1	1
AGRICULTURAL AREAS			
2.1 Arable land	211 – Non-irrigated arable land	1	0
	212 – Permanently irrigated land	1	0
	213 – Rice fields	1	0

Visualize the overlap between lands with high development potential and low-conflict: Using the energy development targets, we combine the energy development potential layer with energy production estimates and the conflicts index to select potential areas for development (Figure 5). Energy production estimates are usually expressed in power or capacity needs. Capacity is derived by multiplying area by a selected power density; power estimates will require an additional capacity factor be applied.

We use those power or capacity estimates to rank or select areas likely to be developed. For example, in a BAU scenario, we select areas (represented as raster cells) by development potential and/or resource yield in descending order and sum total yields until region-level renewable development goals are met. Likewise, in a low-conflict scenario described above, we sort by conflict scores (low to high conflict), then sort by production potential (high to low) and select potential areas for development until energy targets are met.

To highlight trade-offs between different scenarios, we can summarize areas selected for potential development by extent and by proportion or frequency of low or high conflict values impacted. Additional post-hoc evaluations of overlap between areas selected and the conflict index (and its component environmental and social/cultural values) can be useful as subsequent analyses that further informs the planning. Practitioners may use these data inputs to further refine the categorization of suitable sites for low-conflict development.

Figure 4. Combining production potential and conflict scores by scenario.



5.4 Examples

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- The CMS Energy Task Force (ETF) https://www.cms.int/en/taskforce/energy-task-force provides a good example of a participatory process were business, science, practitioners, civil society and others get together to monitor and evaluate impacts of RE on biodiversity, putting together preventive and compensatory measures to mitigate damage.
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6. Conclusion

The energy sector is undergoing a rapid transformation in response to escalating impacts of climate change, increasing energy demands, and decreasing costs of wind and solar deployment. Many governments and businesses are shifting towards renewable energy as a means to address climate change and limit the rise in global temperatures to less than 1.5°C above preindustrial levels. The latter requires countries to halve greenhouse gas emissions by 2030 and to achieve net-zero greenhouse gas emissions by mid-century. And to do so, the world must quickly transition to renewable energy. While there is general agreement that the transition to renewable energy is essential to ensure a path to a sustainable climate, it is also becoming clear that with this transition comes an urgent challenge - the footprint required for wind and solar development could have profound impacts on ecosystems, biodiversity, and communities. It will be important that these impacts are taken into consideration and addressed through responsible planning and development practices.

At the same time, Europe is facing an energy price crisis. Policymakers in Europe are currently faced with the difficult task of reducing reliance on Russian oil and gas without worsening the situation for households that are struggling with high energy prices. The two options available are either to substitute fossil fuel imports from Russia with imports from other countries or to reduce reliance on fossil fuels entirely by investing heavily in low-carbon energy production. The current energy crisis and the climate crisis cannot be treated as two separate issues as the decisions made today will impact future energy and climate policies. With this, we outline steps that can help address some of the key challenges associated with the energy transition:

Footprint: The buildout of renewable energy infrastructure requires a lot of land. In Europe alone, achieving emission reduction targets by 2030 could require a network of land-based wind turbines and solar arrays that would require upwards of 88,000 square kilometers for onshore wind and solar development, even when maximizing energy efficiency, rooftop solar and offshore wind (Kiesecker et al. In prep).

Conflicts: Siting renewable energy in sensitive wildlife habitat or culturally important areas not only harms people and nature, but also increases the potential for conflicts that could slow the transition to clean energy—a delay the renewable energy transition cannot afford. Building renewables on natural lands can also undermine climate progress by disturbing forests and soils, releasing the carbon they store.

Insufficient policy and incentives: Many market factors, including profit and risk, influence where energy developers site projects. However, regulatory requirements are often insufficient to address significant environmental impacts. The ensuing conflicts affect developers' long-term ability to operate. To minimize impacts on wildlife, natural carbon stores, and cultural resources, accessible information and additional incentives are needed. This highlights the importance of strong policy and regulatory frameworks to guide the development of renewable energy infrastructure in a sustainable and responsible manner.

With large-scale planning, we can ensure this development is sited appropriately—where it can meet growing demands for energy without endangering wildlife, habitats or people—and help accelerate the transition to clean energy. But we must act quickly with a coordinated, multipronged strategy to advance smart renewable energy siting across Europe.

The good news is that there is enough already converted or low-conflict land to provide the renewable energy that countries have committed to under the Paris Agreement and other relevant country-level energy and climate targets. In fact a recent assessment suggest that low-conflict converted landcover types have the potential to generate 5.5 million GWh of solar and 2.7 million GWh for wind across Europe – which equals roughly 7-28 times total solar renewable targets (Kiesecker et al. In prep). This land is often near transmission lines, power stations, and load centers, which further reduces the need to develop in natural areas. By using innovative science, tools, and landscape-scale planning methods to improve siting and development practices, we can accelerate the transition to clean energy without sacrificing natural habitats. This approach would help to reduce the environmental and social risks of renewable energy development and support the achievement of sustainable development goals.

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APPENDIX 1:
Constraints, Criteria, and Values

As detailed across the **four key elements** presented in this document, a wide range of factors must be considered in 1) identifying suitable sites for wind or solar development, and 2) ranking suitable lands for low to high conflict based on further criteria. Here, we present a summary table that lists several commonly used data types and broadly classifies factors as “**constraints**” for wind/solar suitability mapping (i.e., excluded as unsuitable), “criteria,” for further ranking of development likelihood and “**values**” which are additional environmental and social or cultural assets in a landscape that are at risk of conflict with future development. While certain factors are predictably deemed to be constraints, other data types can either be used as constraints or values depending on the local context, national legislation or policies, and expert input. Values are what are integrated into a conflict index or avoid layer. “Criteria” are those conditions (e.g., proximity to transmission system) that increase the likelihood of development.

Table 5 suggests some elements that can be considered **constraints** or **values** and how to spatially represent them. This list is not exhaustive nor prescriptive – teams should consider constraints and values that are relevant to their landscapes.

Table 5. Examples of development constraints, restrictions, and conflicts or exclusions for wind or solar suitability mapping at a national, sub-national or local scale, derived in part from Ryberg et al. 2020, but sample thresholds presented here should be adjusted to the regional or local context as appropriate.

Group Exclusion *Detailed Exclusion*	Excludes	Low	Typical	High	Unit
ECONOMIC					
Resource					
Wind speed	values below	4	5	7	m/s
Global Horizontal Irradiance (GHI)	values below	none	3	5	kWh/m2 per day
Road access	distances above	45	10	1	km
Electric grid connection	distances above	45	10	1	km
Land value	cost above	*	*	*	*
CURRENT INFRASTRUCTURE					
Settlements/Buildings	feature + buffer	0	800	1000	m
Urban	feature + buffer	0	1	3	km
Rural	feature + buffer	240	500	200	m
Roads	feature + buffer	50	150	500	m
Major	feature + buffer	50	200	500	m
Minor	feature + buffer	50	100	500	m
CURRENT INFRASTRUCTURE					
Airports	feature + buffer	0	5	8	km
Large & Commercial	feature + buffer	0	5	25	km
Airfields	feature + buffer	0	3	8	km
Railways	feature + buffer	50	150	500	m
Powerlines	feature + buffer	100	200	240	m
Mining / industrial areas	feature + buffer	0	100	500	m
Power plants	feature + buffer	100	150	200	m
PV solar farm	feature + buffer	0			m
Wind turbines	feature + buffer	0	300	500	m
Gas lines	feature + buffer	100	150	300	m
Radio/cell towers (wind only)	feature + buffer	400	500	600	m
BIOPHYSICAL					
Slope	values above				
PV	values above	1	10	30	degrees
Wind	values above	1	10	30	degrees
Water	feature + buffer	0	300	3,000	m
Lakes	feature + buffer	100	400	4,000	m
Rivers	feature + buffer	100	200	400	m
Sea coastlines	feature + buffer	0	1	3	km
Elevation (wind only)	values above	1,500	2,000	3,000	m
Soils					
Sandy	feature + buffer	0	1	4	km
Landcover					
Woodlands	feature + buffer	0	300	1,000	m
Wetlands	feature + buffer	0	1	3	km
Croplands (PV only)	feature + buffer	0	50	240	m
Rock and Ice	feature + buffer				m
REGULATORY (OTHER)					
Protected areas	feature + buffer	0	1	3	km
Local zoning restrictions	feature + buffer	Context – dependent			
Military zones	feature + buffer	Context – dependent			

Group Exclusion *Detailed Exclusion*	Excludes	Low	Typical	High	Unit
ENVIRONMENTAL (SEE SECTION FOR MORE DETAIL)					
Critical habitat	feature + buffer	Context – dependent			
Critical migration corridors	feature + buffer	Context – dependent			
SOCIAL AND CULTURAL (SEE SECTION FOR MORE DETAIL)					
Cultural and historic sites	feature + buffer	Context – dependent			
Spiritual sites	feature + buffer	Context – dependent			
Recreational areas	feature + buffer	Context – dependent			
Tourist zones	feature + buffer	Context – dependent			
Visually aesthetic landscapes	feature + buffer	Context – dependent			
Indigenous Peoples and Local Communities (IPLC) lands	feature + buffer	Context – dependent			
Indigenous and community conserved areas (ICCA) lands	feature + buffer	Context – dependent			
Population density	values above	Context – dependent			

Table 6 suggests some elements that can be considered criteria and how to spatially represent them. This list is not exhaustive nor prescriptive – teams should consider criteria that are relevant to their landscapes.

Table 6. Common criteria used to map development potential for solar and wind energy.

Criterion	Highest suitability (outside of constraints)
Wind speed	highest value
Irradiance	highest value
Distance from demand centers (i.e., urban areas)	nearest pixel
Distance from transmission lines	nearest pixel
Distance from substation	nearest pixel
Distance from roads	nearest pixel
Distance from railroads	nearest pixel
Slope	lowest value

APPENDIX 2:
Representing low-conflict lands as an index

The process of identifying low-conflict areas for renewable energy development often concerns multidimensional issues that reflect the wide range of social and environmental interests of community members, stakeholders, and partners. As a result, the project team may consider several data types for planning and to inform decision-making.

Here, we briefly note the first steps of establishing a framework and selecting indicators to help guide this process. In Table 7, we outline several approaches to represent a complex set of environmental or social elements under Step 6 (i.e., constructing a measure). In all cases, the order and selection of relevant steps to follow are highly context dependent, and likely to differ on a case-by-case basis.

Establishing a framework and selecting indicators that represent environmental and social interests:

1. **Designing a framework:** At the initial stage of considering conservation or social interests for renewable energy siting, it will be useful to develop a conceptual framework that defines which dimensions are most important to address at a given project site/region, and a list of relevant factors respective to each category. This may involve a review of available literature to summarize key environmental and land-use characteristics for a specific area, as well as consultations with the public and relevant stakeholders or participatory mapping with local communities. At this point, it is useful to examine what past, ongoing, or potential future concerns exist to identify categories. Project teams should consider which attributes about variables are most helpful to measure progress towards applicable policy targets or sustainable development goals. For example, practitioners may be focused on all forest types, old growth forests, examples of connected forests, etc. These decisions will drive data selection or data preparation approaches to spatially represent biodiversity or social/cultural values. In short, practitioners should use variables and relevant data that are most suitable for answering the questions that are being asked and tailor the variable to the correct spatial and temporal scale or resolution.
2. **Selecting and formatting indicators:** Across contexts, discussions and consultations with community members and stakeholders will best inform the selection of relevant indicators. Following a framework that defines the key issue(s) to be translated, a list of indicators can be considered under each area of focus that is identified. Before comparing or packaging these indicators for analysis, data should be normalized to transform different measurement units into a common scale (e.g., on a scale of 0-1). Alternatively, teams may choose to base data on a scale relative to an indicator's vulnerability to wind/solar development (based on literature review of expert input). The appropriate mathematical normalization method to use will largely depend on the data types (e.g., min-max normalization, log scaling, z-score normalization).

Starting with a comprehensive set of data, teams can choose to represent the different elements with some of these approaches (or a combination):

- Separately – considering each indicator as an individual measure and spatial layer
- Combined – aggregating a subset of relevant indicators to build an index that may be additive, an average, or using other appropriate summary statistics
- Interpreted – classifying a single indicator or a combined index into categories that represent a ranking system of interest

The choice of approach(es) often depends on data availability, quality, and whether there is need for a summary index. We expand on the possible approaches in Table 7 next page:

Table 7. Suggested approaches to construct a measure to summarize environmental and/or social elements.

SOME APPROACHES TO REPRESENT ENVIRONMENTAL OR SOCIAL ELEMENTS

Treat elements individually

Teams may choose to keep individual elements separate rather than combining them into a single continuous or discrete index. This enables decision-makers to understand more specifically the important values that may exist in a place or how that value or element is cumulatively impacted across a landscape. However, the number of elements that are identified as important in a landscape and the diversity in ways each is represented may make it difficult to compare the consequences of potential impacts from place to place as well as to understand the full scope of what might be impacted. For continuous variables, normalizing all values to a common scale may help with comparing between individual elements that are mapped separately and avoid the complexities of multiple measurement types.

Combine elements into a single continuous index:

One approach to summarize multiple elements is the use of a composite indicator or index, which is a widely recognized tool to assess conditions or trends, and support decision making (Singh et al. 2009). In its simplest form, this method combines a subset of variables into a single continuous index to measure an underlying concept for a given area, which may also be spatially presented and compared. As an example, a richness index would be a straightforward first step to summarize biodiversity measures. Such indices are easy to understand (i.e., areas with a score of 9, indicate the presence of 9 biodiversity elements of conservation interest and so on). A more complex measure might be constructing a social well-being index, which can incorporate indicators that represent education, income, food security, or access to nature.

Two simple options for mathematically combining indicators include creating an **additive index** (i.e., a sum of all variables or the use of a decision-tree to combine indicators in a rule-based process) or a **mean index** (i.e., taking an average across values for each indicator). More complex functions may be used to calculate an index depending on the objective and scope of the index.

The challenge of using a single continuous index is that it can be difficult to understand where individual species of particular concern are, where the best examples (e.g., most intact) of important landcover classes might be, or whether areas of high scores are truly more diverse or ecologically important than low-scoring areas or is an artifact of data availability. Similarly, imbalance in data availability or increased risk from one particular social factor may not be as easily captured when considering a single combined index. These challenges might be addressed through **weighting of individual inputs**, but such decisions come with their own set of caveats (Nardo et al. 2005, Gan et al. 2017). Depending on the use of the index and analysis, one method could be to compute a continuous score that weighs each indicator by their relative vulnerability to wind/solar impacts (e.g., "vulnerability score"). The specific method of weighting and interpretation would be context-dependent and informed by literature reviews and expert inputs

In addition, it is important to consider the relationship between variables (i.e., correlation among variables) when interpreting the index values. There are several methods to explore the statistical relationships and consider consistency among indicators, such as Cronbach's alpha (Cronbach 1951, Tarasewicz and Jönsson 2021), which can also help guide indicator selection.

Combine elements into a single index with categorical classes

A single measure can be further classified into categories or a ranking to provide a system to further differentiate within a measure. This takes the index a step further by designating classes, such as low to high levels of social values, conservation interests, or even conflict risk. Using the previous example of a simple continuous index, a richness index would be binned into discrete classes that might be functionally translated into areas of "Very Low" to "Very High" biodiversity interest.

Again, the easy-to-understand nature of such a classification makes this an attractive approach. However, users should be aware that these classes may simply represent quantitatively derived breaks (e.g., equal area, quantiles) rather than social or ecologically meaningful thresholds. Such an approach still suffers from the same problems of the summed continuous approach above, since areas of "Very High" value may tell us more about the number of elements in a place rather than the quality, rarity, or importance of any single contributing factor.

Practitioners can choose to use several approaches in combination. In some cases, there may be a subset of elements that are best suited to being considered separately as individual layers (e.g., as in an avoid layer), whereas others are combined into an index to highlight areas of overlapping values. Alternatively, teams may choose to provide summaries of conflicts with individual layers alongside a summed index option – to enable decision-makers to consider places according to the specific contributions or concerns (e.g., rarity, irreplaceability, vulnerability) of any of these elements alongside richness of elements respectively.

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APPENDIX 3:
Good data practices

RE suitability and priority mapping efforts rely on an extensive spatial database. Four general steps guide the creation of this database: data selection, data processing, data analysis, and model integration (Figure 6).

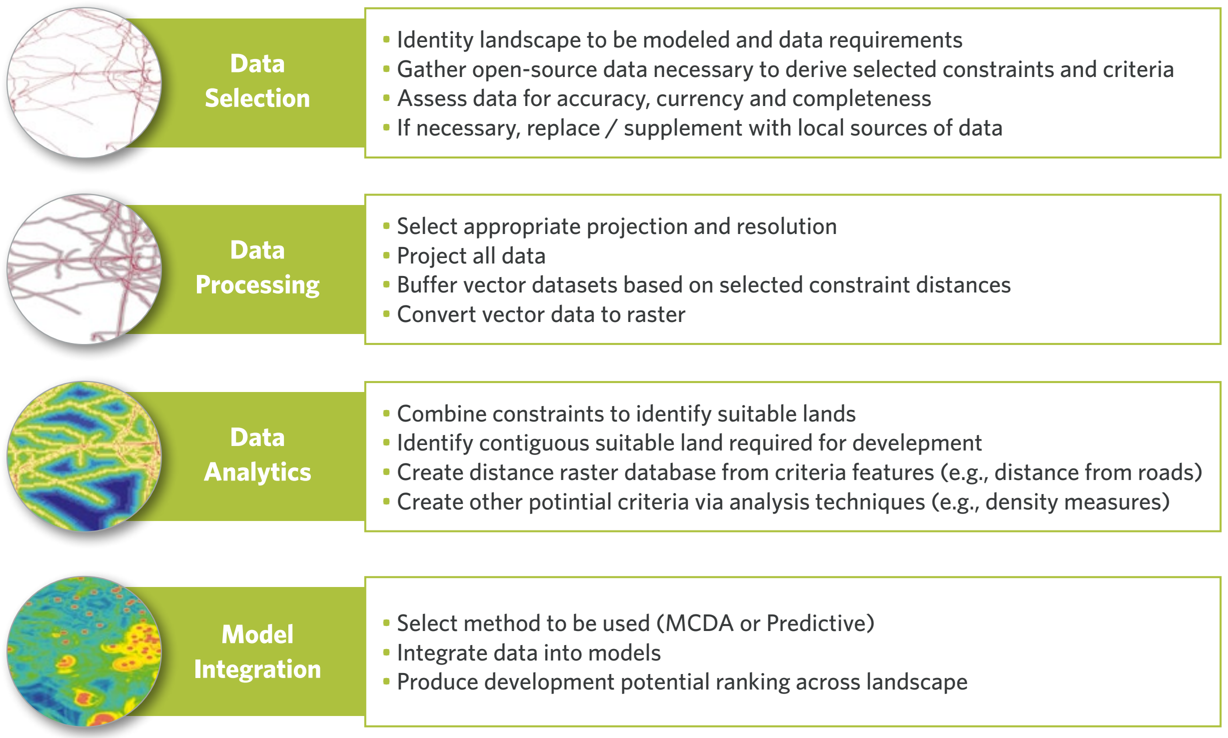
Initially, a study area boundary is created and often matches a country or state/provincial boundary. All spatial data that potentially inform RE siting are then collected (see Table 1 for global, open-access data sources and associate data descriptions). Once a database is created, all data are assessed for accuracy, currency, and completeness across the study area with those not meeting standards replaced by more regional or global data.

Early decisions on projection and resolution:
Renewable energy siting analyses require area and length measurements, thus elevating the importance of thinking carefully about data projection and resolution early. Locally specific projections tend to minimize both area and distance distortions, but more regional projections may be required over more extensive landscapes.

Because most renewable energy analyses are performed using raster data, we recommend defining a standard raster resolution early on. This resolution is often dictated by either; 1) a common data source used in the analysis (e.g., wind speed, irradiance, land cover), 2) spatial accuracy of input data, and/or 3) spatial extent of an analysis (e.g., global, regional, state).

Masking and snapping analysis raster datasets: Once these two parameters (projection and resolution) are established, the study area is often the first dataset to be processed. This provides not only a projected boundary used for clipping features but also when converted to raster provides an analysis mask to align and match extents of all raster datasets produced. All selected constrains are created by selecting appropriate features and/or buffering any identified buffer distances (see Table 2 for typical constraints and buffers). All selected and/or buffered features are then converted to raster data using the established resolution and limited spatially by the boundary mask.

Figure 5. General steps for creating a spatial database supporting RE siting.



Glossary

Conflicts refer to areas that represent ecological, social, or cultural values that are of conservation interest in a region and may pose potential risks for development. Conflict layers can be used to further identify and rank or categorise otherwise suitable areas from low to high risk or preference.

Constraints are areas necessarily excluded from renewables suitability mapping efforts due to economic, administrative, biophysical factors, or local policies on environmental or social restrictions.

RE: Renewable Energy

Renewable acceleration areas (also, **Renewable go-to** areas) are specific locations, particularly suitable for the installation of wind and solar energy from these renewable sources, where the deployment of wind farms and solar arrays is not expected to have significant socio-ecological impacts that can slow the development of projects.

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