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Electric Power & Natural Gas Practice

Land: A crucial resource for the energy transition

To achieve its decarbonization targets, the European Union will need to expand renewable-energy capacity. Identifying and allocating sufficient land will be foundational to the effort.

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As part of the European Green Deal, the European Union set a binding target of achieving climate neutrality by 2050.[1] More specifically, the Fit for 55 package sets an interim goal of reducing greenhouse-gas (GHG) emissions by at least 55 percent by 2030.[2] Furthermore, the European Commission announced its REPowerEU plan, which includes measures "to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition."[3]

Expanding capacity generated by renewable-energy sources (RES) is essential for the European Union to achieve its energy transition objectives. Although specific requirements vary by country, a rapid acceleration in the annual installation rate of new wind and solar photovoltaic (PV) assets is required. REPowerEU has set a target of 1,236 gigawatts (GW) of renewable capacity by 2030, requiring more than 700 GW of additional RES capacity to be added from 2023 to 2030, a threefold increase in annual installations compared with the RES capacity added from 2014 to 2022 (approximately 230 GW).[4] With REPowerEU targets of 600 GW of installed solar PV capacity and 500 GW of wind capacity by 2030, more than 90 percent of the targeted additional capacity will need to be supplied by wind and solar—both of which require large tracts of habitable land.

In a recent article, we explained how finding adequate land for RES projects is becoming increasingly challenging.[5] Beyond the technical suitability of the land, which is a hard limiting factor, a significant amount of land in Europe is unavailable for development because of strict regulations. And the land that remains available is often well suited for—and therefore must compete with—other societal or environmental objectives, such as agriculture and biodiversity conservation. The latter will likely become an increasingly significant limiting factor for land availability, considering the Kunming-Montreal Global Biodiversity Framework, which was adopted at COP15 in 2022.[6] One of the framework's goals is effective conservation and management of at least 30 percent of the world's land by 2030[7] (versus the current amounts of 8 and 17 percent of the world's protected marine and terrestrial areas, respectively[8]).

Using Germany (the largest economy in Europe) as a case study, we assessed the key trade-offs and major obstacles of land availability for RES development, particularly as it relates to protecting biodiversity and the need for other land allocations. Next, we applied geospatial analytics to identify cost-optimal land for RES projects. Finally, we determined actions that stakeholders in the public and private sectors can take to ensure that procuring land enables an orderly energy transition.

The challenges of identifying attractive locations for renewable energy

The amount of land required to meet the wind and solar PV capacity targets in Europe is significant. For instance, in France, Germany, and Italy, where roughly 50 percent of the EU RES installations are expected, meeting 2040 RES capacity targets would require an additional 23,000 to 35,000 square kilometers of land—an area equivalent to the size of Belgium.[9] Land will also need to serve as a source of biogenic CO_2 (easily replenished sources of carbon, such as wood and other biofuels) for bioenergy with carbon capture and storage and the production of e-fuels.

In addition, technical, regulatory, and environmental constraints often reduce the amount of land available for RES development. Technical limits

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1 "European Green Deal: Fit for 55," European Council, March 29, 2023.
2 Ibid.
3 "REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition," European Commission, May 18, 2022.
4 According to our analysis, more than 700 GW gross additions are required, including repowering older RES plants.
5 "Renewable-energy development in a net-zero world: Land, permits, and grids," McKinsey, October 31, 2022.
6 For more information, see *COP15: Final text of Kunming-Montreal Global Biodiversity Framework*, UN Convention on Biological Diversity, December 27, 2022.
7 Ibid.
8 ProtectedPlanet (website), accessed April 3, 2023.
9 Assuming five to eight megawatts (MW) per square kilometer (km) for onshore wind and 43 to 60 MW per square km for solar PV.

include existing RES installations and areas with limited natural wind or sun intensity. And regulatory and environmental limitations, which acknowledge local communities' concerns about land use, can reduce the land available for RES development. These limitations are valid and should be addressed when assessing trade-offs and obstacles as they relate to land availability. With these points in mind, our estimates show that about 9 percent of available land in Germany is suitable for wind and less than 1 percent of land in Italy is suitable without limitations for solar PV (Exhibit 1).

Limiting certain activities in protected areas[10] is key to promoting biodiversity.[11] Further, RES developers should take into account proximity to population settlements and other infrastructure, such as clinics, highways, and industrial areas, to avoid negative impacts on societal well-being. The overlap between such limiting factors can be thoroughly investigated to ensure that the energy transition's targets are achieved through appropriate land use.

The biggest factor affecting land availability in Europe is regulations—specifically, rules that set

Exhibit 1

Regulatory constraints limit the availability of land for onshore wind in Germany and for solar photovoltaics in Italy.

● Potentially suitable ● Build-out restricted due to Italian cropland regulation
● Excluded due to regulatory constraints ● Excluded due to technical constraints and unsuitable land cover

	Germany	Italy
Technology	Onshore wind	Ground-mounted solar photovoltaics (PV)
	104 GW additional wind capacity required to meet 2040 renewable-energy-sources (RES) targets	**63 GW** additional solar PV capacity (excluding rooftop solar PV) required to meet 2040 RES targets
Land availability constraints based on total land mass, %	9 / 39 / 52	1 / 32 / 7 / 60
	50–80% of potentially suitable land is needed for 2040 onshore wind targets while spatial planning, land-use designation in Germany, and ownership further limit the availability of land	**60–85%** of potentially suitable land is needed for 2040 ground-mounted solar PV targets while spatial planning, ownership, and financial aspects further limit the availability of land

Note: For separation of land area, technical constraints and unsuitable land cover are existing wind and solar PV, urban areas, forests, water, airports, low-wind-potential zones (for wind only), slope, and military zones. Regulatory constraints are distance regulations for onshore wind from settlements and on protected land. We separately show areas with regulatory constraints in Italy to develop utility-scale solar PV on cropland. General assumption for onshore wind is a density of 5–8 MW/km^2, not considering additional capacity needed if repowering is not possible in former areas, radars, military flight zones, and further country-specific detailed regulations. General assumption for solar PV is a density of 43–60 MW/km^2, excluding overlapping wind areas and rooftop solar PV (3:1 split between ground-mounted and rooftop solar PV for Italy). Germany has official 2040 RES targets; Italy only has official 2030 RES targets that were linearly extrapolated to 2040 for this analysis.
Source: McKinsey land use optimization model Space Fit based on Copernicus Global Land Service, ESA CCI Land Cover, Global Solar Atlas, Global Wind Atlas, MERIT DEM, Open Street Map, and Protected Area and Key Biodiversity Area data of 2020 downloaded from the Integrated Biodiversity Assessment Tool (IBAT) and provided by BirdLife International

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[10] Includes nature reserves, wilderness areas, national parks, natural monuments or features, and habitat or species management areas.
[11] For more information, see Key Biodiversity Areas (website), accessed April 3, 2023.

a minimum distance between wind turbines and settlements. Such rules are frequently established at the regional level, which means regulatory-compliant land for RES development can vary widely even within countries. This can also create interregional tension. In Germany, for example, rules about distance from settlements and infrastructure for onshore wind vary from state to state, and approximately 60 percent of the country's suitable land is eliminated from consideration based on these rules. In Lower Saxony, the required minimum distance is double the total height of the turbine. By contrast, in Bavaria the distance to settlement is ten times the total height of the turbine,[12] limiting wind deployment to just 160 square kilometers. In Italy, land for solar PV is restricted because of regulatory limitations on the use of cropland, which accounts for roughly one-third of total land area and 80 percent of total available land after technical constraints. Cropland exclusion also poses a significant challenge, as it means that achieving 63 GW of additional solar PV capacity in Italy by 2040 requires up to 85 percent of available land.[13]

In addition to these constraints, using land for RES development can create competition with using land for food and biomass production, which is necessary for societal well-being. This is especially true for ground-mounted solar PV, for which virtually all suitable land can be used for other purposes. Although there are solutions that can help ameliorate the situation—for example, agrivoltaics could be a solution for using cropland for RES installations without significantly limiting food production—a lack of industry standards and regulatory incentives has hampered progress. Meanwhile, wind has only a small impact on crop yields, yet it can significantly affect biodiversity, particularly as it relates to habitat degradation or loss of birds and bats.

Geospatial analytics can help optimize the potential of RES development

Geospatial analytics leverages geographic information from geolocated activities and remote sensing data such as satellites, combined with AI. This can help pinpoint optimal locations for RES projects while accounting for the needs of other land applications. Our analysis focuses on identifying suitable land and deploying spatial optimization for onshore wind projects in Germany.

Identifying suitable land areas for onshore wind development

The starting point for assessing land availability for wind projects is the total territory of a country. Areas are automatically considered off limits for onshore wind development if they are cities, closed forests or water bodies, military areas, or airports.[14] Technical constraints are overlaid on potentially available land; steep slopes areas with low technical capacity factors and other influence zones around existing installations are excluded. The resulting locations typically follow the topographic characteristics of a country. In Europe, mountainous regions such as the Alps and Pyrenees and regions with low potential for solar and wind account for the bulk of land excluded for technical reasons.

Next, prominent regulations for RES development are considered through settlement boundaries and environmental restrictions on strictly prohibited land types,[15] such as nature reserves, wilderness areas, national parks, and monuments. The restriction on settlement boundaries leads to the exclusion of land based on minimum distance to settlements for wind energy. Finally, environmental restrictions are also assessed, excluding loosely protected land and key biodiversity areas.

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[12] This refers to the so-called 10H rule. In November 2022, Bavaria passed a law that introduced some exceptions to the 10H rule, but the rule is still in place. Even with exceptions, the rule limits land availability for wind power build-out in Bavaria in the short and medium term. In the longer term (toward 2027), German national law obliges Bavaria to designate at least 1.1 percent of its land area for onshore wind.
[13] Italy has no official 2040 RES target. For our analysis, we extrapolated official 2030 RES targets to 2040.
[14] Includes a buffer zone of three kilometers.
[15] *Guidelines for applying protected area management categories*, International Union for Conservation of Nature, Best Practice Protected Area Guidelines Series Number 21, 2013.

According to the results of the analysis, technical, regulatory, and environmental constraints reduce available land for wind in Germany by 82 percent (Exhibit 2). The largest reduction (almost 60 percent[16]) is driven by regulatory rules about proximity to settlements, not environmental restrictions.

Deploying spatial optimization to identify locations for RES

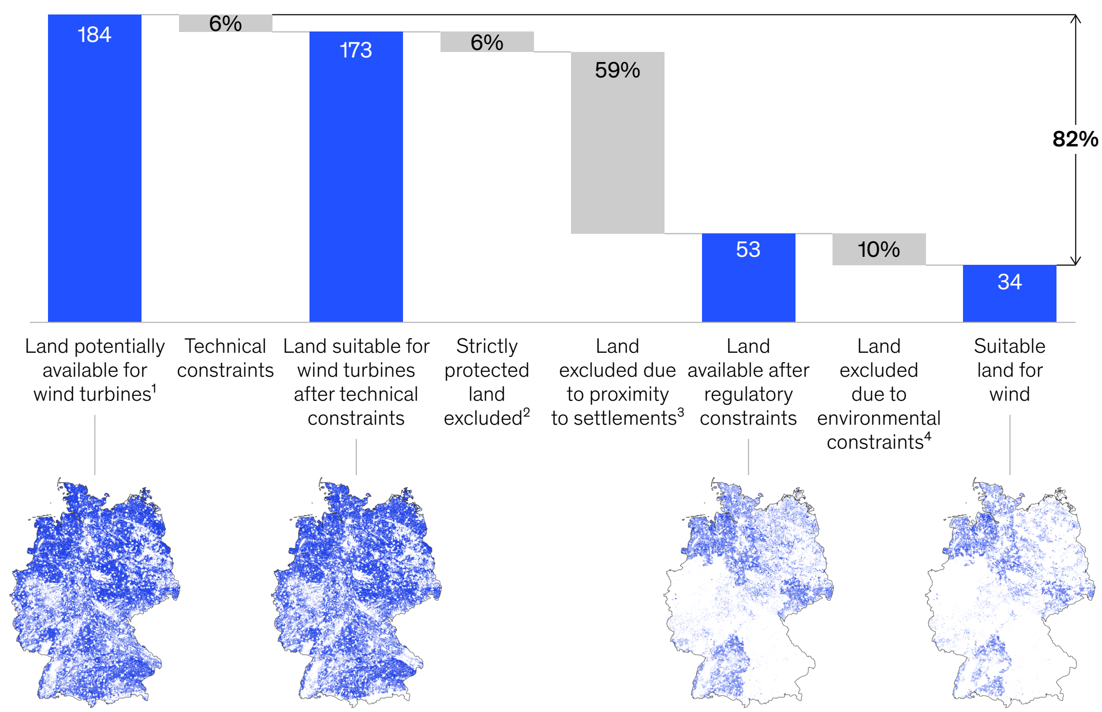
Land that is potentially suitable for RES varies in both energy potential and cost to produce energy. Applying a spatial optimization model can determine systemwide locations for renewable development that reach the total energy-generation target while minimizing the average cost of energy.

Exhibit 2

Technical, regulatory, and environmental constraints reduce available land for wind turbines by 82 percent.

Constrained land suitable for wind turbines   Technical, regulatory, and environmental constraints

Area in Germany suitable for wind turbines, thousands of square kilometers



[1] Potentially available land after removing cities, closed forests or water bodies, military areas, or airports.
[2] Includes a 200m buffer around protected land in protection categories I–IV (strict nature reserve, wilderness area, national park, natural monument or feature).
[3] Minimum proximity to settlements based on regulation at regional level.
[4] Includes protected land in categories V and VI (protected landscape/seascape, protected area with sustainable use of natural resources) or other.
Source: McKinsey land use optimization model Space Fit based on Copernicus Global Land Service, ESA CCI Land Cover, Global Solar Atlas, Global Wind Atlas, MERIT DEM, Open Street Map, and Protected Area and Key Biodiversity Area data of 2020 downloaded from the Integrated Biodiversity Assessment Tool (IBAT) and provided by BirdLife International

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[16] This number differs based on the order in which the filters are applied.

Integer linear programming can help identify cost-optimal solutions for renewable deployment by showing an image of nonrestricted land areas overlaid with a grid. The optimization engine chooses a certain wind turbine technology or excludes it to form a spatial solution. With millions of potential area solutions possible within defined constraints, the optimization allows the integer linear programming algorithm to select the best one to meet objectives such as the lowest total cost accounting for land, construction, grid connection, and maintenance. Additional constraints such as limiting the maximum installation density in a region to promote social acceptance and biodiversity[17] can also be considered.

In the case of Germany, not all suitable land is required to reach the 2040 RES target of 560 GW.[18] Our analysis shows that through a countrywide spatial optimization approach that selects the best wind locations and turbine technology mix, Germany could meet its wind targets by using 3 percent of the total land area, at an energy cost that could be more than 22 percent lower than that of a random selection of sites across suitable land.

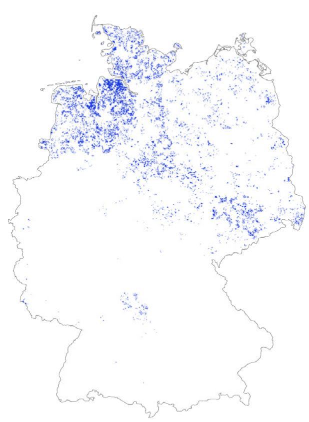
However, this optimal scenario assumes a higher density of wind turbines than what has been achieved to date. Maximum installation density in Germany will need to increase by at least 20 percent over current values to meet the 2040 targets. And with limits on increased wind turbine density, the cost of energy would increase by approximately 16 percent compared with an optimal unconstrained scenario (Exhibit 3).

In the case of Germany, areas with high biodiversity and loosely protected land do not overlap

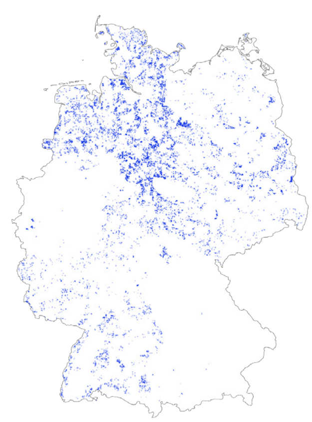
Exhibit 3

Scenarios illustrating different acceptable installation densities show variabilities in available land for onshore wind installations in Germany.

Scenario 1:
No constraints on installation density



Scenario 2:
Installation density limited to an increase of 20%



Source: McKinsey land use optimization model Space Fit based on Copernicus Global Land Service, ESA CCI Land Cover, Global Solar Atlas, Global Wind Atlas, MERIT DEM, Open Street Map, and Protected Area and Key Biodiversity Area data of 2020 downloaded from the Integrated Biodiversity Assessment Tool (IBAT) and provided by BirdLife International

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[17] A biodiversity intactness index can provide an estimated percentage of the preindustrial (before 1750) number of species that remain and their abundance in any given area, given the prevalence of human impact in that area.
[18] Onshore wind and solar PV only.

significantly with favorable wind locations.[19] Protecting these areas therefore does not critically change the costs or the land requirements. In addition, regions with high wind capacity are less favorable for solar PV, meaning that competition between types of renewable energy is not expected to escalate. However, favorable locations for wind energy in Germany show higher land opportunity costs from alternative land use and in general higher numbers of bird species, which further complicates securing the land (Exhibit 4).

Implications for stakeholders

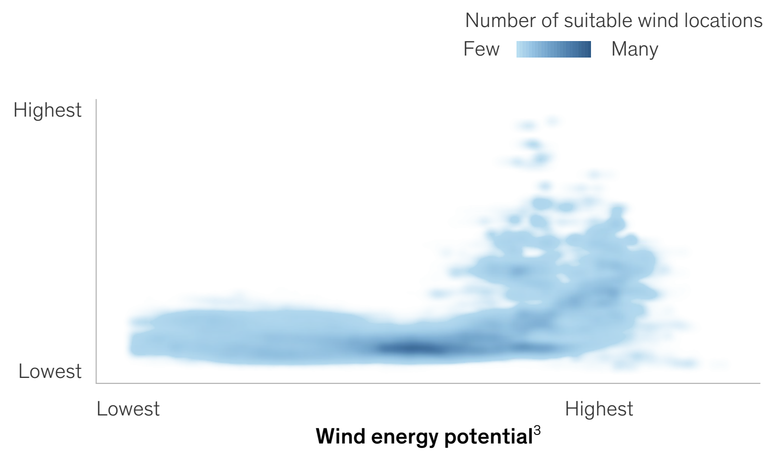
Land-use stakeholders across the value chain can take the following actions to help mitigate the risk of bottlenecks when identifying and securing land for RES development:

Exhibit 4

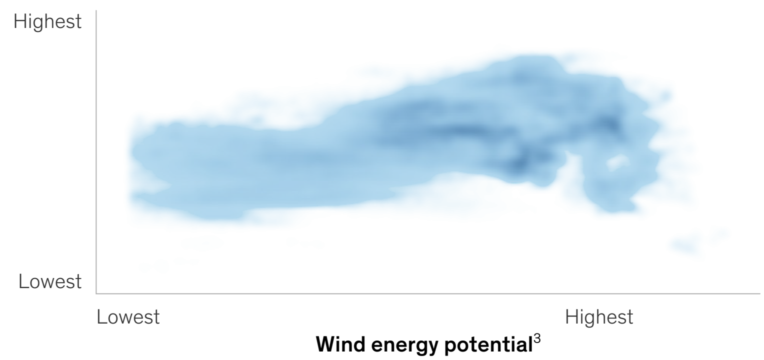
Favorable locations for wind energy in Germany show higher land opportunity cost and higher bird richness.

Land competition analysis

Land opportunity cost[1] is high for land with high wind capacity



Bird richness[2] is high for regions with high wind capacity



[1]Agricultural rent based on economic return (crop yield and livestock) determined from Food and Agriculture Organization and MapSPAM data.
[2]Number of locally present bird species, based on species coverage in IUCN Red List from IBAT (2021).
[3]We use the capacity factor of a class 2 wind turbine from Global Wind Atlas as a measure for wind energy potential.

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[19] Our scenarios show that a significant amount of the suitable land for renewables overlaps with cropland with an inherently lower biodiversity intactness.

It is important for local communities, businesses, and regulators across Europe to act hand in hand and quickly . . .

Updating spatial planning and land allocation. Assess the best sites for RES at the country level by considering parameters such as natural advantages (wind speeds and solar radiation, for example); competing land use (such as food production or biodiversity area); infrastructure proximity (such as road access to the sites); and availability (such as grid capacity) and regulations, including potential assignment of renewable "go-to areas" with low environment conflict risk. These points can help safeguard sufficient land for RES development by allocating suitable areas for deployment based on up-to-date spatial plans. In addition, leveraging geospatial modeling can help increase the effectiveness of the development teams, allowing them to conduct targeted development activities, especially when the data sets are enriched by land ownership data, if available.

Revisiting regulatory rules. Review regulatory constraints that limit land allocation for RES development. For example, rules on RES development in proximity to settlements can be harmonized across different regions, promoting practices favorable for RES development when other alternatives are limited.

Maximizing repowering. Maximize potential development at existing installations by replacing older power stations with newer, energy-efficient ones. This can help increase overall installed capacity without requiring additional land.

Encouraging social acceptance. Consider financial incentives for local communities and landowners to facilitate land deployment for RES purposes. For example, structure and promote long-term land lease agreements, dedicate portions of the profits from electricity generation to citizens who live near wind parks, and work to prevent higher grid charges in RES-intensive areas so that local communities are not penalized for being friendly to RES.

Fostering hybrid land use. Develop mechanisms and relevant business models for land co-sharing while bringing together landowners, RES developers, utilities, and regulators. Large swaths of the land needed to achieve RES capacity targets can also be used concurrently for other purposes. For example, only about 2 to 3 percent of the official land area of a typical wind park cannot be used for other purposes.

Innovating to preserve biodiversity together with RES development. Investigate opportunities to promote and safeguard biodiversity during renewables development and operations in partnerships between environmental groups—such as nongovernmental organizations and governmental agencies—and developers. This could include safeguarded migration routes for animals or new biotopes.

Fostering solar PV deployment on sealed surfaces. Provide incentives for the maximum use of previously sealed surfaces for PV deployment, including those covered with concrete or stone for buildings, roads, parking lots, and other infrastructure. Doing so can help leave natural soil surfaces undisturbed, contributing not only to energy targets but also to food security targets.

Increasing the European Union's RES capacity at the rate needed to achieve its stated objectives will require substantial amounts of land throughout the region, which could be limited in some countries. Therefore, it is important for local communities, businesses, and regulators across Europe to act hand in hand and quickly to ensure that land for renewable-energy development does not become a bottleneck. At the same time, land-efficient and biodiversity-enhancing RES deployment strategies can help ensure sustainability and promote a comprehensive approach to renewable-energy-systems deployment.

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