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LETTER

Countries across the world use more land for golf courses than wind or solar energy

Jann Michael Weinand[1], **Tristan Pelser**[1,2], **Max Kleinebrahm**[3] and **Detlef Stolten**[1,2]

[1] Institute of Climate and Energy Systems (ICE)—Jülich Systems Analysis (ICE-2), Forschungszentrum Jülich GmbH, Jülich, Germany
[2] RWTH Aachen University, Chair for Fuel Cells, Faculty of Mechanical Engineering, Aachen, Germany
[3] Institute for Industrial Production (IIP), Karlsruhe Institute for Technology, Karlsruhe, Germany

E-mail: j.weinand@fz-juelich.de

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Abstract

Land use is a critical factor in the siting of renewable energy facilities and is often scrutinized due to perceived conflicts with other land demands. Meanwhile, substantial areas are devoted to activities such as golf, which are accessible to only a select few and have a significant land and environmental footprint. Our study shows that in countries such as the United States and the United Kingdom, far more land is allocated to golf courses than to renewable energy facilities. Areas equivalent to those currently used for golf could support the installation of up to 842 GW of solar and 659 GW of wind capacity in the top ten countries with the most golf courses. In many of these countries, this potential exceeds both current installed capacity and medium-term projections. These findings underscore the untapped potential of rethinking land use priorities to accelerate the transition to renewable energy.

Introduction

The increasing urgency of addressing the global land squeeze and climate change requires a critical examination of land use priorities [1, 2]. Golf courses, for example, cover large areas around the world [3, 4], often in regions where land availability is limited. This has led to discussions about converting the courses to housing or public parkland, e.g, in Canada [5], Australia [6] and the UK [7–9]. In this paper, we argue that golf courses also provide a notable contrast to the growing demand for renewable energy infrastructure. A recent (non-peer-reviewed) analysis estimated that the total area of golf courses in Germany exceeds that of renewable energy facilities [4].

Golf courses typically require extensive turf maintenance, including significant water use and chemical treatments, resulting in a significant environmental impact [10–12]. In comparison, renewable energy installations such as solar farms and wind turbines offer a sustainable use of land and directly contribute to the reduction of greenhouse gas emissions. Utility-scale solar farms require approximately 0.01 km^2 per megawatt (MW) [13] while wind farms require around 0.12 km^2 per MW [14], although only a small fraction of this land is directly impacted by turbines and infrastructure [15]. In addition, built-up land such as golf courses is typically not included in renewable energy potential analyses, further highlighting the importance of reevaluating land use options.

Furthermore, the cost of renewable energy to decarbonize energy systems has been falling for years [16, 17], but realizing its high economic potential [18] is often hampered by social opposition [19–24], land use trade-offs [25], and siting regulations [26–28]. By evaluating the renewable energy capacity that could be installed on an area equivalent to the total global land area used for golf courses, we present an illustrative case study that highlights the opportunity to optimize land use to achieve broader environmental and societal benefits. This example was chosen not to suggest the conversion of actual golf courses, but to illustrate the potential for renewable energy development on similarly large and underutilized areas. In particular, golf courses were chosen for this analysis because they serve a relatively small, often affluent population, making their land use more exclusive than other recreational spaces such as soccer fields.

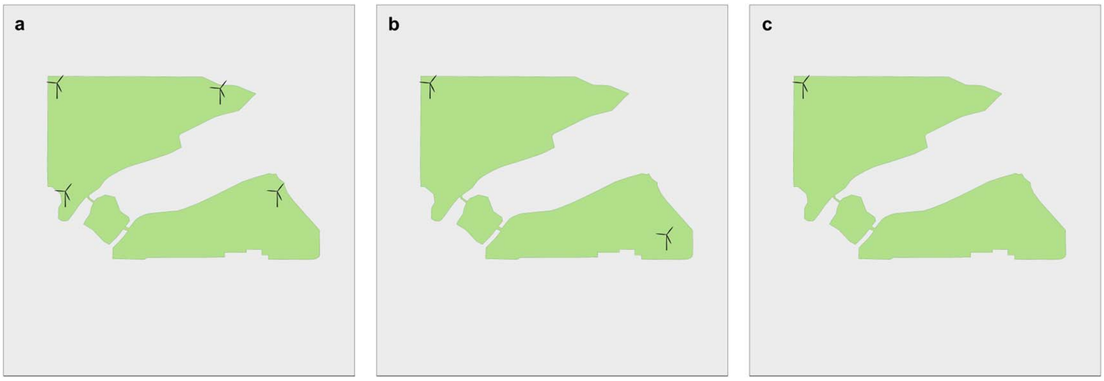

Figure 1. Example wind turbine placement for a golf course in Nebraska, United States.The panels show the placement for 500 m (a), 1000 m (b) and 1500 m (c) spacing between turbines.

Methods

Golf course data

The area, location and metadata for golf courses were obtained from OpenStreetMap using the following query:

[out:json][timeout:99999];
nwr['leisure'='golf_course']({{bbox}});
out geom;

OpenStreetMap contains 38,427 golf courses, which corresponds to the actual number of around 38,400 [29]. The two countries with the most golf courses, the United States (+1%) and the United Kingdom (+/−0%), as well as most other countries, have very good coverage in OpenStreetMap [30, 31]. The area of the golf courses also largely matches, with a deviation of only 1% for the United States [3]. However, for some countries courses are missing, such as for Sweden (−25%), Japan (−12%) and Canada (−6%).

Renewable energy potential assessment

We determine the technical potentials for wind and photovoltaic (PV) energy following the definition outlined by McKenna *et al* [32]: The technical potential refers to the energy generated from wind power within the boundaries of the geographical potential. This calculation incorporates various factors, including wind turbine specifications, as well as losses from wind farm array interactions and electrical energy conversion.

The Renewable Energy Potentials Workflow Manager (REFLOW) [33, 34] was used to develop and execute the software workflow for this analysis. REFLOW is a python-based workflow manager built on Luigi [35] and was developed in response to the fact that many assessments of renewable potential are not accurate or reproducible [18]. It facilitates transparency and reproducibility in renewable energy potential assessments by defining, managing, and running series of tasks relating to data acquisition, pre-processing, analysis and reporting. In this study, we employ REFLOW to manage the data workflow using data acquisition and pre-processing scripts, and then to interface with additional software for the land eligibility assessment (Geospatial Land Availability for Energy Systems (GLAES)) [36].

For the wind assessment, we employ a single theoretical turbine model based on near-future designs [16] with a capacity of 5.5 MW, and a rotor diameter of 135 meters. Since the golf courses are small areas, the low number of turbines that can be distributed on them reduces the need for staggered spacing to reduce wake effects. GLAES is employed to distribute turbines over the golf course polygons for three scenarios: high-, medium- and low-capacity density, equivalent to 1500 m, 1000 m and 500 m spacing between turbines (see figure 1). For the solar PV assessment, we employ three scenarios based on the assumed percentage coverage of the golf courses by horizontal PV panels (75%, 50% and 25% coverage). This is to account for vegetation or water bodies that would mean that not all the space is available for the installations. We assume a capacity density of 79,2 MW km^{-2} [37], such that the total installed capacity for each scenario is calculated by:

$$Installed\ capacity = Area_{golf\ course} \times 79{,}2\frac{MW}{km^2} \times coverage$$

In GLAES, the turbines and PV modules are placed in a spatially explicit approach on the available land as shown in figure 1. Minimum distances between installations are taken into account. As this is a hypothetical analysis of areas equivalent to golf courses, minimum setbacks from other land uses such as residential areas are not considered. The analysis also considers only capacity, i.e., the benefits of sites with good wind conditions or high solar irradiation for electricity generation are not included.

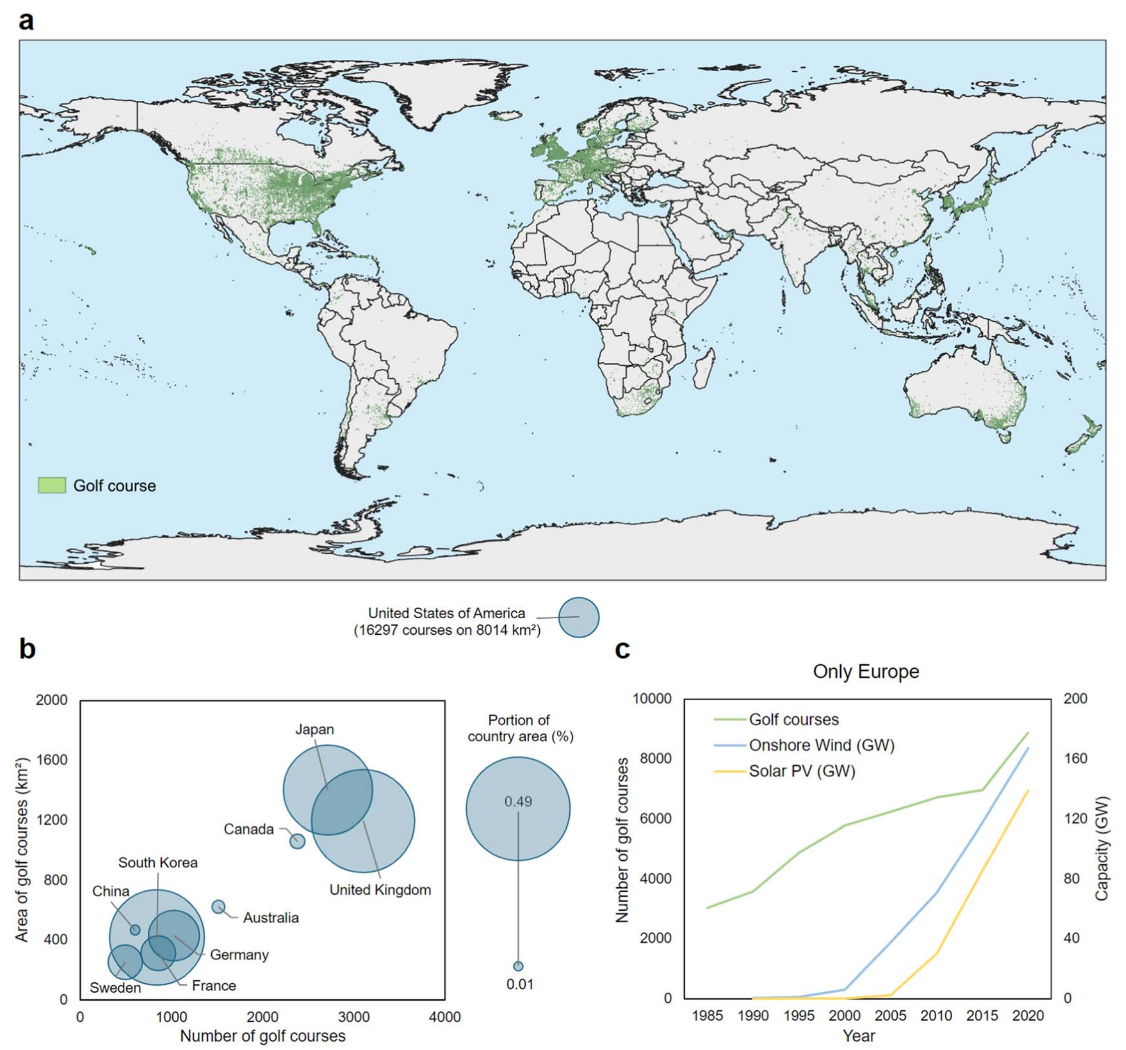

Figure 2. Global land-use of golf courses. (a). The locations of 38,427 golf courses worldwide, obtained from OpenStreetMap [39]. The areas of the golf courses appear larger in the illustration than they are in reality. This is due to the colored outline of the golf courses to make them visible on the global scale in the figure. (b). Area and number of courses for the top ten countries with the most courses, as well as their portion of the country's land area. The United States of America is shown outside the graph to better illustrate the differences between the other countries. c. Temporal development of the number of golf courses [30, 40, 41] and the capacity [42–44] of onshore wind and solar PV in Europe.

Results

More area for golf courses than renewables

In 2024, there were about 38,400 golf courses in the world [29], 80% of which are located in the top ten countries with most courses (see figure 2(a)). With over 16,000 courses, the United States of America tops this list (see figure 2(b)), followed by the United Kingdom (around 3,100) and Japan (around 2,700). With an average of approx. 0.8 km^2, the individual golf courses in China are the largest, with second-placed Japan, at 0.5 km^2, well behind and closer to the other countries. Moreover, golf courses occupy a considerable proportion of the land area within individual nations. In the United Kingdom, this figure reaches 0.49%, with South Korea and Japan following at 0.42% and 0.37%, respectively.

Although the data collection was challenging, it is possible to demonstrate at least for Europe that the number of golf courses has increased significantly since 1985 (see figure 2(c)). Despite the accelerated expansion of wind turbine and solar photovoltaics (PV) capacity in recent years, the individual technologies have not been able to reach the requisite area for golf course development in the top ten countries (except for China). Even when assuming a figure of 0.015 km^2 per MW, it is evident that the area dedicated to golf courses is still significantly larger in some countries than that allocated to utility-scale PV. To illustrate, under this assumption, there would be approximately 16 times more space for golf courses in Canada, six times more in the United Kingdom, or four times more in the United States of America. Germany also has a golf course area that is 1.25 times larger than the area used for utility-scale PV.

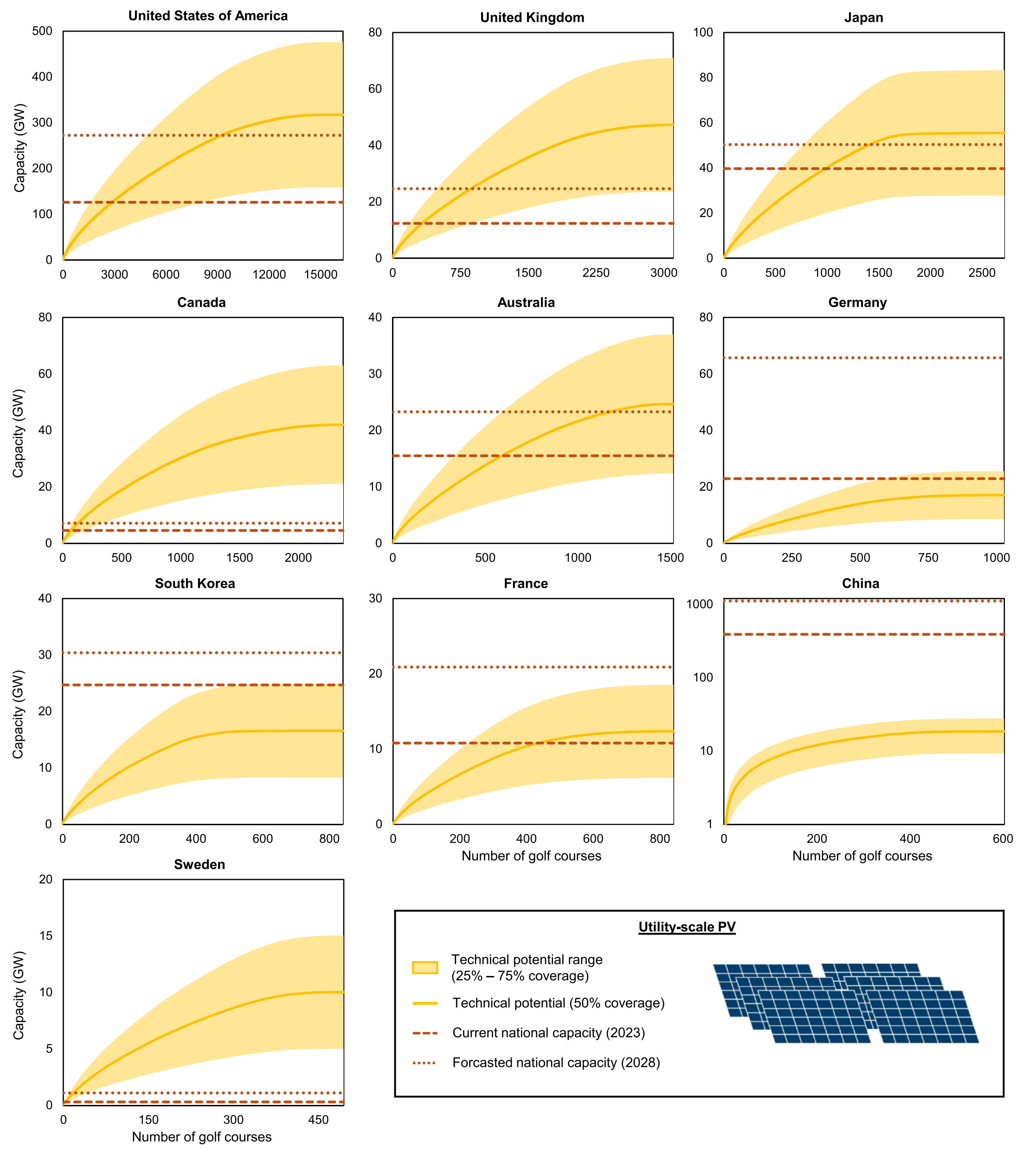

Figure 3. Technical utility-scale PV potential on golf courses in the top ten countries with the most golf courses in the world, as well as current installed and projected national capacity. The golf courses are shown in descending order of size (x-axis). Current figures for 2023 are based on statistical data [45–49] and projected figures for 2028 are based on the International Energy Agency's (IEA) 'Main Case' scenario [50]. Given that the existing and future capacities of China are significantly higher than the potential on golf courses, the y-axis is presented in a logarithmic format for this country.

The number of golf courses is also expected to increase in the future. More than 500 golf courses are currently planned or under construction in 88 countries around the world. The majority of these, 124, are being built in the United States, but Vietnam is also experiencing an upswing with 51 new courses, ahead of the United Kingdom in third place (27) [38].

Renewable energy potentials on golf courses

The top 10 countries could install between 281 to 842 GW of utility-scale PV on 25% to 75% of the golf course land area (see figure 3). The capacity for 75% coverage is slightly higher than the currently installed capacity in the countries [45–49], which totals 646 GW. However, the potential capacity of 842 GW is significantly higher than the currently installed capacity of 257 GW if China is excluded. In fact, the current capacity (excluding China) would even be exceeded if only 25% coverage were assumed on the golf courses. In the countries excluding China, even the capacity forecasts [50] up to 2028 (496 GW) could be achieved with 50% coverage (543 GW) through installations on golf course areas. Although this applies in total, it does not apply to Germany,

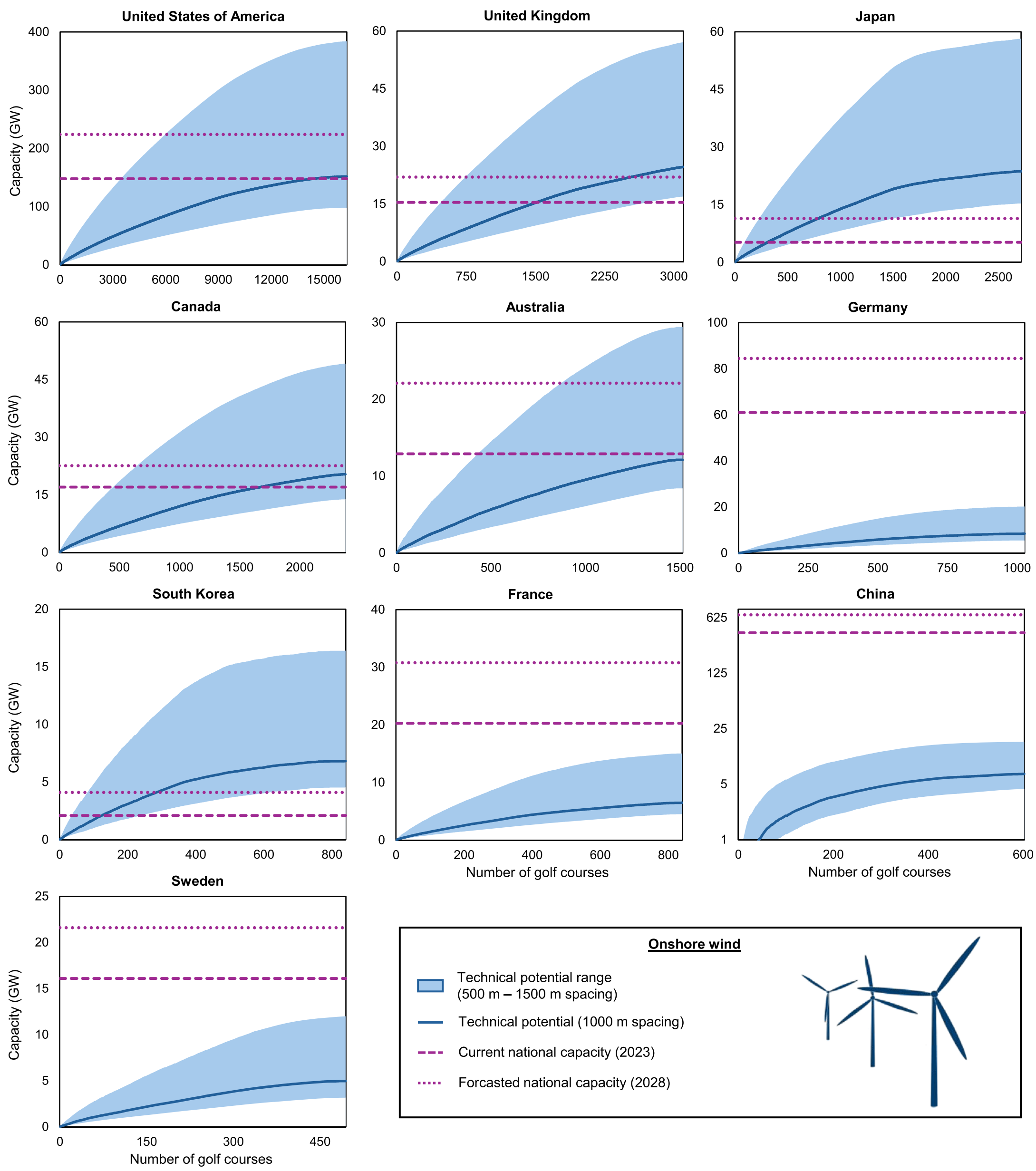

Figure 4. Technical onshore wind potential on golf courses in the top ten countries with the most golf courses in the world, as well as current installed and projected national capacity. The golf courses are shown in descending order of size (x-axis). Current figures for 2023 are based on statistical data [45–49] and projected figures for 2028 are based on the International Energy Agency's (IEA) 'Main Case' scenario [50]. Given that the existing and future capacities of China are significantly higher than the potential on golf courses, the y-axis is presented in a logarithmic format for this country.

South Korea and France, apart from China, where the area on golf courses would not be sufficient to meet the capacity projections.

Depending on turbine spacing (see Methods), the top 10 countries could alternatively install between 174 and 659 GW of onshore wind across the entire golf course area (see figure 4). At 702 GW, the current capacities [45–49] of these countries are above the maximum potential, although they are within the range of the potential at 298 GW if China is again excluded. The capacity forecast [50] of 443 GW in 2028 (excluding China) can also be achieved by golf courses overall, but not in Germany, France, China and Sweden.

When looking at individual countries, it is noticeable that the golf course areas in China, Germany and France in particular would be far from sufficient to achieve the ambitious expansion targets for renewable energy facilities. In addition, some countries prioritize the expansion of onshore wind (Canada and Sweden) and others the expansion of utility-scale PV (Japan and South Korea). The different prioritization has various reasons such as a strong solar lobby in Japan [51, 52] or limited policy incentives for solar PV in Sweden [53]. As a result, in these countries except for Japan, the area on the golf courses would be sufficient for the less prioritized technology but not for the prioritized one. By contrast, in countries such as the United States of America, the

United Kingdom, Japan or Australia, the capacity forecasts up to 2028 and beyond could comfortably be achieved with an area equivalent to the golf course land.

Discussion

This study does not advocate that golf courses should be completely replaced but is intended to provide a perspective on how much renewable energy systems could be installed on a comparable area. It is also important to note that the energy use on golf courses in the United States has decreased since the early 2000s, in particular due to the reduction of the maintained turfgrass acreage and the increased use of clean energy sources [54, 55]. Furthermore, some golf courses are located in the immediate vicinity of urban areas and would therefore not be entirely suitable for the installation of wind turbines. Two well-known examples are The Old Course at St. Andrews, Scotland, which is partially surrounded by buildings, and Augusta National in Georgia, United States, which is completely surrounded by the urban area of the city of Augusta. This means that actual planning would have to consider further aspects, such as minimum distances from certain land-use types or access to distribution and transmission infrastructure, which could significantly reduce the potential.

Conversely, golf courses, which often occupy vast areas of land and are accessible only through exclusive membership [6], highlight significant land use conflicts. The concept of energy justice argues that the benefits and burdens of energy supply and land use should be distributed equitably across society [56–58]. In this context, the general public could benefit if decision-makers decide to use these exclusive golf courses for renewable energy projects. Importantly, this does not mean that golf must be entirely abandoned. For instance, in South Korea, screen golf—a popular alternative involving indoor simulators-offers a more accessible, convenient, and affordable way to enjoy the sport compared to traditional outdoor courses [59]. The feasibility of converting golf course land, even in rural areas, has been demonstrated in the past. In Japan, for example, in a rural area in the Hyogo Prefecture, an entire golf course was converted into a solar park with 260,000 solar panels (125 GWh) [60].

Furthermore, the use of renewable energy would not necessarily prevent golf from continuing to be played on the courses. The deployment of wind turbines has the advantage over utility-scale PV of requiring less land for the actual installations (see figure 1) and no barriers to protect against golf ball collisions [61]. In the United States, for example, depending on the spacing between the turbines, an average of only between 1.1 (1,500 m spacing) and 4.3 (500 m) turbines would be installed per golf course. The hybrid utilization of the golf courses would probably also be possible with up to 25% area coverage by solar modules and could be a possible strategy for the future.

In this article, we were able to show that in some countries, more land is used for the exclusive recreational sport of golf than for utility-scale PV, and that an area the size of the golf courses would be sufficient to meet the medium-term development targets for onshore wind or solar PV in these countries. This provides a useful context for the land requirements of renewables, which are the subject of considerable debate. However, the long-term energy transition will require significantly more land for renewables than golf courses currently occupy. For example, a 100% clean electricity scenario for the United States of America in 2035 would require between 5,000–9,000 km^2 for onshore wind and 15,000–29,000 km^2 for utility-scale solar [62], which would account for up to 0.4% of the total country area. This would be up to 4.7 times more land than the golf courses currently account for in the United States, but still significantly less than the land for active oil and gas leases in 2020 (~105,000 km^2) [62]. In addition, in Germany, the complete decarbonization of the energy system would require at least 6% of the country's land area (21,450 km^2) for renewable energies. However, the 4% for utility-scale photovoltaics and 2% for onshore wind would also replace the 6.5% of land currently used for bioenergy crops [63].

Acknowledgments

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used the tools 'ChatGPT' and 'DeepL' in order to check grammar and spelling in a few places, and to make minor improvements to readability and style. After using this tool, the authors reviewed and edited the content as needed, and take full responsibility for the content of the publication.

ORCID iDs

Jann Michael Weinand https://orcid.org/0000-0003-2948-876X
Max Kleinebrahm https://orcid.org/0000-0002-6957-2379

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