Satellite images reveal major discrepancies between mapped and operating wind turbines in a hotspot of wind energy development

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Abstract ENG: Wind energy is an emerging challenge for biodiversity conservation, due to its impacts on habitats and species. Therefore, effective mitigation and zonation policies require accurate maps of operating wind turbines. However, the current pace of wind energy development raises doubts on how fast existing maps can become obsolete. We used freely available satellite imagery from Google to check the extent to which three open-source datasets about wind turbines in Sardinia (Italy), were still valid in 2023. These were a wind turbine dataset validated by Smeraldo et al. (2020) through satellite imagery, as well as Atlaimpianti and OpenStreetMap, two commonly used open-source datasets. We recorded 1,155 turbines in our study area, a value that was larger than that reported by Smeraldo et al. (n = 914) and much higher than that reported on Open Street Map (n = 766) and Atlaimpianti (n = 507). Moreover, based on projects submitted to the Italian Ministry of the environment, Sardinia could face the construction of 1,026 new onshore turbines over the next few years, an 88.8% increase. Our findings reveal that, wherever wind energy is expanding fast, like in the Mediterranean area, maps of existing infrastructures might be seriously biased. This bias could arise from either from partial coverage and the lack of data updates. Checking and validating existing maps should therefore be a priority for environmental agencies. Moreover, satellite imagery could pave the way for participatory mapping initiatives focusing on biodiversity hotspots.

Abstract ITA: La produzione di energia eolica è una sfida per la conservazione della biodiversità, a causa degli impatti che le turbine hanno su habitat e specie. Lo sviluppo di misure efficaci di zonizzazione e mitigazione passa quindi da avere una mappatura accurata delle turbine. Tuttavia, l'attuale velocità di espansione del settore dell'energia eolica solleva dubbi riguardo al reale livello di accuratezza delle mappe disponibili. In questo studio abbiamo usato delle foto satellitari Google, per verificare il livello di accuratezza che può essere raggiunto nella mappatura delle turbine onshore presenti in Sardegna nel 2023, usando tre dataset di pubblico dominio. Questi comprendevano: un dataset ad alta qualità sviluppato da Smeraldo et al. (2020) tramite immagini satellitari, il dataset ufficiale di Atlaimpianti e Open Street Map. Complessivamente, nella nostra area di studio abbiamo registrato un totale di 1155 turbine. Questo valore si è rivelato essere più alto di quanto riportato da Smeraldo et al. (n = 914), e completamente diverso dalle turbine presenti su Open Street Map (n = 766) e su Atlaimpianti (n = 507). Inoltre, analizzando i progetti sottoposti a VIA, e disponibili sul sito del Ministero per la Transizione Energetica, abbiamo rilevato che 1026 nuove turbine potrebbero essere costruite in Sardegna nei prossimi anni. Un incremento dello 88.8% rispetto alle turbine attualmente presenti. I risultati di questo studio indicano che, in quelle aree del mondo caratterizzate da un rapido sviluppo dell'energia eolica, come le isole del Mediterraneo, le mappe attualmente disponibili possono sottostimare significativamente il numero di turbine effettivamente presente nell'ambiente. Questa sottostima può essere causata sia da una incompleta centralizzazione dei dati relativi alla posizione delle turbine, che dalla mancanza di aggiornamento dei dati stessi. Pertanto lo sviluppo e la validazione di mappe accurate relative alle infrastrutture per la produzione di energia eolica dovrebbe essere una priorità per gli enti predisposti alla tutela delle risorse naturali. Inoltre, la disponibilità di immagini satellitari aggiornate e gratuite può aprire la strada ad operazioni di mappatura partecipativa delle turbine eoliche, in particolare nelle aree a maggior biodiversità.

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Introduction

In the last decade renewable energy development increased across Europe, to cut greenhouse gas emissions, meet climate targets (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en) and to diversify energy sources in an increasingly complex international scenario [1]. Wind energy production is a significant component of this change with wind farms nowadays accounting for approx. 8% of total energy production worldwide (https://www.iea.org/energy-system/renewables).

Wind energy development however poses many challenges for biodiversity conservation [2], due to the multiple impacts of wind farms on ecosystems and biodiversity. For terrestrial ecosystems these include habitat alteration [3], interference with animal behavior [4] and increased mortality from collisions with rotating blades [5][6][7].

Accurate and freely available maps about operating and planned wind turbines is therefore necessary to design effective policies aimed at mitigating their impacts on biodiversity [8]. While potential suitability maps are easily obtained from climatic data [9], mapping existing infrastructures is more challenging [10][11].

For these reasons, open-source datasets based on participatory mapping initiatives (e.g., Open Infrastructure, https://openinframap.org) or arising from specific research projects became increasingly used in conservation. However, these datasets can suffer from three main problems. First, by centralizing opportunistic records they might suffer from incomplete spatial coverage. Moreover, absent any legal requirement about data sharing regarding wind turbines, they can contain only publicly available coordinates. Finally, they might not be updated continuously and therefore can rapidly become obsolete.

These three bias can produce a gap between the number of mapped turbines and the number of turbines that are effectively present in a certain area. This gap is concerning, because for many species the impact of wind turbines is highly variable in space, with most collisions arising from few turbines positioned at particular locations [12][13]. Therefore, even a low number of non-mapped turbines can seriously misled zonation policies. In Europe this risk can be particularly high for areas like the Mediterranean, which are important biodiversity hotspots but also affected by global change [14].

Satellite imagery can address this gap. Satellite images improved steadily over the last few years [15], with many images nowadays being freely available to researchers, an aspect which could massively improve their adoption in the conservation sciences (es. wildlife counts)[16], including the large-scale mapping of renewable energy infrastructures [11].

In this study we used aerial pictures from Google Earth Pro to appreciate how three publicly available datasets truly reflect the current presence of onshore wind farms in Sardinia (Italy). Sardinia is a Mediterranean island undergoing a rapid expansion of renewables, but at the same time hosting many species and habitats which could be negatively affected by wind farms. Namely, we mapped wind turbines in 2023 and assessed differences with existing datasets. Our findings reveal a concerning situation and call for the use of satellite imagery for large-scale validation initiatives aimed at updating existing maps.

Methods

We mapped onshore wind energy development in Sardinia, the third largest island of the Mediterranean Sea. Due to the prolonged presence of wind throughout the year, Sardinia is highly suitable for wind energy production [17], with more than 3 GW of potential power (https://www.anev.org/wp-content/uploads/2022/07/Anev_brochure_2022.pdf). However, at the same time the island hosts both fragmented populations and endemic subspecies of birds and bats that are potentially vulnerable to collisions. Among birds, these include approx. 332-378 Griffon Vultures (*Gyps fulvus*)[18] and the last Italian declining population of Little Bustards (*Tetrax tetrax*)[19], two species which are prone to collide with wind turbines due to their visual field [20]. Moreover, Sardinia hosts the critically endangered endemic Sardinian Long-eared Bat (*Plecotus sardus*)[21], a decreasing population of red kite (*Milvus*

milvus)[22], a small reintroduced population of Bonelli's eagle (*Aquila fasciata*)[23] and the endemic Corsican finch (*Carduelis corsicana*).

In Italy wind farms are subjected to a preliminary environmental impact assessment and must comply with zonation policies that prevent their construction on Natura 2000 sites, protected areas and ecological corridor. However, there is no legal requirement about the design [24] and methodology [25] of monitoring schemes, nor about mitigation measures such as selective stopping [26] or blade painting [27]. Wind farms with a power greater than 30 MW are authorized by the Ministry for the Environment, while smaller wind farms by regional environmental authorities. Noteworthy, contrary to other countries (e.g., Finland)[28] there is no governmental initiative to collect and share data about operating turbines.

Between December 2023 and February 2024 we collected data about wind turbines in Sardinia, from three publicly available datasets: OpenStreetMap, Atlaimpianti and the data provided by Smeraldo *et al*. (2020) [29]. OpenStreetMap (https://www.openstreetmap.org) is an open-source mapping service, proposed as a framework to map wind energy development globally [30] where wind farms are georeferred by voluntary collaborators. Atlaimpianti (https://www.gse.it/dati-e-scenari/atlaimpianti) is the official wind energy atlas for Italy, maintained by GSE, a national authority for electric energy. Wind turbines on OpenStreetMaps have been updated continuously by volunteers, until early February 2024, while turbines on Atlaimpianti faced their last update in 2017. Finally, Smeraldo *et al*. [29], validated multiple pre-existing datasets through satellite imagery, to map wind turbines operating in Italy until 2020 and produce a national risk map for the Black Stork (*Ciconia nigra*).

We used Google Satellite to validate these three datasets, with respect to wind turbines that were present in 2023. Google offers high-resolution satellite pictures from Airbus (https://intelligence.airbus.com/newsroom/satellite-image-gallery/), which are available on a yearly basis. In our study area, the most recent pictures had been acquired in September/October 2023. For each one of the three datasets we generated a buffer of 5 km around each turbine, then we generated a vector grid of 1km, and for each cell of the grid we checked the number of turbines. By using a radius of 5 km we also accounted for potential errors in the coordinate of each turbine, as well as for the fact that turbines could have been built around pre-existing ones. It must be noticed that, by using our 5 km buffer, we did not cover the entire Sardinia, but rather an area of approx. 8,123 km^2 (approx. 33.8% of it), that corresponded to hotspots for wind energy development (Fig. 1). This approach was deemed suitable, as we did not aim to make inference about the total number of turbines in the island, but rather to detect discrepancies with respect to pre-existing datasets.

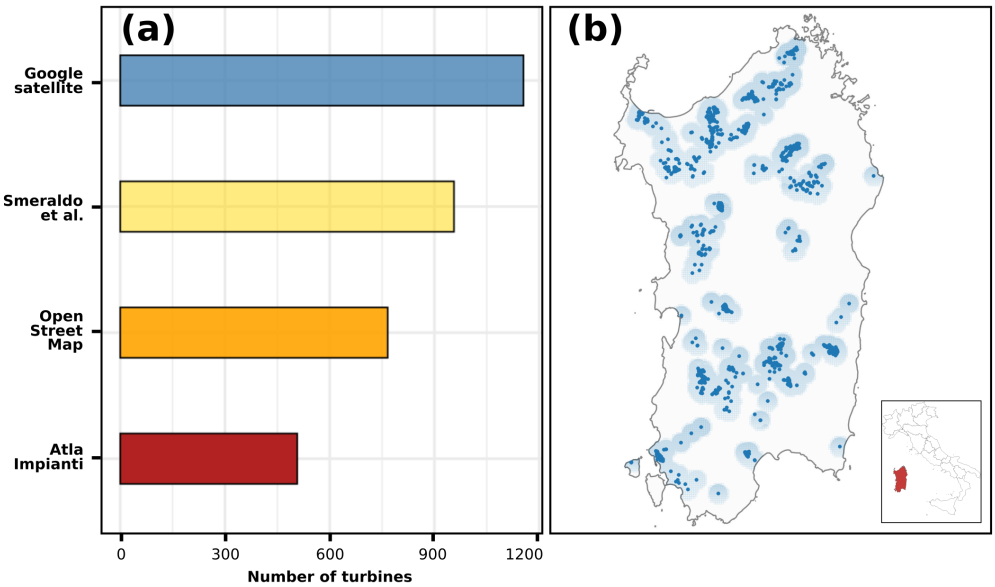

Figure 2: Panel (a): total number of turbines detected with Google Satellite, compared to that of the three datasets that were tested. Panel (b): overview of Sardinia with the location of turbines that were found through Google Satellite (blue dots) as well as the area that was covered (shaded area).

Results and Discussion

By using freely available satellite pictures from late 2023 we recorded a total of 1,155 turbines in our study area. This number of turbines was significantly higher (+ 26.3%) than that reported by Smeraldo *et al.* (n = 914) and was enormously higher than the number of turbines reported on Open Street Map (n = 766, + 50.7%) and on Atlaimpianti (n = 507, + 127.8%)(Fig.1).

These findings raise serious concerns about the quality of existing data about onshore wind energy. Particularly for those countries whose governments did not implement public mapping initiatives, and located in areas where the development of renewables is going fast. Although many studies are proposing open-source datasets for research and management [30] and integrate them with other data (e.g. animal movement) [31], we raise caution against the indiscriminate use of these data in conservation, absent their validation on the field. At least in hotspots of wind energy development, existing maps of wind energy infrastructures can be seriously biased. For example, even high-quality data obtained from satellite, like those collected by Smeraldo *et al.* [29] could become obsolete in only 3 years.

Neglecting these discrepancies can have devastating effects on wildlife conservation. For example, Voigt *et al.* [32] estimated that each wind turbine might kill up to 70 bats per year. By assuming similar values for our study area, population viability analysis for bats using data from Smeraldo *et al.* [29], Open Street Map or Atlaimpianti, would underestimate between 16,870, and 45,360 bat fatalities every year. Although these overall values could be lower, due to differences in the distribution of bat species or differences in bat behavior between Sardinia and Germany, it is easy to see how underestimating the real number of turbines could significantly bias estimated mortality rates and in turn affect population viability analyses [33]. Moreover, ignoring the real number of turbines can also lead local authorities to underestimate their cumulative impact on ecosystems functionality and animal behavior [34], and to miss potential ecological traps [35].

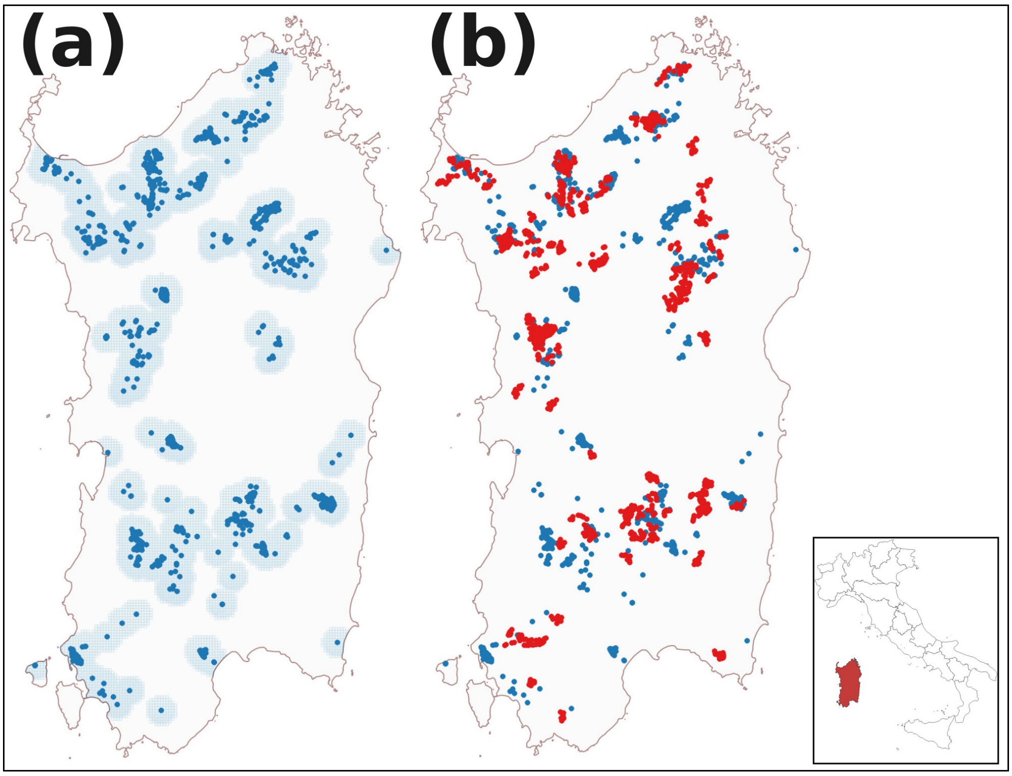

Figure 2: Panel (a): overview of turbines that were identified in 2023 (blue dots, n = 1,155), altogether with the area that was checked on Google Satellite (shaded area). Panel (b): overview of turbines that were identified in 2023 (blue dots), altogether with turbines who are under evaluation by the Ministry for the Environment (red dots, n = 1,026).

Although our findings are limited to a single study area, considering the current pace of onshore wind energy development in many areas of the world, we believe that discrepancies between mapped and operating wind turbines might be greater than previously though. Updating existing maps of operating wind farms and make this data transparent and freely available (e.g., FAIR)[36] should therefore be a priority for policymakers and environmental agencies. Furthermore, considering the current pace of wind energy development, we also believe that it will be fundamental to map ongoing projects for wind energy development: based on data from the Italian Ministry for the environment (https://va.mite.gov.it/it-IT), Sardinia might face the construction of 1,026 new turbines over the next few years, a 88.8% increase (Fig. 2, Fig. 3). Navigating an environmental change of this magnitude without updated and easily accessible spatial data will simply be impossible.

In conclusion, our findings from a hotspot of wind energy development in the Mediterranean raise serious questions about the accuracy of existing maps of wind turbines. In areas of the world where wind energy development is going fast, the number of non-mapped wind turbines might be substantial, with potentially serious consequences for biodiversity conservation. Updating existing maps, and creating accessible data is therefore a global priority for environmental agencies, but freely available satellite imagery could also empower conservation stakeholders, by allowing them to independently map wind energy development at the local scale.

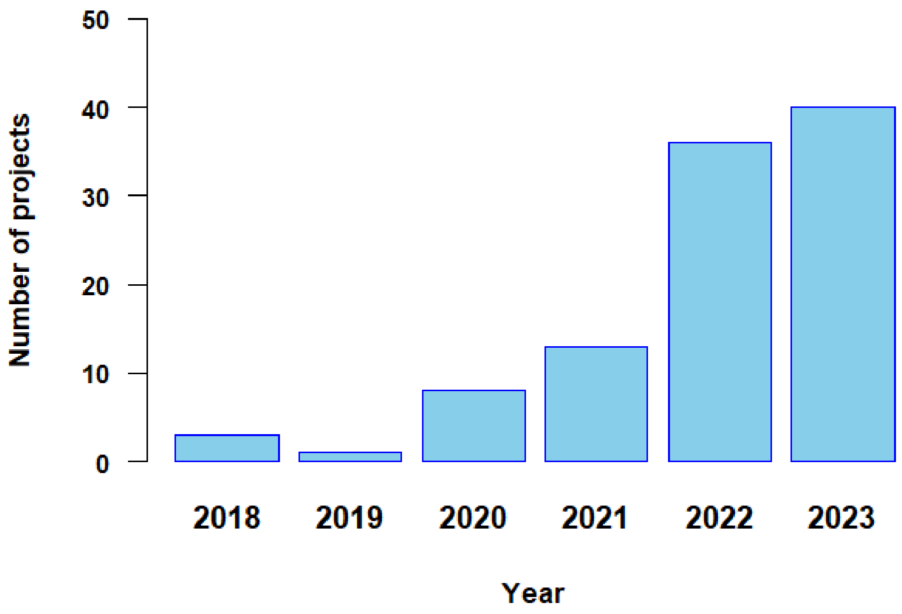

Figure 3: Number of projects about new onshore wind farms in Sardinia, submitted to the Italian Ministry for the Environment, between 2018 and 2023.

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Data availability statement

The location of wind turbines that we detected through Google Satellite is available at https://osf.io/pr984/

Conflict of Interest

The authors declared no conflict of interest.

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