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Evaluating ecosystem service trade-offs with wind electricity production in Switzerland

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ABSTRACT

In Switzerland, different types of land use, including electricity production, compete directly for little available space. The Swiss energy strategy relies heavily on incorporating renewable sources of electricity, including wind. In order to ensure long term efficient, socially acceptable and sustainable electricity production, land-use conflicts should be addressed and properly managed through a comprehensive and balanced process. We propose a method to apply the ecosystem service (ES) approach combined with an optimisation tool to tackle the complex problems posed by wind electricity development in a topographically challenging landscape. Marxan was used as optimisation software to evaluate, assess, and quantify the trade-offs between ES provisioning and wind electricity production. Expressing different ES in comparable units and evaluating the costs to the system when these are lost versus the benefits gained from wind electricity production generated an output of possible solutions. When compared to similar studies modelling wind electricity output that avoid negative interaction with ES throughout Switzerland, the current results using the optimisation tool Marxan suggest a solution requiring 13.5% fewer turbines (1903 in an average solution) in order to produce 12 TWh/yr of wind generated electricity and 18% fewer turbines (842 on average) to produce 5 TWh/yr. Thus, using optimisation software can lead to more efficient spatial planning solutions. Our methodology can be applied toward cost-effective renewable energy development that minimises opportunity cost in terms of foregone ES provisioning.

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1. Introduction

Switzerland aims to replace a large portion of its electricity supply with renewable sources (such as wind) in order to make up for the shortfall from the planned phaseout of its nuclear reactors [1]. With an ambitious aim of producing 74% of its electricity via renewable technologies by 2030 (50% of which will be from hydro power), and a goal of 93% renewable-sourced electricity (around 25 TWh/yr) by 2050, Switzerland is faced with an immense planning challenge. Already, there is evidence that the land use changes associated with renewable energy production will cause conflict with ecosystem services (ES) provided by the landscape, resulting in alterations in the amount, location, and quality of these services [2,3]. Additionally, competition for limited land resources in a densely populated country with high landscape awareness, such as Switzerland, may affect the future deployment of renewable energy technologies [4,5]. To mitigate this conflict, this small country must make trade-off decisions on where to place wind farms and other renewable electricity installations in order to maximise benefits (electricity production) while minimising costs (loss of services provided by the landscape).

In general, energy planning has difficulty integrating ES due to a variety of factors [6] but recent progress has been made toward spatially explicit solutions in this regard [7]. Calvert and Mabee [8] and Palmas et al. [9] stress that appropriate siting of renewable energy projects, including wind, can help mitigate the compromise to ES provisioning by the landscape through increased spatial efficiency. To better understand this spatial planning problem, the ES approach has been applied to assess a range of environmental issues associated with expanding renewable energy exploitation [10]. This technique uses the spatial dimension of ES expressed in certain units to address, describe, and predict the relationship between ecosystems and human activities, even when more traditional monetary-based assessments fail to do so [11–13]. The ES approach allows both extractive and non-extractive anthropogenic uses to be assessed [14], along with the perceived value of environmental aspects, such as aesthetics, and how these may affect policy decisions relating to wind electricity production [15].

The ES approach helps to outline the relationships between ES and abiotic outputs generated by the landscape, such as the production of electricity through renewable technologies [16]. The direct competition for space between this abiotic output and ES provided by the same landscape generates conflict, a relationship that has been the focus of several recent studies [4,8,10,15,17]. Assessing and evaluating this conflict is a powerful tool to help bridge the gap between science and policy in a field that is becoming increasingly important as governments turn to developing renewable sources of energy production.

Hastik et al. [10] developed a set of broadly applied conflict matrices based on a literature review to outline the key ES impacts resulting from conflict with renewable energy projects in the Alps region. Impacts of wind electricity generation were local and user-oriented, with the greatest effects on wildlife and aesthetics. Jongbloed at el. [18] classify the interactions between offshore wind farms and other uses of the marine landscape (including ES provisioning) into varying degrees of support, co-existence or conflict. Kienast et al. [19] used a systematic ES mapping approach to identify areas of low or no conflict with wind or solar electricity production. They then calculated the energy output resulting from the conversion of these limited areas, while their conflict-minimising strategy avoided areas of high conflict. Huber et al. [4] assessed conflict in a similar manner but included land use change models and technological advances to assess future conflict between ES provisioning and abiotic outputs. In particular, electricity production from wind is predicted to result in economic impacts with regards to tourism or species protection. By overlaying ES maps of Switzerland to identify conflict, Kienast et al. [17] considered the overall "conflict-free" power production resulting from several renewable sources. They concede that restricting renewable energy development to areas of low ES conflict is insufficient to meet Switzerland's future energy strategy. Given the required output of this changing electricity mix, there is a clear need to include areas with variable levels of conflict in spatial planning of electricity production.

Although previously applied to help mitigate land use conflicts in spatial planning, management, and decision making [20–24], the notion of trade-offs between ES and renewable energy is a relatively new field, with the few relevant studies having been reviewed by Kienast et al. [19]. Other studies interpreted trade-offs between using land for different types of renewable energy production, but their analyses were limited by models that lack the ability to offer a mix of energy carriers in their solutions [8,23]. In their review, Seppelt et al. [20] demonstrate the importance of optimisation combined with scenario analysis in order to help understand the trade-offs between ES and land use. Lester et al. [24] and White et al. [25] use efficiency frontiers to illustrate trade-offs between ES and create simple models in an attempt to find an optimal solution in a marine spatial planning environment. However, we know of a sole study to attempt a spatially explicit evaluation of the trade-offs between ES provisioning and (offshore) wind electricity production, made by Göke and Lamp [26]. Their methodology allows for the comparison and combination of different ES and is further enhanced by using optimisation software that evaluates conflicts in such a way that the relevant ES can be weighted. The present study incorporates some of the ideas and methods from this marine study and transposes them into a terrestrial setting where the trade-off with ES will be assessed differently. By further incorporating information about these trade-offs into a decision-making framework, the end result is the balance between the costs borne by the entire system and resources gained by the installation and operation of renewable energy projects, such as wind farms. Before these trade-offs can be properly incorporated into a decision-making framework, however, they must be assessed and evaluated.

In the present study, we propose a method to apply the ES approach in a spatially explicit setting combined with an optimisation tool to evaluate, assess, and quantify the trade-offs resulting from wind electricity development. Marxan is optimisation

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