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Conflicts between decentralized renewable electricity production and landscape services – a spatially-explicit quantitative assessment for Switzerland

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Abstract

The production of decentralized renewable electricity often collides with the provisioning and regulating of cultural services of the landscape. In this paper, we operationalize the landscape service approach and generate conflict maps between three renewable energies (wind; PV; forest biomass) and six competing landscape services (nutrition and materials; aesthetics; physical and experiential interactions; heritage and symbolic content; water and liquid flows; lifecycle maintenance, habitat and gene pool protection). Media content analysis and expert interviews were used to ground-truth the national conflict maps in several Swiss regions and to understand to what degree the national conflict assessments match the regional and local perceptions of these conflicts. In Switzerland (approximately 40,000 km²), biomass from forests is by far the least conflicting renewable energy, followed by PV on roofs. For the latter, 68% of the technically feasible energy potential can be generated with low conflict, and more is expected with new materials. Wind has a high conflict potential: only 12% of the technically feasible energy potential is low conflict. PV on open land, marginal land and shrubland, is—at the moment—not currently feasible in Switzerland. The accuracy of such conflict assessment is sufficiently high to estimate the proportion that socially sustainable energy could cover of the overall energy gap of 22-25 TWh/year caused by the phase-out of Swiss nuclear plants by 2050. Low-conflict solar energy from rooftops could contribute approximately 30% of the required 22-25 TWh/y. Intensified wood production and wind energy could add another 40%. The gap of approximately 30% must come from undisputed energy sources such as biogas from recycled organic material, from centralized renewable energies such as geothermal or large hydropower, or from new or technologically improved renewable energies. The presented decision support tools are a timely contribution to the designation of legally binding zones for renewable energy production.

Keywords: land-use conflict, GIS, landscape service mapping, Switzerland

1. Introduction

In the aftermath of the nuclear disaster in Fukushima (spring 2011), the production of decentralized renewable electric energy (wind, small hydropower, photovoltaic, and biofuel energy) ranks high in the agenda of many countries. However, pioneers in the field (e.g. summarized in Wüstenhagen and Menichetti, 2012) emphasized the use of renewable energies long before the Fukushima accident in order to fight climate change. At the European scale, the hotspots of renewable energy potential are located in the Atlantic regions (wind), the Mediterranean (solar: photovoltaics (PV) and solar heat; to some degree wind), and Central and Northern Europe (biomass). PV has increased considerably in the European Union energy market, i.e. from installed 2.2 GWp in 2005 to 86.7 GWp in 2014 (Euroobserver 2007-2015). Germany, Italy, and Greece are the major producers. Installed wind electricity potential in the EU & candidate countries and EFTA has increased from approximately 65,700 MW to approximately 134,000 MW between 2008 and 2014, which would – in a normal wind year – provide 284 TWh, approximately 10% of Europe's electricity demand (EWEA 2009-2015). The main producers are currently Spain, the UK, Germany, France and Italy.

There is broad consensus that electricity production from decentralized renewable resources is sustainable (Wüstenhagen and Menichetti, 2012). However, devices with high land consumption often generate major landscape¹ changes, and trigger conflicts with current land use. In principle, land managers have three options when siting renewable energy devices:

- avoid conflicts with existing land use by placing power generators in the least conflicting zones;
- generate multifunctional landscapes by fostering synergies or co-existence (Jongbloed et al. 2014), e.g., between wind and agricultural production;
- 'promote' energy regions where even the broad use of land-consuming renewable energies represents a region's democratically authorized commitment to both economic prosperity and sustainability.

All three approaches can be observed concurrently, depending on the planning culture of the country concerned. Whatever management option is adopted, however, research-based strategies for minimizing conflicts with other land uses are decisive. Since unsolved land-use conflicts and legal uncertainty might easily paralyze needed investment, spatially explicit conflict-mitigating strategies need to be implemented in the spatial planning of sustainable energy devices. Switzerland is in the midst of such a planning effort: cantons (internal state jurisdiction level) must revise their master plans in order to accommodate zones for renewable

¹ The term "landscape" is used to describe "a medium-scale excerpt of the globe's surface, shaped by nature and humans and perceived by people" (Kienast et al., 2007; Müller et al., 2011).

energy production. Our presented approach is therefore timely and enables planners to base their decisions on sound scientific and transparent decision support tools. Before describing the present study, we define important terms, explain why certain energy types are excluded in the assessment, and review literature relevant to the present topic.

1.1 Definition of “landscape services” and other terms used in the present paper

A land-use conflict is defined as “a situation in which involved parties or individuals have incompatible interests concerning the use of a certain piece of land” (von der Dunk et al., 2011, 2015). The “incompatible interests” concerning land-use go beyond land-use in a strict sense, involving other benefits of the land, such as aesthetics. Wind turbines, for example, have an impact on scenic beauty and perceptions regarding the value of landscapes. Since the best wind conditions usually occur on ridges or off-shore, wind turbines can also lead to conflicts with wildlife such as birds, bats, or fish (Göke and Lamp, 2012; Kienast et al., 2014). Because of these diverse land benefits, we claim that the “incompatible interests” are best framed by using the concept of “landscape services” (Helfenstein and Kienast, 2014; Kienast et al., 2009; Termorshuizen and Opdam, 2009). The term “landscape services” is used instead of ecosystem services² (Potschin et al., 2016) to express that (1) services are context-sensitive and do not only depend on the characteristics of a patch of land but also on its surrounding landscape; (2) services also refer to the cultural and perceived environment, which is best expressed with the term “landscape”; and (3) “landscape” is a widely accepted concept in spatial planning (Kienast et al., 2007; Swanwick, 2002, European Landscape Convention ELC (Council of Europe, Web Resource)).

As shown by Dijkman and Benders (2010), the conflict potential between decentralized renewable energies and landscape services increases with decreasing energy density of the energy resources. Energy density is defined as the amount of land consumed per unit energy (Dijkman and Benders, 2010).

1.2 Selected energy resources and landscape services

This paper examines landscape-sensitive energy resources only, i.e., resources with generally low energy density/m², such as wind, PV and biomass (Denholm and Margolis, 2008; Dijkman and Benders, 2010). Consequently we exclude large hydropower plants (> 10MW). In Switzerland, new and modernized large hydropower plants are expected to contribute between 3-4 TWh/y by 2050 (EAWAG, 2011). Small hydropower plants (> 10MW) are excluded here

² “Ecosystem services are defined as the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, scientific, spiritual, and other nonmaterial benefits.” (Costanza 2016)

since the ecological footprint is too large compared to the energy output, at least for Switzerland (EAWAG, 2011). Out of the biomass-related options, we only consider biomass conversion from forest biomass. Biofuels from arable land has a very limited potential in Switzerland since it is not wanted politically (competition with food) and thus no economic incentives are given to farmers. Biogas from recycled organic material in Switzerland has an estimated potential of 1-2 TWh/y (BFE, 2050). Due to the fact that it is based on disposable or recycled material, it is undisputed and has no landscape-related conflicts. Therefore, it is not treated in our report.

Out of the many conflicts between decentralized renewable energies and landscape services, we concentrate on conflicts with six services which are relevant to the landscape, namely (1) nutrition and materials, (2) aesthetics, (3) physical and experiential interactions, (4) heritage and symbolic content, (5) water and liquid flows, and (6) lifecycle maintenance, habitat and gene pool protection. All services are named using the official classification of ecosystem services (CICES V4.3, Haines-Young and Potschin, 2013). In line with this classification, renewable electricity production is not considered a landscape service but an ‘abiotic output’.

1.3 Review of relevant approaches in the research field

The use of ecosystem or landscape service concepts to frame land-use conflicts with renewable energy sources is still in the early stages, except for biomass-related energy studies. The latter have reached an advanced stage with publications by Dale et al. (2016), Gissi et al. (2016), Lupp et al. (2015), and Papathanasopoulou et al. (2015). The successful implementation of the service approach in biomass-related energy studies has been facilitated by the fact that mapping of competing provisional services is relatively easy. Other services such as aesthetics or heritage—which present major conflicts with services such as wind energy—are far more complex to map. This may have had an adverse effect on using the service approach for renewable energies other than biomass. Thanks to the pioneering work of Hastik et al. (2015), a comprehensive list of possible conflicts and trade-offs between most sustainable energy sources and ecosystem services is available. Consequently many of their conflict tables are adapted in the present paper. However, their paper does not operationalize the services and conflicts into easily applicable maps, thus rendering the estimation of “conflict”-free energies for larger areas nearly impossible.

Apart from Hastik et al. (2015), two innovative publications by Calvert and Mabee (2015) and Angelis-Dimakis et al. (2011) should be mentioned in this brief review. Both papers suggest a hierarchical approach to identify mutual lands, i.e., land that has a sufficient energy potential which can be technically exploited, but has no legal or social restrictions that would impede its use for wind and solar power or other renewable energies. Calvert and Mabee (2015) and Angelis-Dimakis et al. (2011) suggest the use of mathematical models to predict how various

renewable energies will compete for mutual land. Crucial drivers in these models are accessibility, energy market (e.g., price for electricity produced by hydro, solar, or wind power) and corresponding land-energy trade-offs (e.g., land uptake by renewable energy type). One might argue that many of the environmental layers used by Calvert and Mabee (2015), Angelis-Dimakis et al. (2011), or Aydin et al. (2013) to exclude renewable energies are indeed proxies for landscape services, even though they are not explicitly conceived as such. Nevertheless, their research does not really offer straightforward guidelines for land managers on how to assess trade-offs between energy production and landscape service provision.

The use of spatially-explicit multicriteria analysis is suggested by Watson and Hudson (2015). For each land parcel (not only for the ‘left over’ parcels resulting from a filtering approach), energy potentials, as well as technical, legal, and social restrictions, are combined to generate suitability maps. The most suitable sites are then selected based on user-defined suitability thresholds. The importance of optimization combined with scenario analysis to find optimum trade-offs between ecosystem services and (offshore) wind devices is shown in Lester et al. (2013), White et al. (2012) and Göke and Lamp (2012). The latter uses MARXAN, an optimization software originally designed for reserve design and natural resource management. Recently the field of land-use conflict assessment has broadened considerably. It currently focuses on a wide range of siting conflicts triggered by, for example, open-pit mining (Helwege, 2015) or externalities of wind energy plants (Josimovic & Pucar, 2010). Further, there is increasing research on conflict resolution (Tudor et al., 2014), which complements the established handbooks of environmental conflict management (Susskind et al., 1999). In the field of landscape conflict mitigation and consensus building, considerable advances have been made by Buchecker et al. (2010). In an effort to establish good governance structures for wind farm siting in Germany, Juerges and Newig (2015) provide a framework for understanding scaling conflicts, such as at what spatial and governance scales decision making is most appropriate. Their findings combined with a research-based design of sustainable energy landscapes, as suggested by Dale et al. (2016), could eventually lead to strong energy regions where a high level of commitment to support a sustainable energy future is present among inhabitants.

1.4 Aim of the paper

This paper aims at reducing the knowledge gaps mentioned in section 1.3 by operationalizing the pioneering analysis of Hastik et al. (2015). We show how landscape service mapping can help identify conflict-poor sites for renewable electricity production. The study is spatially explicit, i.e., all energy calculations are based on service and energy maps covering an area of 40'000 km². The analysis consists of four pillars: *First*, a straightforward logical framework for

identifying potential conflicts between renewable energy and existing landscape services is established. This pillar is used by Hastik et al. (2015) as a baseline. *Second*, land with and without conflicts with decentralized renewable energies is geographically located by overlaying energy potential maps with landscape service maps. *Third*, the conflict maps are ground-truthed and evaluated through expert interviews and the analysis of media reports. *Fourth*, total energy amounts for low, medium, and high conflict locations are calculated and compared with the Swiss Government's 'Energy Strategy 2050' that aims to generate 22-25 TWh/yr from decentralized renewable energies to replace Swiss nuclear power plants.

2. Material and methods

2.1 Study area

The current assessment is performed on approximately 40,000 km² of mountainous and hilly terrain covering all of Switzerland. The climate is temperate humid, but conditions range from intra-alpine dry and continental (Central Alps) to oceanic (Northern Alps, Jura Mountains, Plateau). The Southern Alps are characterized by an insubrian climate with relatively mild and dry winters, and warm-humid summers. Roughly 15,000 km² of the land mass is agricultural (Leifeld et al. 2005). Most settlements and agriculture areas are concentrated on the Plateau and the inner Alpine Valleys which comprise approximately one third of the total area.

2.2 Geographical and climatological prerequisites of electricity production in Switzerland

The Swiss electricity production in 2013 amounted to approximately 68 GWh, out of which approximately 40 GWh stemmed from large hydropower, approximately 25 GWh from nuclear, and the rest from thermic and decentralized renewable energies such as solar, wind, and biomass power. The government's energy policy calls for a replacement of nuclear power by decentralized renewable energies, a slight increase in large hydropower (>10MW), and a considerable effort to save energy. Preliminary studies show four distinct regions for decentralized renewable energies in Switzerland:

- the western hilly region (Jura mountains, up to 1,600 m asl) with – for Central Europe - a relatively high and constant wind potential and easily accessible sites;
- the Plateau and the Pre-Alps with high biomass stored in forests. Mountain forests are still increasing in area due to land abandonment;
- the Plateau and the intra Alpine valleys with more than 450 km² of building surface for solar panels and approximately 1,700 km of motorways for solar panels on embankments (not considered in this study). Additionally, there is a large portion of land adjacent to

industrial complexes and infrastructure which could be used for PV on open land, owing to its low value from the perspective of landscape aesthetics;

- the high mountain ridges in the Alps that have considerable wind potential. Many of these peaks, however, are expensive to access, climate is harsh, and site maintenance is costly.

This region could provide a considerable amount of partially abandoned, marginal land for PV.

2.3 Spatially-explicit calculation of energy potential, landscape services, and mutual conflicts

Conceptually, our approach is a mix between the methods presented by Calvert and Mabee (2015), Angelis-Dimakis et al. (2011), Aydin et al. (2013), and Jongbloed et al. (2014). In contrast to their assessments, and in line with Hastik et al. (2015), we apply a systematic landscape service mapping approach to identify areas having no or very few potential conflicts with renewable energies. Our approach is strictly based on a conflict-minimizing strategy, i.e., if serious conflicts are predicted, the site is not included in the energy assessment.

2.3.1 Technically feasible areas for wind energy production (TFAW)

The amount of wind energy that can technically be produced was calculated by following the approach of Meteotest (2012). We included all areas with a mean wind speed of greater than 4.5 m/s (100 m above ground), stable soil, and a slope of < 20%. We then excluded lakes, military areas, and all strictly and non-negotiable³ protected nature conservation and landscape protection areas. Settlements were buffered with a buffer of 300 m (federal regulation). Accessibility was considered by excluding areas which are located farther than 500 m from any road > 2 m in width. A map showing the technically feasible areas (TFAW) for wind production is presented in Figure 1. In order to calculate the maximum number of wind turbines that can be installed on suitable land patches, we followed Lütkehus et al. (2013). They suggests a minimum distance between wind turbines of 456 m (for turbines with a hub height of 120 m). A theoretically best use of suitable sites would thus be to place wind turbines in hexagons with an edge length of 263 m, a diagonal of 527 m, over an area of approximately 180,000 m². If two turbines were placed at the center of adjoining hexagons, they would lie 456 m apart, the recommended minimum distance between turbines (Egli et al, submitted). In reality, wind turbines would require less space since they are optimized in groups. We used an area of 150,000 m²/turbine and a mean yearly output per turbine of 5 GWh/y to convert suitable area to energy output. In the course of the proposed procedure in this paper, the technically feasible area (TFAW) is further reduced by subtracting conflicting sites (see section 2.3.6).

³ mire landscapes of national importance; raised bogs (Hoch- und Übergangsmoore) of national importance; fenlands (Flachmoore) of national importance; **core zones** of the national park (Nationalpark) and the entire area of nature discovery parks (Naturerlebnispark); cantonal protected areas

2.3.2 Technically feasible areas for solar energy production (TFAS)

For solar energy, we calculated energy potentials for solar panels on roofs and open land.

PV on roofs: The maximal potential of solar energy produced by photovoltaic panels on roofs was determined following an approach by Meteotest (2012). Calculations were performed for all buildings mapped in TLMswissBUILDINGS^{3D}1.0. To assess the technically feasible areas for solar energy production (TFAS), percentage reductions of the total roof area were made based on field results from pilot regions (Meteotest, 2012). In line with Meteotest (2012) the following assumptions are decisive for our study: a) For buildings with a projected area of > 1,000 m², we assumed that 80% of them have flat roofs, 20% steep roofs, and that 20% of the roof area is unsuitable for panels (disturbing structures, aspect of roof). The percentage of realized PV on large roofs (> 1,000 m²) was assumed to be 60%, with 40% remaining unused due to economic reasons. b) For small buildings (< 1,000 m²), we assumed that 40% of them have flat roofs and that 50% of the roof area is unsuitable. The percentage of realized PV was assumed to be 40%. Furthermore, suitable area was reduced by 50% for both steep and flat roofs because of unfavorable orientation (steep roofs) and the required distance between inclined panels (flat roofs). A map showing the technically feasible areas for solar production on roofs is shown in Figure 1. In the course of the proposed procedure in this paper, the technically feasible area (TFAS) is further reduced by subtracting conflicting sites (see section 2.3.6). To calculate energy budgets, the suitable area was multiplied by global irradiation (Meteotest, 2012), and the efficiency of solar panels was set at 20% to assess PV electricity production. This efficiency is likely to be reached within the next 5-10 years.

PV on open land: The production of solar energy with photovoltaic panels on open land in Switzerland is heavily contested because of nature protection, accessibility, and cultural heritage. We generated two maps featuring land uses that could host PV:

- PV on shrubland and pastures. We selected shrubs, abandoned pastures, and farm pastures from the Swiss land survey 2004/09 (BFS GEOSTAT 2004/09) with the following conditions: (a) stable soils, (b) within 500 m of roads having a width of 2 m or more (c), outside building zones (buffer 300 m), (d) outside strictly protected conservation areas (see footnote 2), and (e) within a buffer of 200 m from a feed-in installation (grid, mobile antenna, skilift etc.). To account for the time when panels are in the shade (mountain terrain), we divided the suitable area by 2.
- PV on agricultural or open land adjacent to industrial complexes and other technical infrastructure. We selected open land or farmland from the Swiss land survey 2004/09 (BFS GEOSTAT 2004/09) within a distance of 50 m from industrial areas, technical installations,

and motorways (e.g., train stations, sewage plants etc.). Since these areas are already close to infrastructure, PV would probably not be seen as a new blight. To control for shading of the panels by large buildings, we divided the suitable area by 2. For some countries, brownfields or landfills could be welcome sites to host PV.

In the course of the proposed procedure in this paper, the technically feasible area (TFAS) is further reduced by subtracting conflicting sites (see section 2.3.6). To calculate energy budgets, the suitable area was multiplied by global irradiation (Meteotest, 2012), and the efficiency of the solar panels was set at 20% to assess PV electricity production.

2.3.3 Forest biomass-related energy potential

We used the yield model MASSIMO (Management Scenario Simulation Model, Thürig et al., 2005) - a dynamic individual-tree based forest model derived from NFI data (National Forest Inventory, 1.5 km resolution) - to estimate both the development of forest structure and the volume of living and dead tree biomass under a business-as-usual cutting scenario. Subsequently, we interpolated the 1.5 km points for each year using Inverse Distant Weighting (IDW for 12 points) to obtain a biomass estimate for any of the forest polygons from the high resolution vectorized topographic map of Switzerland (TLM 1.0, geocat.ch). Finally, strictly protected conservation areas (see footnote 2) were excluded.

2.3.4 Landscape service mapping

We used a widely accepted look-up table approach to map landscape services (Grêt-Regamey et al. 2014; Verhagen et al. 2015; Burkhard et al., 2012; Haines-Young et al. 2012; Kienast et al., 2009; Troy and Wilson, 2006). The look-up tables link any given land characteristic to the services (e.g., arable land links to the service ‘Nutrition’; the number of nights spent at tourist accommodation establishments links to the service ‘Physical and experiential interactions’, etc.). Hence, there is no mechanistic model behind the assessment, only binary links. The look-up tables were designed with the aid of experts and the scientific literature. Due to data constraints, we did not distinguish between the capacity (stock) and the actual flow of landscape services (De Groot, 2002; Wiggering et al., 2006; Kienast et al., 2009). Some services express flow (e.g., nutrition, experiential), while others are a mix between stock and flow.

Based on a literature review (Hastik et al., 2015; Grilli et al., 2013; Lester et al., 2013), the landscape services described below have been identified as potentially conflicting with the selected renewable energies. Terminology follows CICES 4.3 (Haines-Young and Potschin, 2013).

Landscape services 'Nutrition (Biomass)' and 'Materials (Biomass)': The maps for these services rely on the Swiss land-use statistics 2004/09 (BFS GEOSTAT 2004/09) and include forests and agricultural areas.

Landscape service 'Aesthetic aspects of landscapes': A map of this landscape service was derived from two spatially-explicit datasets. The first is the Federal Inventory of Landscapes and Natural Monuments of National Importance (ILNM, Swiss Federal Council, 2015), an expert inventory of 162 areas covering 19% of the country's surface. The second dataset originates from the Swiss Landscape Observatory (LABES, Kienast et al., 2015), and is based on a Swiss-wide survey about people's landscape perceptions (2814 valid questionnaires). Inhabitants of Swiss municipalities were asked to assess their municipality on the basis of different perception concepts, such as 'perceived landscape beauty' (Kienast et al. 2015). For the map featuring the service 'Aesthetics', we considered an area to have a high aesthetic value if it was a designated area in the ILNM inventory and was perceived as a beautiful landscape by the interviewees. Low aesthetic values were assigned to areas that are not found in the ILNM inventory, and, if people expressed neutral to low appreciation for the landscape in question. This map is not a grid, but contains information on administrative boundaries at the spatial level.⁴

Landscape service 'Physical and experiential interactions': A map (Figure 2) was developed using the following data sources:

- The Swiss-wide map of the potential for nearby recreation (Kienast et al., 2012). This map uses the empirically gathered preference patterns of people. It includes accessibility from home to landscape attractors such as forests, lakes, hills, hiking trails, restaurants, or castles.
- Several maps from SwitzerlandMobility (www.schweizmobil.ch) were added to account for tourist use (e.g., skate routes, mountain biking etc.).
- Finally, we used the database of page hits of Swiss municipalities (Venkateswaran et al., 2014), which documents the number of queries ('tourism'+place+'Switzerland') from web search engines of places listed in the Swiss toponym database 'SwissNames' (swissNAMES^{3D}, geocat.ch).

All databases listed above were spatially overlaid and classified to yield an overall assessment of the landscape service 'Physical and experiential interactions' (Figure 2).

⁴ district (English and French); Bezirk (German); distretti (Italian); Average size 270 km²

Landscape service 'Heritage, symbolic content': This map was created by overlaying the following datasets: (1) the Federal inventory of historic routes (IHR, geocat.ch), (2) Sites from the UNESCO world heritage list; (3) sacred or historic buildings from the topographic map; (4) hamlets, villages, and small towns considered as national heritage sites (ISOS, geocat.ch). All four databases were overlaid and classified to estimate heritage potential.

Landscape service 'Water and liquid flows': The maps indicating drinking water potential was developed by extracting the zones S1 (immediate surrounding of wells) and S2 (inner protection zone designed to prevent microbial contamination) from groundwater protection zones (FOEN, geocat.ch). As recommended by BFE/BAFU/ARE (2010), these zones should be avoided for wind turbines and biogas production to prevent contamination of drinking water.

Landscape service 'Lifecycle maintenance, habitat, and gene pool protection': This service was mapped using the inventories of the following conservation areas which are not excluded in the wind and solar potential map (see footnote 2): federally protected wetlands, amphibian sites, dry grasslands, Smaragd and Ramsar sites, no-hunting zones and Biosphere reserves (all geocat.ch), bird inventories for nesting sites, and migration flyways for migratory birds (Horch et al., 2012).

2.3.5 Conflict tables

Parallel to the development of energy potential maps (sections 2.3.1 to 2.3.3) and landscape service maps (section 2.3.4), we generated a conflict matrix (Table 1) yielding the major conflicts between decentralized renewable energies and landscape services. Conflicts are identified based on the literature (e.g., Hastik et al. 2015) and expert opinion. Wind power infrastructure frequently conflicts with, for instance, the landscape service 'Lifecycle maintenance, habitat, and gene pool protection', in particular because of potential collisions with birds and bats. Conflicts with the landscape service 'Aesthetics' consist of visual blight, noise, and shadow flicker. PV is primarily problematic on open land due to conflicts with provisioning services (agriculture) and 'Lifecycle maintenance, habitat, and gene pool protection'.

411 Table 1: Conflict matrix between decentralized renewable energy types and landscape services. Conflicts are highlighted. The conflicts are identified based on
 412 the literature (e.g. Hastik et al. 2015) and expert opinion. Landscape service terminology follows the CICES classification (CICES V4.3, Haines-Young and
 413 Potschin, 2013).

Energy source	Landscape services					
	Nutrition (Biomass), Materials (Biomass)	Aesthetic (aspects of landscapes)	Physical and experiential interactions (Tourism, recreation)	Heritage, symbolic content	Water and liquid flows	Lifecycle maintenance, habitat and gene pool protection
Wind	Co-existence	Visual blight, impacts on the horizon on ridges	Visual blight, noise, shadow flicker	Co-existence	Conflict with groundwater protection zone	Collision with birds and bats
PV on roof	Co-existence	Co-existence	Co-existence	Visual blight on historic and traditional buildings	Co-existence	Co-existence
PV on openlands (bush, abandoned)	Co-existence, or enhancing (e.g. sheep grazing)	Visual blight in areas that are free of technical installations	Conflict with symbolic content of places expected by tourists	Conflict with symbolic content of places expected by locals	Co-existence	Impacts on species diversity on land with low-intensity use
PV on agricultural lands close to industry	No arable production, only grazing possible, shade, installation)	Visual blight	Conflict with near-by recreation	Co-existence	Co-existence	Impacts on species diversity on land with low-intensity use
Biomass from forests	Co-existence	Co-existence	Co-existence	Co-existence	Co-existence	Co-existence or enhancing

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2.3.6 *Generating conflict maps and low-conflict energy amounts*

Maps featuring the conflict between energy production and landscape services were generated for all conflicts identified in Table 1, by overlaying the technically feasible area for energy production (TFAW & TFAS, see sections 2.3.1 & 2.3.2) with the landscape service maps. Table 2 yields an example protocol of such an overlay for wind vs. the landscape service ‘Physical and experiential interactions’. Five conflict classes can be identified: some feature co-existence (classes 1&2), some are not commercially viable (classes 1&5), and still others have high conflict levels and are consequently not commercially viable (class 4). The procedure shown in Table 2 was repeated for each conflict identified in Table 1. To estimate the realistic electricity budget (see Table 3, Results), we only considered the areas in classes 2 & 3 from Table 2 since, in a country with a highly participatory planning system, only these low conflict levels result in a high potential for projects to be realized in due time. The areas in classes 2 & 3 are named “ecologically and socially sustainable areas” (ESAW for wind; ESAS for PV). The following formulae were applied to convert ESAW and ESAS to electricity output:

$$\text{Wind: } E = (\text{ESAW} / \text{APT}) * \text{EOT}$$

$$\text{PV: } E = (\text{ESAS} * \text{SSI} * c) * \text{EFS}$$

Where: (E) = Electricity production in GWh/y; ESAW = ecologically and socially sustainable area for wind production in m²; APT = required area per turbine in m², here 150,000 m²; EOT = expected average electricity output per turbine, here 5 GWh/y for medium to high wind potential in Switzerland; ESAS = ecologically and socially sustainable area for PV production in m²; SSI = site-specific solar irradiation per m² in kWh/y; c = conversion factor kWh/y to GWh/y; EFS = efficiency factor for PV, here 20%.

440 Table 2: Method for generating a conflict map. The example shows the conflicts between wind (see Fig. 1) and the landscape service ‘Physical and experiential
441 interactions’ (Fig. 2). Columns indicate the technically feasible area (TFAW) with low (4.5-5.4 m/s) and medium to high (>5.5 m/s) wind speed. Rows indicate
442 sites where the landscape service ‘Physical and experiential interactions’ is of low, medium-low and medium-high to high importance. Intersections indicate
443 conflict classes. Only sites in the shaded fields are worth exploiting. These are the ecologically and socially sustainable areas for wind production (ESAW).

		Map featuring the technically feasible area for wind energy production (TFAW) at two average wind speeds... (Fig. 1)	
		4.5-5.4 m/s (low energy potential)	>5.5 m/s (medium to high energy potential)
Map featuring the importance of landscape service “Physical and experiential interactions” (Fig. 2)	low	Class 1: Co-existence; but commercially not interesting sites	Class 2: Co-existence; highly desired sites, no conflict mitigation strategy needed
	Medium-low	Class 5: Conflicting sites with low energy potential; not worth exploiting	Class 3: Minor conflicts, highly desired sites, conflict-mitigation strategy necessary
	Medium-high and high		Class 4: Interesting sites from an energy point of view, but high conflict sites with high conflict mitigation and legal costs

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2.3.7 Evaluating the conflict maps with local experts and media analysis

In order to evaluate the conflict maps in selected regions, two independent sources of information were used, namely interviews with local experts and media content analysis. The first validation based on interviews was performed in a well-known tourist area in the mountains (district Visp, Martin 2009). The expert interviews were conducted to gain a thorough understanding of the selected cases (Yin 2008). Representatives of cantonal administrations, electricity production companies (hydropower, solar and wind), as well as experts in spatial planning, and nature and landscape protection were selected as interview partners. During the interview, the experts were first asked to give their point of view regarding conflicting areas (topics and spatial areas). They were then shown the conflict maps and were invited to comment on them. We asked whether the areas depicting conflict potential on our maps (1) have experienced conflicts in reality or (2) correspond to areas where experts expect conflicts. The second validation was based on interviews and media content analysis in the cantons of Aargau, Berne, and Grisons. Media content analysis of regional newspapers is an accepted source for gathering data on land-use conflicts (Darly & Torre, 2013; Torre et al., 2014; von der Dunk et al. 2011, 2015). The conflicts covered in regional-level quality newspapers have clearly reached a certain level of public relevance. Thus they complement the rather subtle information from the expert interviews. Despite the fact that journalists are not free of bias and subjectivity, we assume that in politically independent quality newspapers rather objective journalism prevails. We used Swissdox (<http://www.swissdox.ch/Swissdox2/>) to access regional newspapers at a reasonable cost and checked the years 2011-2013.

3. Results

3.1 Validation of the conflict maps with local experts and media analysis

The overlays of the maps gave a detailed spatially-explicit picture of the inferred energy potentials with associated expected conflicts. Validation of the conflict maps with local experts in the well-known tourist area Visp (Martin 2009) indicated that some local context (e.g. meaningful places for locals) was lacking in the national conflict assessment, in particular concerning the landscape service ‘Aesthetics’. Regional conflict hotspots were, however, anticipated correctly despite the fact that the exact location of the conflicts with ‘Aesthetics’ differed frequently from the local perception. This is not surprising since this service’s data sources are at the spatial scale of districts and higher, and, consequently, one should not expect an assessment at high spatial resolution. This was not the case for regulating and provisioning services which were quite accurately modeled. Validation of the conflict maps with interviews and media content analysis in the cantons of Aargau, Berne, and Grisons confirmed the findings of Martin (2009): the national conflict maps indicating conflicts with the services ‘Physical and experiential interactions (Tourism, recreation)’ and ‘Lifecycle maintenance, habitat, and gene pool protection’ match well with the regional appraisal from experts and the media. Conflicts with ‘Aesthetics’ are less accurately modeled as they often lack local context.

3.2 Low-conflict energy potentials

Having obtained evidence that the maps realistically depict conflicts with landscape services at the national level (see section 3.1), we generated national budgets of electricity production, taking into account conflicts with different landscape services. For a country with a highly participatory political and planning system, only areas with low conflict levels (ESAW & ESAS, section 2.3.6) have high potential for projects to be completed in due time while maintaining economic profitability. For example, the potential conflicts between ‘Physical and experiential interactions’ (Figure 2) and wind energy (Figure 1, wind pixels) reduces the technically feasible potential of 41 TWh/year to approximately 12 TWh/y, which is equivalent to roughly 2,200 rotors. However, many of these sites still have considerable conflicts with other services. Most conflicts with wind energy are found in mountain areas (i.e., Jura & Northern and Central Alps) where wind speeds are relatively high but at the same time scenic landscapes provide important landscape services relating to the ‘Aesthetic aspects of landscapes’.

For a full energy assessment illustrating the complete cascade of conflicting landscape services, see Table 3 with corresponding explanations. The analysis clearly shows that biomass from forests is by far the least conflicting renewable followed by PV on roofs with 68% low-conflict energy. The latter loss is due to a conflict with cultural heritage sites where PV is seen as an unnecessary visual blight on roofs and fronts (facades). It is likely, however, that this conflict

will soon be eliminated due to advancements in PV technology, such as using less visible panels. PV on semi-natural or abandoned agricultural sites have a very high conflict potential with a 94% reduction due to conflicts. First, there is an issue with the regulating service ‘Lifecycle maintenance, habitat and gene pool protection’ since these areas are often important for biodiversity. Second, there is a conflict between PV on semi-natural or abandoned agricultural sites and the scenic beauty and landscape character of these areas. Indeed, tourists favor these areas due to their high naturalness and distinct vegetation structure (Hunziker et al., 2008). PV on arable land close to industries and other infrastructure has as little conflicts as PV on roofs (62% low-conflict energy). As a rough estimate over all potential locations of PV (roof, open land), conflict-related reductions run between 32 and 94% of the technically feasible potential. The potential reduction is strongly dependent on whether PV is to be placed on roofs (32% reduction or less if less visible PV is selected) or on openland (38-94% reduction). These reductions hold for the Swiss context, in other words, for a country with a relatively high population and municipality density, relatively strict landscape conservation legislation, and a highly participatory method of planning.

Wind has a high conflict potential, and only 12% of the technically feasible energy potential can be considered low to no conflict (Table 3). Surprisingly, the greatest energy losses are not—as often expressed in the interviews—with the landscape service ‘Aesthetic aspects of landscapes’, but with ‘Lifecycle maintenance, habitat, and gene pool protection’ and ‘Physical and experiential interactions’ (Tourism, recreation). Concerning ‘Lifecycle maintenance, habitat, and gene pool protection’, there is hope that higher turbines with a greater distance between rotorblades and higher efficiency will enable the producer to turn rotors off at windspeeds below 6.5m/s in order to save bats that do not fly at higher windspeeds. In addition, technology offers early warning sensor systems that detect bats and birds early enough to shut down the rotors (Horn et al., 2008; Minderman et al. 2015).

534 Table 3: Total amount of energy produced on low-conflict sites (ESAW & ESAS sites, section 2.3.6). Shaded areas are identified as having a conflict between
 535 energy production and landscape service (see Table 1). Landscape service terminology follows the CICES classification (CICES V4.3, Haines-Young and
 536 Potschin, 2013).

Energy source	Electricity potential (TWh/yr) from technically feasible areas (TFAW & TFAS, sections 2.3.1 & 2.3.2)	Remaining energy on sites with low conflict with the corresponding landscape service (ESAW & ESAS sites, section 2.3.6) (TWh/yr)						
		Nutrition (Biomass), Materials (Biomass)	Aesthetic (aspects of landscapes)	Physical and experiential interactions (Tourism, recreation)	Heritage, symbolic content	Water and liquid flows	Lifecycle maintenance, habitat and gene pool protection	All landscape services together (in brackets: % of low-conflict energy in relation to technically feasible potential in column (1))
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Wind	41	41	33	12	41	40	13	5.1 (12%)
PV on roof	11	11	11	11	7.5	11	11	7.5 (68%)
PV on openlands (bush, abandoned)	18	18	13	3	13 (estimated based on expert opinion)	18	10	1 (6%)
PV on agricultural lands close to industry	13	9 (estimated based on expert opinion)	10.2	8.4	13	13	10	8.1 (62%)
Biomass from forests	5 (converted)	5	5	5	5	5	5	5 (100%)

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Our conflict assessment enabled us to estimate whether the 2050 energy target of 22-25 TWh/y of decentralized renewable energy can be realized with sites exhibiting no or low conflict with current landscape services. For wind-generated electricity, we estimate that a total of 5.1 TWh/year could be profitably produced at a low conflict level (Table 3). Biomass from forests managed in a business-as-usual management scenario would yield approximately 5 TWh/year outside national and cantonal conservation areas. PV on roofs yields low-conflict energy of approximately 7.5 TWh/year. Expert interviews confirm that the expected low-conflict energy potential for PV on open fields on extensively used open land patches primarily located in the Alps is extremely low. At the moment - and this is likely specific to a country with a strong tourism industry and a population which is sensitive to landscape issues - acceptance of PV on these extensively used fields is very low. A total of 1 TWh/year would be socially sustainable, which is only approximately 5% of the technically feasible amount of approximately 18 TWh/year. PV on arable land close to industries and other infrastructure has a potential of 8.1 TWh/year. This provides us with a final budget calculation: wind, PV on roofs, and biomass from forests yield approximately 17 TWh/year. The shortfall with respect to the expected 22-25 TWh/year must be generated with other renewable energies, such as large hydropower, geothermal energy, or, despite its low acceptance, from PV on open fields.

4. Discussion

In this paper, we present a transparent methodology and a powerful application of landscape service mapping to identify areas with low conflict between the production of renewable energy and landscape services. The strengths of the approach are (1) its systematic yet parsimonious landscape service mapping, as suggested by Maes et al. (2016) (2) its incorporation into an environmental conflict framework, as suggested by von der Dunk et al. (2015) (3) the ground-truthing of the conflict maps with media and expert analysis as exemplified in Torre et al. (2014), and (4) the estimation of low-conflict energy budgets for national energy planning. As such, it is currently one of the few systematic spatially-explicit conflict analyses available for a larger region (40,000 km²) with a complex terrain, a high population density, a strong dependency on landscape resources via tourism, and a high landscape conservation status. Hence, the present paper makes a significant contribution towards reducing the knowledge gaps mentioned in the literature review (section 1.3) and is an important step towards the operationalization of the landscape service approach in practice.

To ensure a successful application of the presented methodology, we discuss several critical points of our endeavor with relevant findings from the literature. These critical points should be considered before applying the approach in, for example, spatial planning.

- First, our assessment is a simple map filtering technique yielding land parcels whose current services are least affected by energy production. The found trade-offs between energy and landscape services are neither monetarized nor expressed in terms of their impact on the regional economy such as presented in Moreno and Lopez (2008) or Mundaca and Richter (2015). *We do not* challenge the notion that renewable energies introduce new and potentially more profitable opportunities for economic development in rural areas compared to traditional goods and services. We can foresee that a regional-economic assessment of the trade-offs between ecosystem services and gained energy would thus be a valuable next step in the analysis.
- Second, the approach assumes *technology to be static*, i.e., we calculated our energy potentials on the basis of current technological constraints for solar and wind technology (such as efficiency, required space etc.). Benson and Magee (2014) identify considerable technological innovation in the field. An own assessment among technology experts in Switzerland yielded values of +20% energy efficiency for wind, +20-25% efficiency for PV, and the potential to use PV on facades because of new materials. Consequently, our energy assessment is a rather conservative estimate.
- Third, *the landscape service assessment is representative of the year 2010 and is not considered in the analysis as a dynamic entity*. Specifically, our energy calculations are based on current land use and do not take into account further land abandonment or urbanization. Both land changes could alter the production areas of renewable energies considerably. Price et al.'s (2015) model calculations for Switzerland show that—depending on the scenario used—between 10,000 and 180,000 ha of new urban area may exist by 2035, offering, for example, new roof areas suitable for PV. Scenario calculations also show abandoned agricultural land of up to 40,000 ha depending on the scenario used, providing new areas for openland PV.
- Fourth, our assessment is rather conservative concerning the co-existence of services and energy production which could lead to an underestimation of the total amount of energy.
- Fifth, mapping of *cultural services* is difficult, as evidenced in the conflict validation section of this paper (section 3.1) or repeatedly mentioned by Potschin et al. (2016) in their handbook of ecosystem services. Out of all services it is the least reliable. We show, however, that with sound empirical data on landscape perception by people, and maps from research on nearby recreation (LABES, Kienast et al. 2012, 2015), credible maps can be generated.

5. Conclusions

Our target audience includes national authorities, and regional to local land managers who might use the approach to (1) strategically frame the replacement of nuclear and fossil energy with minimal impact on the landscape, (2) design master plans at the regional level, and (3) initiate a dialogue with the affected population by using the maps in an operational context, such as for stakeholder workshops.

In conclusion, we have reduced the research gaps identified in section 1.4 significantly and reached the following milestones:

(1) *Landscape service approach operationalized for 3 energy sources and 6 competing landscape services.* Ground-truthed conflict maps are a significant step forward towards operationalizing Hastik et al.'s (2015) approach and to further the landscape service approach in energy trade-off analyses. Biomass from forests is by far the least conflicting renewable energy, followed by PV on roofs. 68% of the technically feasible energy potential of PV on roofs can be generated on low-conflict sites, and more is expected with new materials. Wind has a high conflict potential: only 12% of the technically feasible energy potential can be generated on low-conflict sites. PV on open land and marginal land, as shown in Milbrandt et al. (2014), is – at the moment – not currently feasible in Switzerland. Nevertheless, in agreement with Eleftheriadis and Anagnostopoulou (2015) and Mbzibain et al. (2013), we confirm that diffusion of the idea of renewable energies in the population and acceptance by people is possible but might take a long time.

(2) *Contribution of low-conflict sites to the national energy budget calculated:* Thanks to the ground-truthed conflict maps we are— for the first time—able to perform realistic energy planning for an area of roughly 40,000 km² by estimating the share of socially acceptable sustainable energy that can contribute to the overall energy gap of 22-25 TWh/year caused by the phase-out of Swiss nuclear plants by 2050. Low-conflict solar energy on roofs could contribute approximately 30% of the required 22-25 TWh/y. Intensified wood production and wind energy could add another 40% on such low-conflict sites. The remaining gap of approximately 30% must come from undisputed energy sources such as biogas from recycled organic material or from centralized renewable energies such as geothermal or hydropower (new or higher dams). We also expect significant contributions from new, yet unknown or improved renewable energy sources.

(3) *Spatially explicit decision tools for developed master plans:* The conflict maps are a valuable element in the early stages of spatial planning processes to support the development of sound plans, and to facilitate negotiation processes (Dale et al. 2016; Hersperger et al. in press). Once again we stress the fact that legal uncertainty and endless lawsuits hinder investments in renewable energy far more than technical constraints. In order to achieve legal certainty Swiss cantons are required over the next 6 – 10 years to

646 revise their master plans in order to accommodate suitable areas for renewable energy
647 production. Our maps are timely tools to facilitate the negotiation process with
648 stakeholders and to provide a sound scientific basis for legally binding zones for renewable
649 energy production.

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Figure captions

Figure 1: Technically feasible areas for wind energy (TFAW) and PV on roofs (TFAS) for Switzerland. (wind: average wind speed $> 4.5\text{m/s}$, stable soils, slope $< 20\%$; solar: current rooftop area).

Figure 2: Map of the landscape service ‘Physical and experiential interactions’ (for details, see text).