RE-BD AR2024 | ASSESSMENT REPORT ON RENEWABLE ENERGY AND BIODIVERSITY

ACCELERATING RENEWABLE ENERGY DEVELOPMENT WHILE ENHANCING BIODIVERSITY PROTECTION IN SWITZERLAND

URGENT RECOMMENDATIONS BASED ON A REVIEW OF SCIENTIFIC LITERATURE

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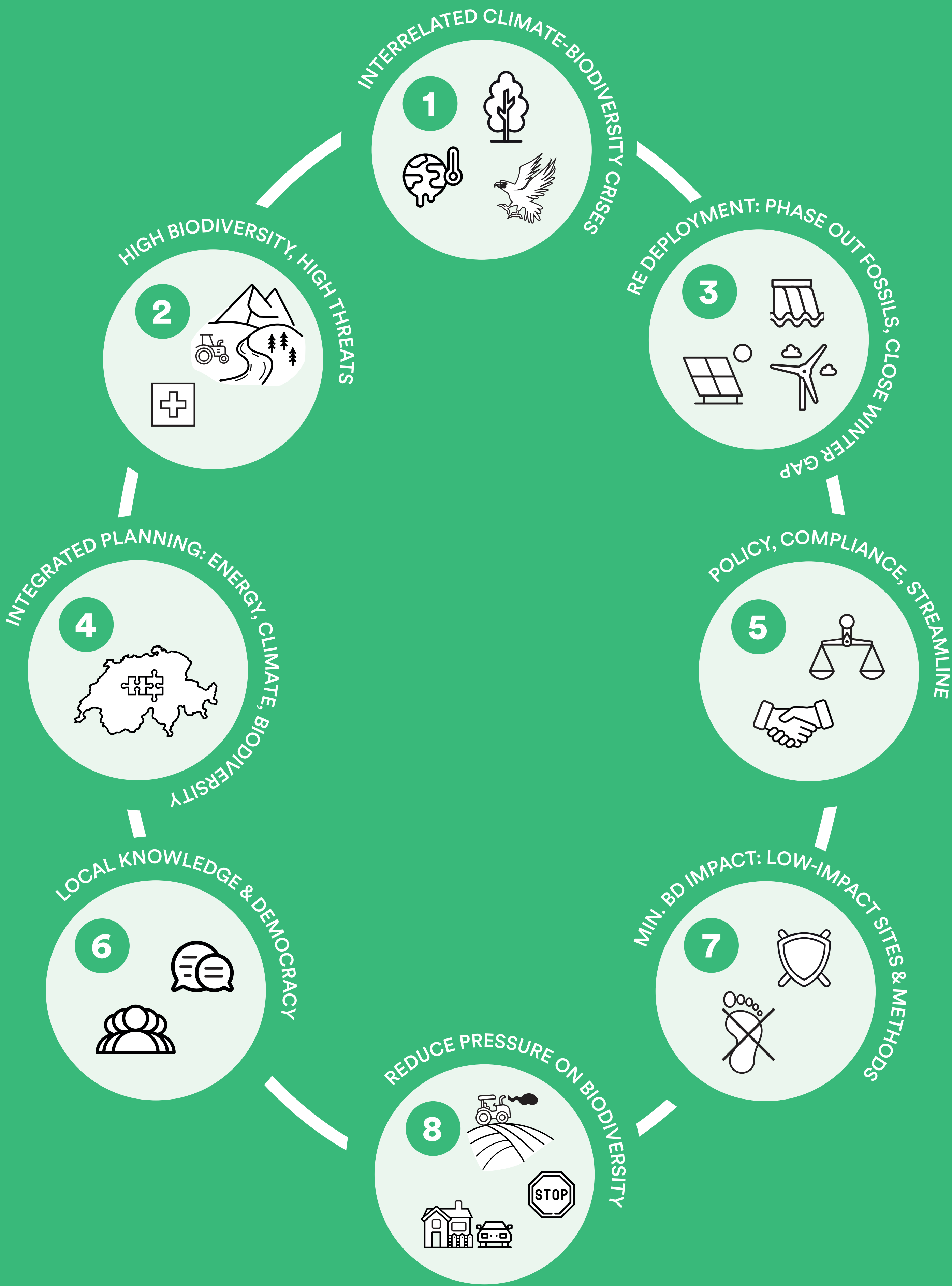
CONCLUSIONS AND RECOMMENDATIONS

Chapters 2-7 together support the following messages with high confidence. Green pages opening each chapter show which messages the chapter support. Urgent actions are summarized in Chapter 8.


1
INTERRELATED CLIMATE-BIODIVERSITY CRISES
2
HIGH BIODIVERSITY, HIGH THREATS
3
RE DEPLOYMENT: PHASE OUT FOSSILS, CLOSE WINTER GAP
4
INTEGRATED PLANNING: ENERGY, CLIMATE, BIODIVERSITY
5
POLICY, COMPLIANCE, STREAMLINE
6
LOCAL KNOWLEDGE & DEMOCRACY
7
MIN. BD IMPACT: LOW-IMPACT SITES & METHODS
8
REDUCE PRESSURE ON BIODIVERSITY
STOP

Supports recommendations:

1 2 3 4 5 6 7 8

CHAPTER 1

CHAPTER 1

Executive Summary

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1.1 Context and scope

RE-BD AR2024, the 2024 Assessment Report on Renewable Energy and Biodiversity, addresses the critical balance between expanding renewable energy (RE) and better protecting biodiversity in Switzerland, with a special focus on the Alpine regions. It is the result of the project "Towards new renewable energy developments in Switzerland that preserve biodiversity", supported by CLIMACT, the Center for Climate Impact and Action of UNIL & EPFL, conducted between June 2023 and September 2024. The project reviewed published scientific literature in order to define the conditions needed to reach three key societal goals: climate action, energy security, and ecological integrity. It unites experts in RE, climate, and biodiversity from diverse scientific bodies and universities across Switzerland, aiming to foster mutual understanding and collaboration to achieve the outlined societal goals.

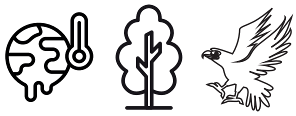
The project team and participants met in three interdisciplinary workshops: June 2023 at UNIL in Lausanne, October 2023 at EPFL in Neuchâtel, and January 2024 at ETHZ in Zurich. Most of the work was undertaken by eight chapter teams, led by chapter lead authors. At least three external reviewers reviewed each chapter, in two rounds. A regular dialogue took place with complementary national projects Speed2Zero and Engage, as well as with the Swiss Academy of Natural Sciences (SCNAT). The full list of editors, chapter lead authors, and chapter authors is in the Credits section and in each chapter - a total of 45 scientists were involved in writing and reviewing this report. This report presents the current state of scientific knowledge to guide this crucial transition. Each chapter explores a key topic, drawing on published scientific literature, includes a summary and a detailed reference list, and can be read independently.

While our overall recommendations align with other projects and reports addressing biodiversity and RE, our report offers several original contributions: (a) A holistic perspective of biodiversity, considering cumulative and interlinked impacts; (b) Specific best practices to minimize impacts of RE; (c) Emphasis on reducing current pressures on biodiversity and minimizing additional pressures from the nationwide deployment of RE infrastructure; (d) The necessity for a coordinated, spatially optimized national approach to RE development; and (e) The importance of democracy and community engagement in the decision-making process.

1.2 Conclusions and recommendations

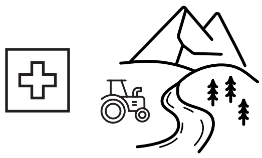
The following main conclusions and recommendations, all established with high confidence, are summarized from Chapters 2-7. The most urgent recommendations are summarized in Chapter 8.

1



Human activities both cause and suffer from the interrelated crises of climate change and biodiversity destruction. While climate change impacts biodiversity and ecosystems, healthy biodiversity and intact ecosystems help regulate our climate and especially mitigate climate change, and provide a wide range of other ecosystem services.

2

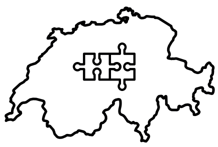


Switzerland has an exceptionally high diversity of ecosystems and species, which are inadequately protected and increasingly threatened, primarily by industrial agriculture, urban sprawl, and roads (fragmentation, soil sealing). In fragile alpine areas, transport and construction activities cause significant damage.

3

Large-scale renewable energy (RE) deployment is necessary to phase out fossil fuels and reach net zero emissions by 2050. Additionally, sufficiency and efficiency will make a timely transition possible. A key challenge is to close the winter energy gap, which could be best achieved with Alpine photovoltaic (PV) and wind energy, complementing existing hydroelectricity and lowland PV on infrastructures and intensively used space. However, RE developments must not exacerbate the already high pressure on biodiversity.

4

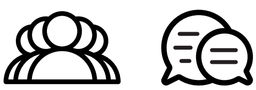


Large-scale expansion of RE across Switzerland should follow an integrative approach (as recommended by the Convention on Biological Diversity), ideally at the federal level, where energy, climate, and biodiversity criteria are assessed together, with potential synergies and conflicts considered (as proposed among others by SCNAT and IUCN).

5

Swiss policy must comply with international biodiversity and climate commitments. Such compliance is only possible with a coordinated approach at the cantonal, national and international levels. Procedures of democracy, participation, and control are essential for the legitimacy of implementation measures towards Swiss RE expansion. These should be reinforced, not overstepped in the name of urgency. Still, the approval procedures must be significantly streamlined and accelerated.

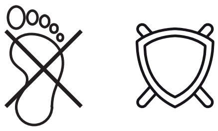
6



At the local level, engaging communities is crucial for successful energy transitions and biodiversity protection, requiring: (a) Incorporating the knowledge and experience of local stakeholders into new RE projects, (b) Strengthening community capacity, (c) Creating synergies between RE and biodiversity restoration, and (d) Ensuring communities have a meaningful role in shaping their future.

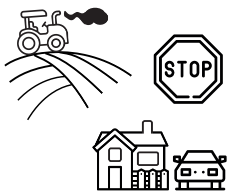
Through deliberative and participatory democracy, communities can not only influence how these initiatives impact their lives but also contribute to broader societal goals and a just transition.

7



To minimize pressure on biodiversity, all new RE projects in the natural environment should (a) Be embedded in a national plan that prioritizes projects that have the lowest biodiversity impact, or even offer positive effects; (b) Re-evaluate the minimum size for projects of national importance, to enable the inclusion of smaller projects on less critical sites; (c) Carefully select sites accessible without new roads, ideally using already degraded sites and excluding areas of biodiversity significance; (d) Adopt best-practice, low-impact construction methods; and (e) Conduct detailed assessments before building and long-term biodiversity monitoring post-construction.

8



Reducing the overall pressure on biodiversity requires more than minimizing additional impacts; it necessitates reducing the damaging effects of existing human activities and infrastructures. This involves halting and reversing the most harmful activities (see #2) and undertaking ecological restoration to achieve a net gain for biodiversity and accordingly mitigate climate change.

1.3 Outlook

On 9 June 2024, 68.7% of Swiss voters approved the Secure Renewable Electricity Supply Law, mandating a significant increase in renewable energy (RE) generation, to 35 TWh in 2035 and 45 TWh in 2050, not including hydroelectricity. The law also sets a cap on electricity imports to 5 TWh during the winter months. To achieve this ambitious, legally binding goal while reinforcing biodiversity protection, four major challenges must be overcome:

- Rapidly developing a large and diverse portfolio of RE sources, including Alpine PV and wind energy to ensure adequate winter supply.
- Minimizing additional pressure on biodiversity by following best practices.
- Reducing existing pressure on biodiversity by halting current damaging activities.
- Engaging local communities and strengthening democratic processes.

We call upon all Swiss stakeholders, particularly planners, administrations, local communities, and energy players, to reinforce dialogue and collaboration to address these challenges.

We wish you excellent reading, thoughtful reflection, and, most importantly, engagement with others.

Supports recommendations:

1 2 3

CHAPTER 2

CHAPTER 2

The Context of the Joint Climate and Biodiversity Crises, and Implications for Energy Development

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2.1 The twin crises of climate and biodiversity

Switzerland, like the rest of the world, is currently facing two major and interrelated environmental crises, the climate and biodiversity crises, both stemming from human activities and affecting our societies and economies at an accelerating pace (Ismail et al., 2021; Guisan et al., 2022b; European Commission et al., 2024). The climate crisis – the unprecedented global warming and change in climate variability – primarily stems from anthropogenic greenhouse gas (GHG) emissions and directly threatens human survival and the survival of other terrestrial and aquatic species (IPCC, 2023). The biodiversity crisis – the decline in biodiversity and biological populations – is caused by the steady expansion and intensification of human activities (IPBES, 2019) and threatens humanity through its negative impact on ecosystem services (see Chapter 3).

Biodiversity contributes to regulating climate, and its degradation further accelerates climate change. For instance, loss of biodiversity increases CO_2 concentration as species-poor ecosystems absorb less CO_2 than species-rich ecosystems (Weiskopf et al., 2024). In turn, climate change strongly affects biodiversity, creating a complex feedback loop between the Earth's climate system and the biosphere. In designing sustainable mitigation strategies, it is pivotal to consider the processes linking biodiversity and climate.

Strategies focused solely on reducing anthropogenic GHG emissions may conflict with the mitigation of biodiversity loss (Martin and Watson, 2016; Malhi et al., 2021; Pettorelli et al., 2021); Chapter 5). Deploying renewable energy (RE) infrastructures could increase pressure on ecosystems already strained by agricultural expansion, urban sprawl, and other developments (Dauber et al., 2010; Warren et al., 2013; Martin and Watson, 2016; Arneth et al., 2020), but spatial planning tools could help identify areas where such infrastructure would have minimal harm on biodiversity (Chapter 5). This chapter discusses the interdependence of these two crises and their implications for RE infrastructure development, as shown in Figure 2.1, with a special focus on Switzerland.

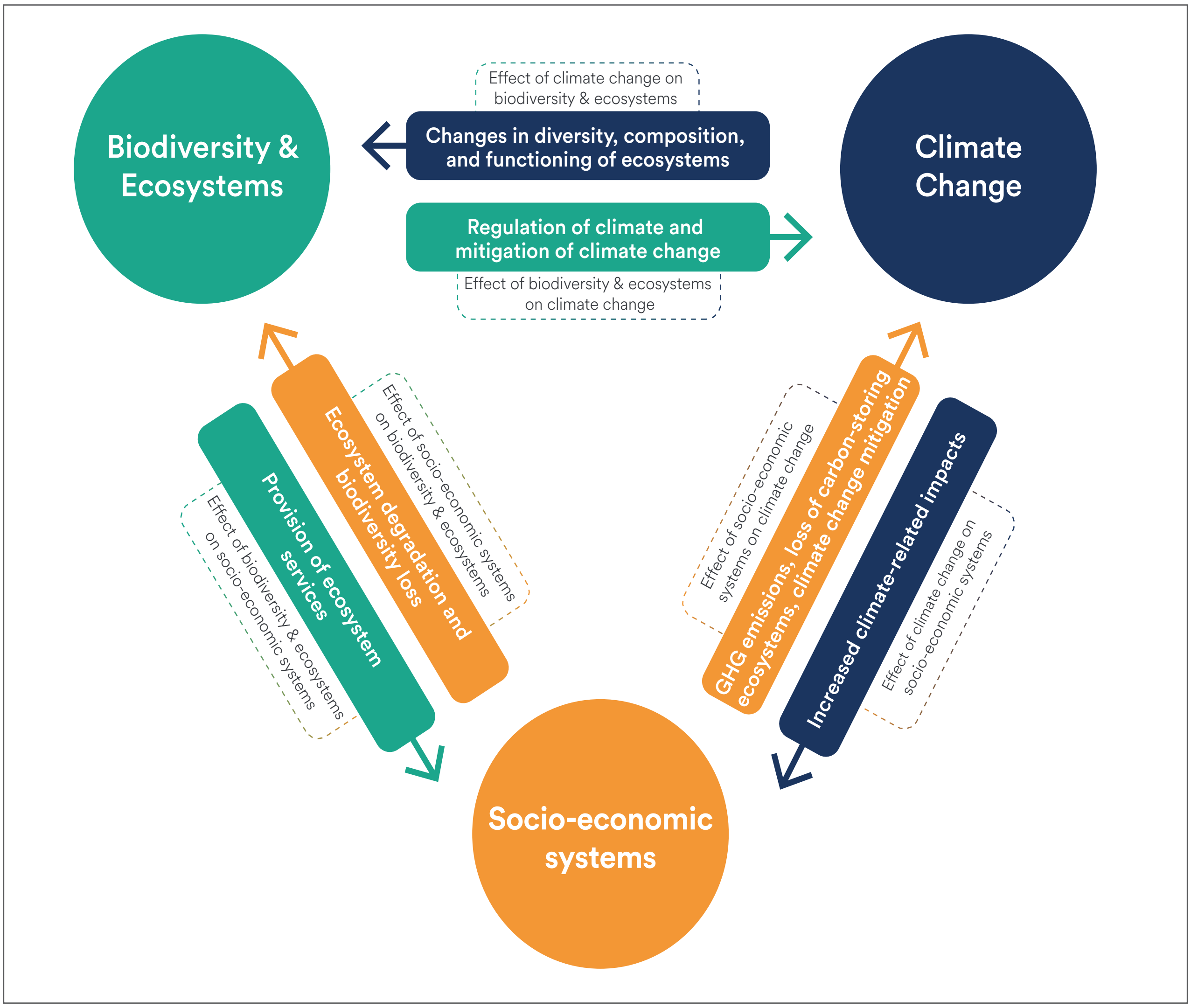

Figure 2.1 | **The interrelatedness of the climate and biodiversity crises, their effects on people, and how humans have contributed to these crises. Arrows represent the directionality of effects. These three interrelated dimensions affect Switzerland, as they do other countries. Figure adapted from Figure SPM.1 IPCC (2022a).**

2.2 The climate crisis

Climate change is now recognized as an environmental crisis of utmost and existential importance. Large, direct, and irreversible impacts are already occurring, and more are predicted, not only on human populations and society but also on natural biodiversity and ecosystems, in turn damaging ecosystem services (IPBES, 2019; Pörtner et al., 2021; Kemp et al., 2022; UNEP, 2022; IPCC, 2023). While the Earth's surface has already warmed by more than 1.1°C compared to preindustrial temperatures i.e., 2013–2022 compared to 1871–1900 (NASA Earth Observatory, 2024), Switzerland has experienced a much higher average temperature increase of 2.5°C, as shown in Figure 2.2 (NASA Earth Observatory, 2024). The global temperature of the last decade (2013-2023) was the highest on record over the last 6500 years, and probably over the last 125'000 years.

Effects of climate change are also confirmed by many biological fingerprints, i.e. biological evidences of climate change, such as phenological and range shifts, growth increase, vegetation greening; (Parmesan and Yohe, 2003), including in Switzerland (Vittoz et al. 2013; Rumpf et al. 2022; see Section 2.3 and Chapter 3). Future projections suggest that if global GHG emissions persist in their current upward trend, Switzerland may encounter drier summers and wetter winters, with overall less variation in monthly precipitation throughout the year, but with more extreme weather events, and reduced snow cover and duration at low and middle altitudes (IPCC, 2023; MeteoSchweiz, 2023). Any further degradation of the world's climate will expose humans and nature to dangerous, unprecedented situations, through increased flooding, extreme heat, increased food and water scarcity, more disease, economic loss (IPCC, 2022a), and large changes in species and ecosystems (Adde et al., 2024). Climate mitigation requires a rapid reduction of anthropogenic GHG emissions, and shifting to renewable energy is a key lever (Chapter 4).

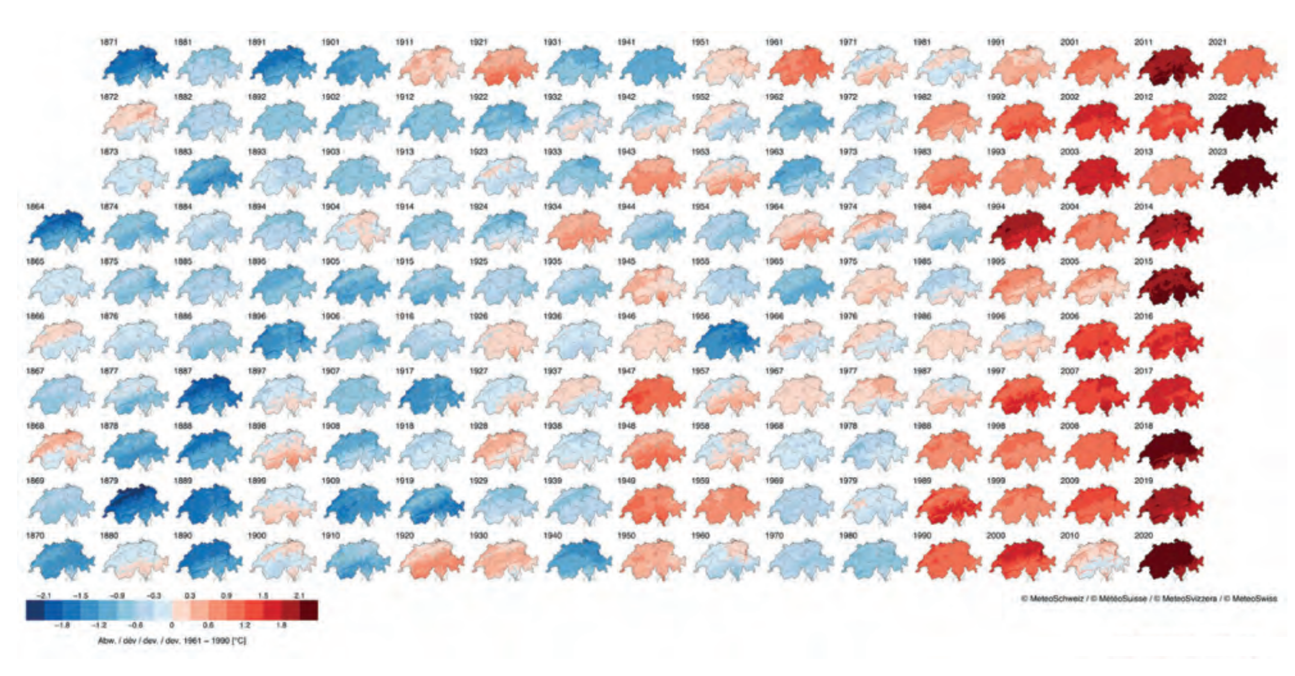

Figure 2.2 | **Temperature deviations from the 1961–1990 average in Switzerland for each year since 1864. Below-average years are shown in blue, above-average years in red. Source: MeteoSwiss**

2.3 The biodiversity crisis

Biodiversity is commonly measured as the number of species in a given area, but also comprises phylogenetic and genetic diversity, and the diversity of the morphological traits and ecological roles of species in a community. These facets and the ecosystems they form are vital to human wellbeing, providing a wide array of ecosystem services (The World Bank, 2009; IPBES, 2019; Retsa et al., 2020). These services include provision of food, pollination for crops, pest control, and medicinal products; maintenance of fresh water and air quality; reduction in flood intensity and the risk of natural hazards (Mahecha et al., 2022); recreation (Sandifer et al., 2015); climate regulation through the maintenance of evapotranspiration (Pielke Sr. et al., 1998), and alteration of the planet's surface albedo, and its capacity for heat exchange (Fu et al., 2013; Díaz et al., 2018; IPBES, 2019). Human activities threaten ecosystems and their services, with the most significant negative drivers being land use and direct exploitation, followed by climate change (IPBES, 2019). The effect of climate change is accelerating, and it is expected to surpass other drivers of biodiversity loss (Garcia et al., 2014).

In Switzerland, climate change has led to higher tree lines, drought-related degradation of forest health, changes in species phenology, and faster invasion by exotic species (Vittoz et al., 2013). Climate change has also had both positive and negative effects on species richness. Some species of southern origin are benefiting from global warming, expanding their distributions northwards (Arlettaz et al., 2024). Yet, the significant greening of the Alps (i.e. melting of snow and subsequent growth of plants) is causing a decline in alpine specialist species (Lin et al., 2020; Rumpf et al., 2022; Vittoz et al., 2013), while the rise in ambient temperatures has triggered the decline of boreo-alpine species (Furrer et al., 2016). As a result of direct anthropogenic and climate change pressures on biodiversity, 17 of 21 ecosystem services are already declining at the global scale, while six of nine planetary boundaries (including biosphere integrity) have already been transgressed (Richardson et al., 2023). In Switzerland, biodiversity is also declining, mainly due to the loss, degradation or fragmentation of habitats caused by human activities, including agricultural intensification, construction (causing soil sealing), too intensive use of natural freshwaters, pollution (esp. nitrogen and pesticides) (Schweizer Bundesrat, 2022; Chapter 3). While energy infrastructures have had relatively low impact on terrestrial species, they have significantly degraded aquatic habitats (Chapter 5).

2.4 The interrelatedness of climate and biodiversity

The climate and biodiversity crises have direct and indirect effects on human societies by influencing each other through complex feedback loops; see Figure 2.1 (Zimov et al., 2006; Beugnon et al., 2021). The degradation of natural habitats undermines ecosystems' capacities to store and sequester carbon, aggravating climate change and its associated risks at the global and local scales (Martin and Watson 2016, Rockström et al. 2021). At the global scale, the loss of certain ecosystems through changes in land use is leading to a decline in soil organic carbon, which is in turn released into the atmosphere (IPBES, 2019).

In Switzerland, cool temperate forests, peatlands and grassland ecosystems store large amounts of carbon. However, their degradation could substantially increase carbon emissions, while their restoration could substantially increase the amount of carbon sequestered (Bai and Cotrufo, 2022). Biodiversity sustains the capacity of these ecosystems to store carbon, and biodiversity loss thus contributes to the decline in soil organic carbon (Rockström et al., 2021; Bai and Cotrufo, 2022).

At local scales, the alteration of natural ecosystems degrades local climate regulation and reduces the protection from natural risks they provide (Bradshaw et al., 2007; The World Bank, 2009; Hoffmann and Sgrò, 2011; Pielke Sr. et al., 2011; Ferrario et al., 2014; Beugnon et al., 2021; Senger et al., 2021). As above, biodiversity enhances the capacity of ecosystems to sustain extreme climatic events, and biodiversity loss impairs the resilience of ecosystems and reduces their ability to regulate the climate (Loreau and de Mazancourt, 2013; Carrick and Forsythe, 2020). The feedback loop between biodiversity and climate has further impacts on human health, threatening food and drinking water supplies (IPCC, 2023).

Climate change, together with the loss of biodiversity, also favors the emergence of pandemics, because they are exacerbated by increasingly rapid alterations in the environment (e.g., depletion of drinking water, accumulation of waste, poor management of arable land and deforestation), which can bring wild ecosystems and new microorganisms into direct contact with human populations and their livestock (IPBES, 2020; De Oliveira and Tegally, 2023). Climate and biodiversity are therefore interdependent systems. Mitigating climate change thus largely depends on maintaining (near-) intact ecosystems and vice versa (Martin and Watson, 2016), a point that advocates for addressing the biodiversity and climate crises jointly (Ismail et al., 2021; Guisan et al., 2022b).

2.5 Addressing the Swiss climate and biodiversity crises jointly

Addressing the climate and biodiversity crises jointly requires including these components more systematically in Swiss policy at all levels (Guisan et al., 2022b). While the protection of near-intact ecosystems is vital, the areas that are currently protected are both too small and insufficiently protected. Degraded ecosystems must also be restored to ensure sufficient climate mitigation (Rockström et al., 2021).

To safeguard biodiversity, Switzerland, along with many other countries, has committed to protecting 30% of land area by 2030 under the December 2022 COP15 biodiversity conference, which aligns with global biodiversity protection targets (i.e., 30x30 targets under the Kunming-Montreal Global Biodiversity Framework). Importantly, climate change mitigation measures may conflict with the achievement of this target (Niebuhr et al., 2022). Increasing pressure for the development of RE facilities to satisfy winter demand, move towards a net-zero society, and reduce dependency on other countries (Li et al., 2020) is currently shaping the Swiss policy debate. However, the resulting policies may lead to a weakening of biodiversity protection (Niebuhr et al., 2022) in order to facilitate the rapid development of RE capacity, especially in Alpine regions (Salak et al., 2019; Wissen Hayek et al., 2019). The development of spatial planning tools that can help identify priority areas where energy developments will not or will only minimally harm biodiversity and ecosystems is key to designing optimal strategy for jointly tackling the climate and biodiversity crises (Egli et al., 2017; Gasparatos et al., 2017; Bennun et al., 2021; Vignali et al., 2021, 2022).

2.6 Key messages

1. We are currently facing two major and interrelated environmental crises, the climate and biodiversity crises, neither being adequately addressed. Both crises arise from human activities and affect our societies and economies at an accelerating pace. Climate change affects biodiversity and ecosystems, while biodiversity and intact ecosystems regulate climate and mitigate climate change.

2. Abandoning fossil fuels and switching to renewable energy is imperative to limit climate change and halt future biodiversity loss. Yet, renewable energy infrastructure must not contribute to further biodiversity destruction, impairing the ability of ecosystems to regulate climate and mitigate climate change.

3. To address the climate and biodiversity crises jointly, and the related implications of renewable energy development, ecological and infrastructural components must be more systematically and jointly integrated in Swiss policy at all levels.

Supports recommendations:

1 2 4 7 8

CHAPTER 3

CHAPTER 3

Biodiversity and Ecosystems: Pressures and Climate Impact

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3.1 Switzerland and its biodiversity

Located in the heart of the European Alps, Switzerland has a unique combination of landscapes shaped by millennia of geological and evolutionary processes, and, more recently, land-use and climate change history (BAFU, 2017a; Fauquette et al., 2018; BAFU, 2023a). Mostly mountainous (~70%), its geographic complexity encompasses numerous macro- and micro-climate regions and a wealth of ecosystems and biodiversity, while its position at the interface of four major continental watersheds (Rhine, Rhône, Danube, and Po) connects it to most European biomes (OECD, 2017). Although modest in size, Switzerland possesses a very large number of species, with around 56'000 species of plants, fungi, and animals recorded to date (Figure 3.1) and another 30'000 estimated as yet to be discovered (BAFU, 2023a; BAFU and InfoSpecies, 2023). Thanks to its complex topography and central position among major biomes, Switzerland hosts one of the richest and most diverse flora in Europe (Kempel et al., 2020; Chauvier-Mendes et al., 2024). The country is also home to highly specialized biodiversity, including near-pristine alpine ecosystems and endangered freshwater ecosystems.

Aquatic ecosystems (including lakes, rivers, and groundwater) harbor some of the highest levels of endemism for all organismal groups, in particular fish and groundwater crustaceans (Alexander and Seehausen, 2021; Altermatt et al., 2019; Jardim De Queiroz et al., 2022; Knüsel et al., 2024), making Switzerland's role in maintaining this biodiversity vital. Switzerland's terrestrial and aquatic biodiversity provides significant natural contributions and services to human survival and wellbeing (BAFU, 2017b; OECD, 2017; BAFU, 2023a), but has been on the decline for centuries (BAFU, 2017a, 2023a; OECD, 2017). Current land-use and climate change have put biodiversity at risk locally and globally (Fischer et al., 2018; CBD, 2022), and very industrialized and urbanized countries such as Switzerland are more exposed to serious loss of species diversity (Essl et al., 2013).

3.2 Swiss biodiversity crisis

According to recent assessments, Switzerland has some of the highest percentages of natural threats across the OECD countries, with ~50% of its natural habitats and >30% of its flora and fauna populations under threat, which is much more than most European Union (EU) member states (BAFU, 2017a; OECD, 2017; Widmer et al., 2021; BAFU, 2023a; BAFU and InfoSpecies, 2023), see Figure 3.3. Many inland water ecosystems are at risk, biodiversity-rich grasslands are vanishing, and alluvial zones and wetlands have significantly decreased over the past 150–200 years (Fischer et al., 2015; OECD, 2017). This constitutes a sizable challenge for Switzerland, and the urgency of the situation has now been highlighted through estimates of the areas needed to maintain its biodiversity (Guntern et al., 2013; Rutishauser et al., 2023). Despite political efforts, such as sustaining close ties with the EU in environmental-related matters (e.g., EU's Green Deal; OECD, 2017; BAFU, 2023b; Weber et al., 2019), strong federal solutions to reconcile Switzerland's economic growth and its high resource needs with biodiversity protection and restoration challenges are still needed (BAFU, 2017b; OECD, 2017; SCNAT and Interface Politikstudien, 2022).

Twenty years after the 1992 Rio Conference, where Switzerland signed the Convention of Biological Diversity (CBD), 2012 was a turning point with the adoption of the Swiss Biodiversity Strategy (SBS). Supplemented with a companion action plan in 2017, the SBS aims to strengthen the protection of Switzerland's natural environment, with a particular emphasis on the establishment and integration of an ecological infrastructure at both national and cantonal levels (BAFU, 2017b; Weber et al., 2019). Following an extensive review (BAFU and InfoSpecies, 2023), and an initiative of the Federal Council, the Federal Office of the Environment (BAFU) has been mandated to develop guidelines and measures for the second implementation phase of the SBS (2025–2030). The goals of the SBS can be achieved only if other sectoral policies – e.g. energy – are developed and implemented with biodiversity in mind. See Chapter 7 for the legal implications of implementing the SBS.

3.3 Beyond species diversity

Biodiversity includes multiple facets through which its persistence over time and over space, as well as its role in ecosystem services, can be evaluated (Devictor et al., 2010; Thuiller et al., 2014; Pollock et al., 2017). While the most common metric is species richness, i.e. the number of species in a given area, the shared evolutionary history within and among species (i.e. phylogenetic and genetic diversity respectively) (Jardim De Queiroz et al., 2022) influences the capacity of communities and ecosystems to adapt and be resilient to environmental changes (Lavergne et al., 2010; Winter et al., 2013; BAFU, 2017a). The diversity in morphological traits and ecological roles of species in a community (functional diversity) is also crucial for ensuring the functioning of our ecosystems and the services they provide to people (Petchey and Gaston, 2002; Cardinale et al., 2012; Díaz et al., 2018; Fischer et al., 2018). Beyond ecosystem services, individual species, the diversity of their interactions, and their phylogenetic and functional roles should also be considered in conservation efforts (Jetz et al., 2014; Violle et al., 2017; Ho et al., 2022; Rey et al., 2023).

Each dimension of biodiversity, from genes and species to ecological communities, along with the ecosystem services it provides for human wellbeing and the economy, is strongly dependent on ecosystem intactness. Intactness refers to the extent to which natural environments have been restored to their assumed initial pristine state or have not yet been significantly altered by human activities, i.e. are pristine (Martin and Watson, 2016; Watson et al., 2018). Except for some high-alpine areas, most ecosystems have been modified and none are therefore truly intact in Switzerland (Vittoz et al., 2013), yet today in our heavily modified landscapes, some habitats can be highly biodiverse but depending on some human management practices to be maintained (e.g. dry meadows, some peatlands). Given this situation, national strategies that focus on keeping ecosystems as intact as possible should become the standard in the face of increasing climate change challenges (Martin and Watson, 2016; Rockström et al., 2021) (see also Chapter 5). In addition, preserving and restoring multifunctional ecosystems may be a complementary way towards a more balanced human–nature coexistence into the future (Heinze et al., 2020).

3.4 Human impact and climate change

The numerous threats to Switzerland's biodiversity (Figure 3.1) include increasing land-use change, loss and fragmentation of natural habitats, climate change, pollutants in soils and waters, and spread of invasive exotic species (BAFU, 2017a, 2022a; Cordillot and Klaus, 2011; Fischer et al., 2015). While habitat degradation and the exploitation of land and water resources have been the potentially overshadow other threats, becoming the predominant challenge in the future (Maxwell et al., 2016; Fischer et al., 2018; Barras et al., 2021; Jaureguiberry et al., 2022).

Impacts of climate change in Switzerland are expected to be very heterogeneous across the country with faster warming outside the main plateau, as already shown with alpine greening (Rumpf et al., 2022). Accelerated warming at

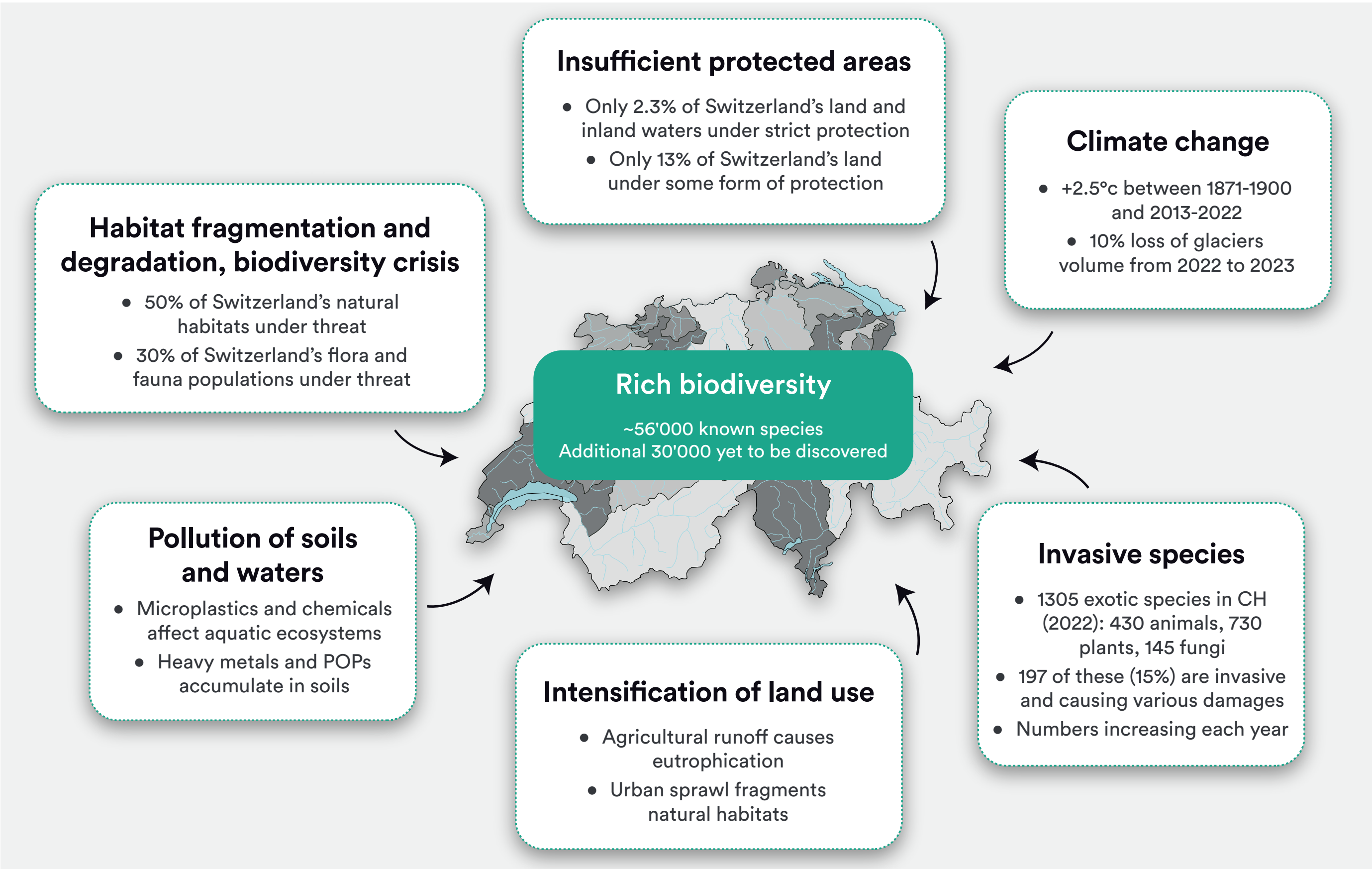

Figure 3.1 | **General overview of the environmental challenges currently faced by Switzerland and expected to increase in the near future**

primary drivers of global biodiversity decline so far, the impact of climate change is increasingly recognized as an interacting factor. As global warming is much more pronounced in cold regions like Switzerland, with an increase of 2.5°C from pre-industrial times (Chapter 2), effects of climate change are expected to escalate and high altitudes caused glaciers to lose 10% of their remaining volume during 2022–2023 alone (GLAMOS, 2023). In fact, under a business-as-usual climate change scenario, glaciers are predicted to largely disappear by the end of the century (Zekollari et al., 2019). This loss has important consequences for the provision of ecosystem services (e.g., water provision, loss of cultural and identity landscapes) as well as considerable effects on aquatic ecosystems (BAFU, 2021a).

The alterations in Swiss biodiversity resulting from these changes are already evident as shifts and contractions in the distributions of various species (BAFU, 2023a). A recent conservation planning study conducted in the European Alps highlighted Switzerland's anticipated role in spearheading efforts to protect the future shifts of multifaceted plant diversity in the region by 2080 (Chauvier-Mendes et al., 2024). But tracking these shifts in certain species could be difficult because of the high level of exploitation and fragmentation of the Swiss landscapes (Jaeger et al., 2008; Vittoz et al., 2013).

In addition, the increase in temperatures is anticipated to be a catalyst for range shifts of southern species northwards (Arlettaz et al., 2024; Chauvier-Mendes et al., 2024), biological invasions, and pests (Petitpierre et al., 2016). For example, 1305 species in Switzerland have exotic origins, with 197 of them already recognized as constituting a threat (BAFU, 2022b). Invasive species not only threaten biodiversity and ecosystems but also pose a threat to human health, economy, and wellbeing (Roy et al., 2023).

3.5 Urgent need for improved conservation at the federal level

Switzerland has made improvements in biodiversity conservation and sustainable ecosystem use with better monitoring[1] (BAFU and InfoSpecies, 2023), a national biodiversity strategy and action plan (BAFU, 2017b), and increased public spending (OECD, 2017). However, despite increased forest cover and a modestly slowed decline in some species groups, there is still insufficient progress: most objectives of the SBS have not been achieved (BAFU, 2017b). Pressures persist from land use changes, pollution, habitat degradation, and climate change (OECD, 2017; BAFU, 2023a). Whereas Switzerland's geographical location is highly strategic for the development of a future transnational European conservation network (Chauvier-Mendes et al., 2024), federal conservation goals and plans have so far been insufficient to halt the ongoing loss of biodiversity and natural resources in the country.

Furthermore, Switzerland possesses a smaller and more fragmented network of protected areas than its neighboring countries (OECD, 2017; Chauvier-Mendes et al., 2024), with only ~13% of land under some form of protection (Guisan et al., 2022b) – half the proportion of land protected in the EU (Eurostat, 2022) (Figure 3.2) – and higher levels of threatened species (Figure 3.3). The quality of its network is also lacking, with protected areas often too small and poorly connected to other protected areas and to European networks (e.g., Natura 2000). Furthermore, only 2.3% of the country's land and inland waters enjoy sensu stricto protection as defined by the International Union for Conservation of Nature (IUCN) category I-II (OECD, 2017; Chauvier-Mendes et al., 2024). The national biodiversity strategy calls for ecological infrastructure – protected areas and connectivity among these areas – to enhance the sustainable preservation of biodiversity and ecosystem services (BAFU, 2021b). The goal set in 2021 was for the ecological infrastructure (Grêt-Regamey et al., 2021) to encompass 17% of the territory under strict protection, with an additional 13% designated for buffering or connecting protected areas, thereby achieving a combined coverage of 30% (BAFU, 2021b, 2017b). This strategy would ensure fulfilling the commitment made by Switzerland at the Kunming-Montreal Global Biodiversity Framework convention of protecting 30% of its land for biodiversity by 2030 (CBD, 2022). Unfortunately, the current situation still falls far short of this target, as shown in Figure 3.2.

1 https://biodiversitymonitoring.ch

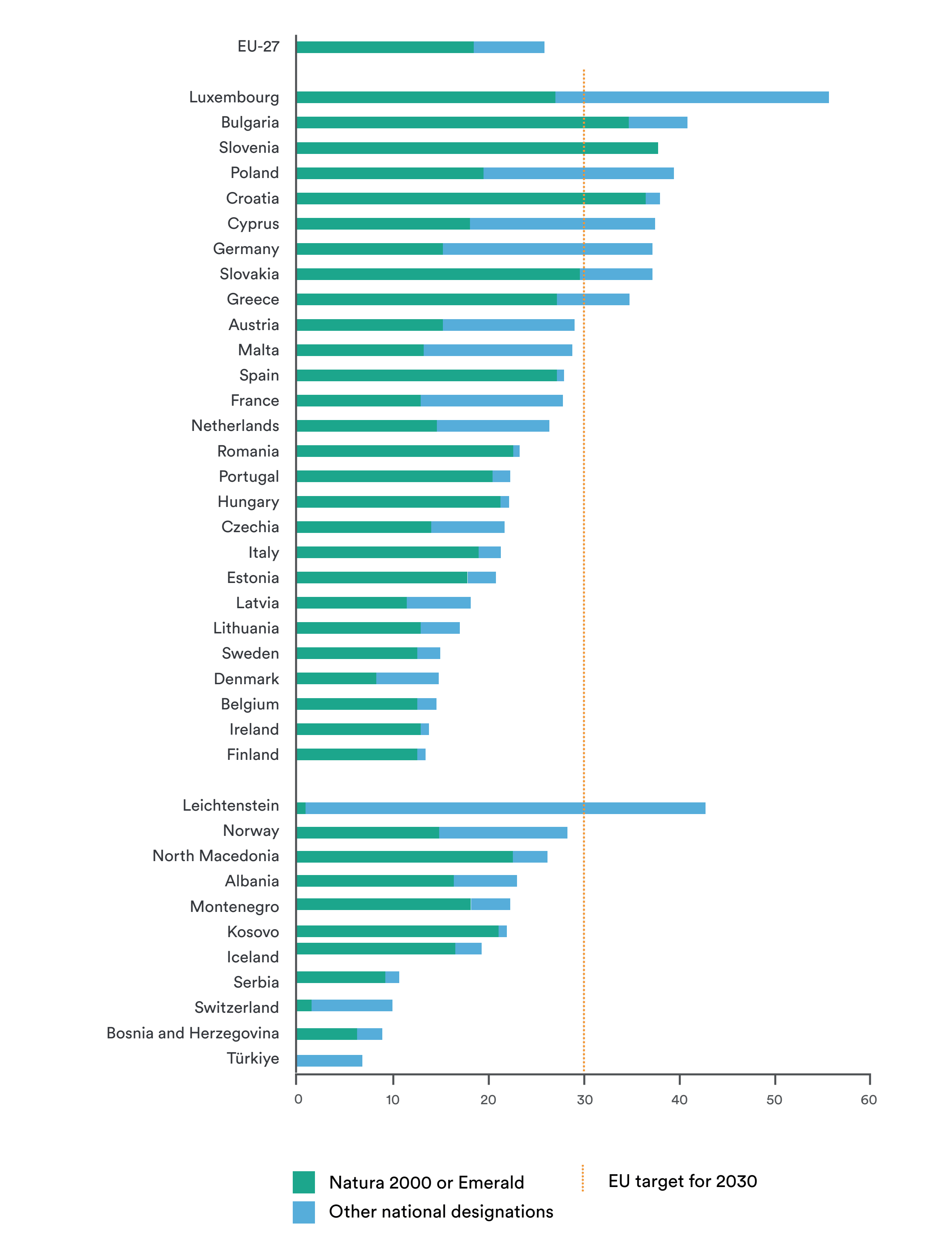

Figure 3.2 | Terrestrial protected area coverage by country and in the EU-27 by the end of 2021 under different designations: Natura 2000 or Emerald Network and other national designations (e.g., national and regional parks). The dashed vertical line delimits the 30% protection target of terrestrial and inland water area by 2030, towards which countries committed under the current Global Biodiversity Framework (GBF) (see Chapter 7). Figure from European Environmental Agency (EEA, 2023a). Data sources: (EEA, 2022a, 2022b, 2020)

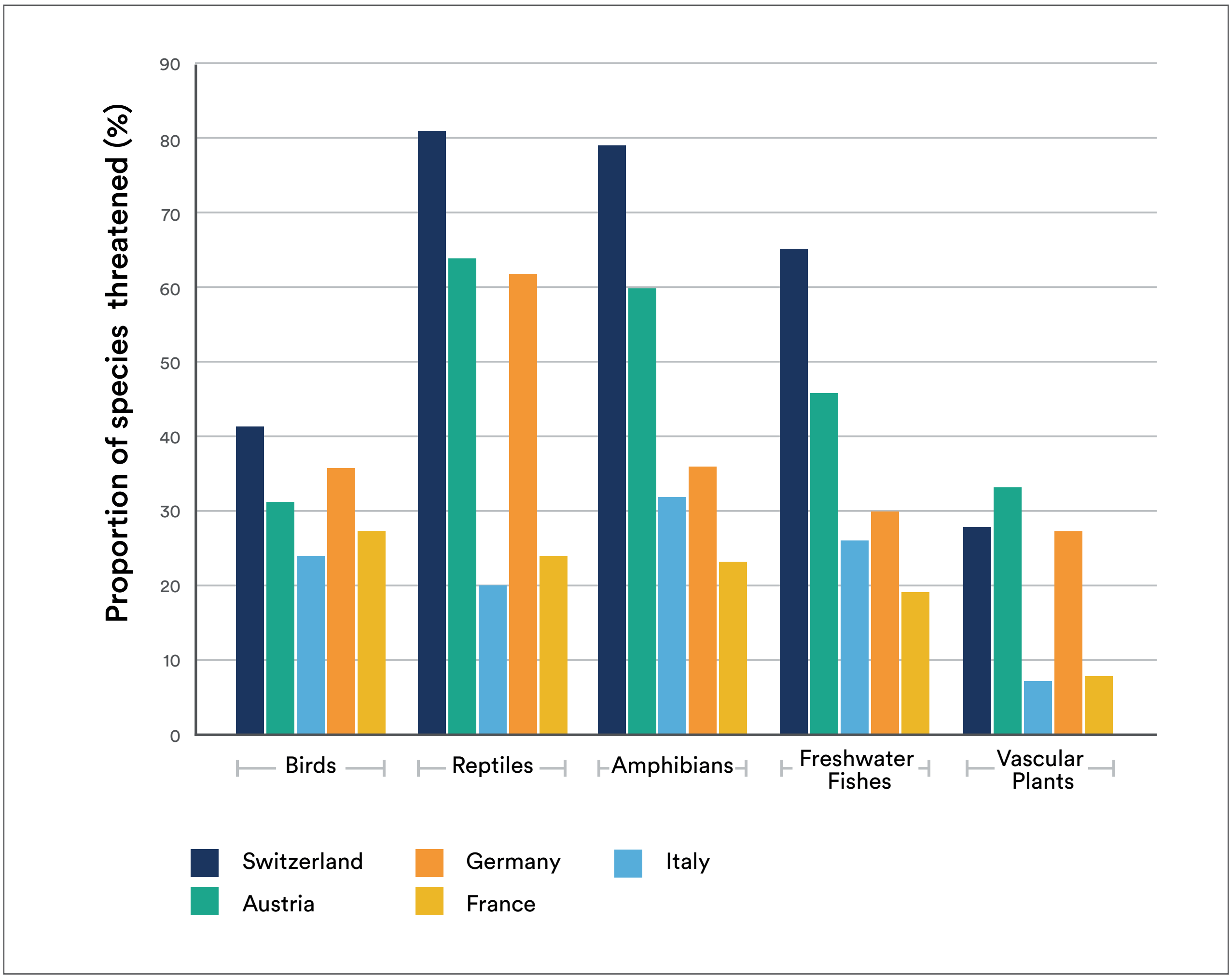

Figure 3.3 | **Percentage of species in Switzerland and neighboring countries that are threatened. This summary accounts for extinct (EX), critically endangered (CR), endangered (EN), and vulnerable species (VU), as classified by the International Union for Conservation and Nature (IUCN) red list. Reproduced from (BAFU and InfoSpecies, 2023).**

3.6 Anticipating conflicts for biodiversity conservation

New impact and conservation studies are needed in Switzerland to forecast more specifically how the overall distribution of biodiversity and ecosystem services in the country will be further affected, and to suggest how to optimize the future expansion and connectedness of the Swiss protected areas network (e.g. toward higher altitudes) at federal (Rutishauser et al., 2023) and transnational scales (Chauvier-Mendes et al. 2024). These studies must anticipate future conflicts with other land-use pressures required by society, including the development of efficient renewable energy infrastructures throughout Switzerland by 2050 (see Chapter 5), as many of these foreseen transitions and changes can have major effects – both direct and indirect – on biodiversity and ecosystem services (Brosse et al., 2022) (see Chapter 2). Key to minimizing negative effects on biodiversity is ensuring that new infrastructure does not overlap with the areas of highest biodiversity and ecosystem service conservation value (Bennun et al., 2021), especially at higher elevations, where less knowledge on species distribution is available (Rutishauser et al., 2023). Ensuring this would facilitate Switzerland's task of both reaching its biodiversity preservation goals and contributing to climate change mitigation by keeping its ecosystems as intact as possible (Chapters 2 and 5).

3.7 Key messages

1. Although modest in size, Switzerland is home to an exceptionally high diversity of species and ecosystems, which provide a wide range of ecosystem services and benefits for Swiss society and neighboring countries.
2. The multiple facets of biodiversity and ecosystems, and the services they provide, are threatened in Switzerland, in large part due to habitat loss and land/water degradation, and are increasingly at risk due to climate change.
3. Improved conservation actions are needed at the federal level to better protect biodiversity throughout the country, as only 2.3% of Switzerland’s lands and waters are currently under strict protection, and 13.4% under some level of protection.
4. Given this situation, new renewable energy developments should not degrade biodiversity and ecosystems further.

Supports recommendations:

3 4 5 7

CHAPTER 4

CHAPTER 4

Current Renewable Energy Landscape and Challenges

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4.1 Key issues

The key aspects of the decarbonization of the Swiss energy landscape will be significant efficiency gains (better insulation of buildings, renovation, energy-efficient heating, ventilation, cooling, circulation systems, etc.) and a switch to electricity, in particular for mobility and heating. Efficiency and clean energy are unlikely to lead to net zero rapidly enough to meet Swiss international commitments; sufficiency measures and policies will have to be systematically included in all areas of society. Although this will lead to a significant reduction of the total energy demand, it will still require a 50% increase in the domestic electricity supply over the current level, from 60 to 90 TWh per year (BFE, 2022a). In addition, 23 TWh of nuclear electricity must be replaced. Thus, Switzerland will need to increase its annual electricity supply by around 50 TWh by 2050, either by increasing domestic supply or through imports.

In addition, Switzerland faces the major challenge of increased electricity demand in winter. There is already a shortage of domestic winter supply, and legal or technical risks could restrict use of the grid for additional imports in winter. The imbalance between electricity supply in summer and demand in winter would be exacerbated if conventional (rooftop-) photovoltaic (PV) systems were the only ones deployed. Both wind and PV installed in alpine regions generate significant energy in winter (around 66% of the annual electricity output is generated in winter for wind and around 45–50% for alpine PV). Such installations would help relieve both the short- and long-term risks to the electricity supply in winter, and, in conjunction with biomass and energy from waste, make it easier to progressively exit nuclear power. Moreover, wind and PV complement the Swiss hydroelectric system and its planned adaptation particularly well, as hydro-energy can be partially stored for winter supply, and because it can help cover the fluctuating wind and solar electricity supply.

From a cost perspective, from a resilience and autonomy perspective, from a CO_2 perspective, and from the perspective of preventing pollution in other countries, extensive development of PV and wind and a moderate development of hydro are key to the Swiss energy transition. Wind and solar are remarkably good for CO_2 avoidance and have small ground footprints (e.g. for the supports of PV systems or the construction supporting the wind turbines). Alpine PV induces only a minor reduction in ground irradiance during the growing season because of the configuration of installations in the alpine environment: they must be elevated and widely spaced. So far, the partial shading by PV systems in already degraded environments has been reported as promoting biodiversity and protecting against over-radiation, but there is little to no experience to draw on for PV systems in natural ecosystems and especially in the fragile alpine environment. Thus, close follow-up and assessment of the first projects will be important.

The major environmental impact of Alpine PV or wind will be from new roads and additional traffic, from damage to soil during installation, and possibly from fragmentation of habitat if fences are used. Wind turbines in specific locations could have additional environmental effects, e.g. for endangered bird species; these can be partly mitigated through careful site selection, the use of warning tools, the mapping of critical locations, and/or automated stopping during migration time.

Hydropower, already extensively developed in Switzerland, exerts high pressure on aquatic ecosystems. New or modified dam infrastructures will further increase pressure on freshwater biodiversity, and make the way in which environmental flow requirements are set and managed more central. Finally, it has to be noted that all Alpine PV, wind, and hydro projects have to provide extensive studies of their impact as well as recommendations and/or compensations for possible environmental effects.

Better energy efficiency and a greatly expanded clean energy supply will not be enough to get to net zero by 2050. This goal can only be reached if "policy packages, which combine ambitious sufficiency, efficiency, and renewable energy measures, are effectively implemented and barriers to decarbonization are removed", to achieve "demand-side mitigation encompass[ing] changes in infrastructure use, end-use technology adoption, and socio-cultural and behavioral change" (IPCC, 2022b). Furthermore, household consumption and behavioral decisions cannot be ignored, and simply retrofitting housing and supplying clean energy will not produce net-zero outcomes; dedicated sufficiency policies are required, aligned with household living situations (Dubois et al., 2019). Finally, even at the level of a single sector such as housing, with widely available technology, the transformation to net zero before 2050 requires significant societal efforts and a strong focus on sufficiency (Nick, 2024).

4.2 The energy situation in Switzerland

The annual domestic net energy demand in Switzerland peaked between 2005 and 2015 at just below 250 TWh. Since then, it has decreased, reaching 213 TWh in 2023 (BFE, 2022a, 2023). Electricity represented 56.1 TWh or 26.3% of that total, while fossil energy represented 126 TWh, i.e. almost 60%. Electricity supply is predominantly from hydropower (40.8 TWh) and from nuclear energy (23 TWh), whereas solar energy and wind turbines contributed 4.6 TWh and 0.17 TWh, respectively. Fossil energy was used mainly as fuel for mobility (74.5 TWh) and heating (52 TWh).

In the coming years, three important developments will change this distribution from 2023. First, mobility will shift increasingly towards electric vehicles; second, more and more buildings will be heated by heat-pumps; and third, nuclear reactors are unlikely to be renewed. To meet the increasing electricity needs for decarbonization, the Swiss Parliament accepted in the new electricity law (Fedlex, 2023), confirmed by the referendum of 9 June 2024, the mandate that the supply of new RE (excluding hydro) reach 35 TWh in 2035 and 45 TWh 2050, compared to 5 TWh in 2022. The hydropower supply is to be 37.9 TWh in 2035 and 39.2 TWh in 2050. The law prioritizes the building of new dams and the adaptation of existing dams, but it does not include specific targets for new renewable technologies (PV, wind, biomass, geothermal). The law also states that electricity imports should not exceed 5 TWh in the October to March period. Indeed from a purely technical point of view, such a goal would be easiest to achieve with mostly wind energy and high altitude solar.

In addition to the new electricity law, the Solar Express legislation aims for an additional 2 TWh of electricity from high elevation PV systems (with a specific production of at least 500 kWh/kWp during winter). To benefit from the 60% subsidy on the system costs, an Alpine PV system must be operational at minimum 10% of its capacity by the end of 2025.

At the same time, the Wind Express legislation accelerates procedures for wind turbine projects at an advanced planning stage. The Wind Express and Solar Express legislation address the security of supply for Switzerland, which could become critical by the end of the current decade. In particular, Alpine PV should not replace rooftop or other traditional PV systems, but supplement them, with the goal of supplying one extra TWh of electricity in the winter season by around 2030.

4.3 Hydro energy

The target values for hydropower are close to the average of the electricity supply in recent years, with the exception of the unusually low supply in 2022. Of around 2300 registered hydropower plants in Switzerland, 195 plants have a capacity exceeding 10 MW, collectively contributing 90% of the Swiss hydropower production (BFE, 2022a). To expand hydropower supply in Switzerland, a broad alliance known as the roundtable on hydropower identified 15 sites that could provide an additional 2 TWh of winter electricity using storage power plants (UVEK, 2021). At 11 of the 15 sites, storage capacity would be increased by raising dam heights. New dams would be built at two of the locations, and new areas would be connected to the existing scheme at the last two (UVEK, 2021). The increasing storage capacity would increase the potential for shifting electricity supply from summer to winter. Under climate change, flow conditions in Swiss rivers will continue to change, particularly without climate mitigation measures (NCCS, 2021). Observations indicate a trend of more precipitation falling as rain and a rising snow line, leading to increased winter streamflow in high elevations, and thus to higher hydropower supply in winter (Wechsler and Stähli, 2019).

Intensive hydropower also impacts aquatic ecosystems, which are already under high pressure due to anthropogenic impacts (Lanz et al., 2021). Hydropower modifies flow conditions, sediment transport, and connectivity of aquatic habitats. Switzerland ranks fourth globally in the number of extinct fish species, and 60% of the remaining fish species face extinction (Altermatt et al., 2022a). Key to creating diverse habitats in rivers affected by hydropower are sufficient water depth and wetted areas, which enable longitudinal, transverse (between banks), and horizontal (between surface water and groundwater) connections. By 2030, Swiss hydropower operators are required to restore fish migration routes, sediment transport processes, and hydropeaking, to reduce negative impacts of hydropower on the aquatic ecosystem (Lanz et al., 2021).

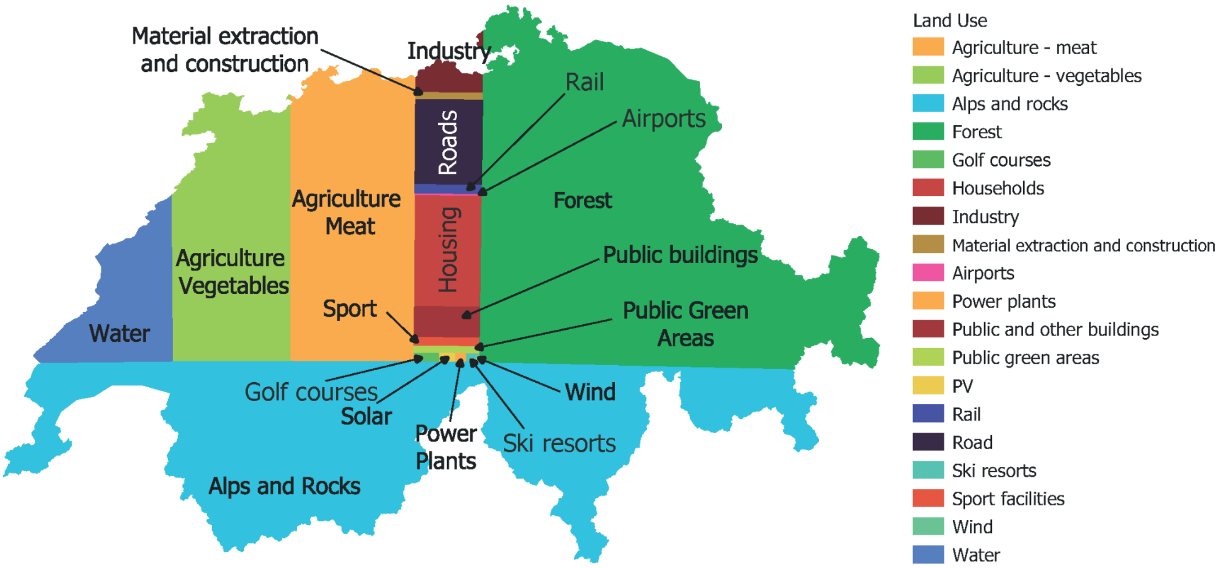

Figure 4.1 | **Illustration of area land use in Switzerland (Bundesamt für Statistik BFS, 2018), accessed 4 July 2024, cartography by N. Jeannin. The tiny area for solar and wind correspond to the prospective areas which could be occupied if the Solar Express legislation is fully implemented (around 20-25 km^2) , and the direct land use for around 3000 wind turbines.**

4.4 PV potential and development

Within the above-mentioned target values of new renewable electricity supply in Switzerland, i.e. 35 TWh in 2035 and 45 TWh by 2050, PV is expected to cover a major share. To reach the target values, the annual installation volume should be at least in the range of 1.7 to 2 GWp/year after 2025.[2]

Assuming a moderate module efficiency of 20%, installing 2 GWp/year would correspond to a total PV module area of 10 km^2/year. For a free-standing ground installation, where module rows are usually spaced for access or double-use, such as grazing, or to ensure reflection or albedo from the ground, the requirement for the actual ground area would be in the range of 15–30 km^2/year. Noticeably, except for industrial land, or in specific cases such as the Solar Express legislation, it is not foreseen to install ground mounting systems, with a maximum usage planned on existing infrastructure Figure 4.1 illustrates the area that would be impacted by PV in case of full realization of the Solar Express.

The potential for using existing buildings for PV installations has been assessed in several studies. Based purely on orientation and shadowing, roof areas and façades could potentially provide 49 and 17 TWh (Anderegg et al., 2022), respectively, thus greatly surpassing the target values for 2050. However, when socio-economic and practical considerations are also taken into account, roofs and facades could more realistically provide about 23 and 8 TWh, respectively (Remund et al., 2019). Vertical installations on façades are particularly valuable as they offer a better balance

2 The unit W or Wp denotes the nominal capacity of a PV system. In Switzerland, a capacity of 1 GW averages to a supply of around 1 GWx1000 hours = 1 TWh over one year for typical rooftop systems on the plateau.

between summer and winter electricity supply. Whereas technically more difficult to realize than rooftop systems, they can be implemented in conjunction with energy-efficient building renovation that contributes to reducing the heating demand in winter. In combination, PV on existing buildings could provide about 60% of the target according to the numbers, but it would require a significant effort by house and building owners. Notably, PV (and thermal) systems on the envelope of existing buildings and other infrastructure impacts biodiversity only minimally (Desing et al., 2019). PV can also be combined with green roofs, increasing biodiversity in urban spaces, cooling buildings, and increasing PV yield due to the cooling effect on PV panels (Fleck et al., 2022). Nevertheless, when the need for additional winter electricity and typical fog patterns are taken into account, the benefit of unconventional installation at higher altitudes is clear.

Given the geography of Switzerland, these extra PV installations would need to be integrated either with land used for agriculture in the plateau or with pastures in the Alps or the Jura. It is important to note that for both types of installations, alpine and agricultural[3], the ground area is not sealed; the only deep disruption is the anchoring of fixation poles and for most types of installation, the ground remains covered with plants. Potentially, PV installations on land also used for agriculture could provide 132 TWh, but again considerations such as accessibility and proximity to the electricity grid reduce this to a realistic value of about 30 TWh (Jäger et al., 2022). The potential for Alpine installations is estimated to be around 16 TWh, but here, considerations of accessibility yield the more modest value of only 3.3 TWh (Remund et al., 2019). Depending on the definition of "alpine environment" the estimated potential could be substantially larger (Ratnaweera et al., 2023).

4.5 PV in the alpine environment and winter electricity supply

The alpine environment is interesting as it offers a variety of advantages specifically for PVs. Higher altitudes provide a higher incident radiation and the high albedo of snow-covered ground boosts electricity supply in winter (Kahl et al., 2019), especially when bifacial modules are installed at high-yield locations (Von Rütte et al., 2021). A field study reported a yield of 1870 kWh/kWp for bifacial modules with a near-vertical mounting angle of 70°, a massive increase from the Swiss average of 980 kWh/kWp and largely due to a three-fold increase of winter productivity (Anderegg et al., 2020). The study did not consider possible partial shading provided by the other module rows, which, if too close, will impact the energy yield. To secure the precious supply of electricity in winter as soon as possible, it is strategically attractive to quickly deploy solar parks in the alpine environments in addition to more traditional PVs. To this end, it is essential to develop technological solutions that can withstand the harsher conditions of the alpine environment at a competitive cost and to select suitable design options such that snow accumulation would not cover panels.

Given these challenges, the Solar Express legislation will heavily support Alpine PV installations with up to 60% investment support for the installation until a nominal production of 2 TWh/year is reached. This corresponds to an installed capacity of 1.3–1.5 GWp, or 6.3 to 7 km^2 of panels with high winter production yield. The impacted landscape (at least visually) area will typically be a factor 3 to 4 higher because of the spacing between the module rows Even though reference is often made to "Alpine" PV systems – which would suggest the alpine environment at or above tree-line, which is at altitudes of around 2000 meters in the Alps – Indeed several potential Solar Express projects are

3 PV combined with agriculture is referred to as Agrivoltaics, as discussed in more detail in Chapter 5 (Sturchio and Knapp, 2023). In principle it allows for smaller and lower cost systems than Alpine PV.

mostly on altitudes slightly about 1700 meters, and even projects at lower altitude (e.g. Mont-Soleil at 1200 m) will apply for funding. Some of the propositions have been discarded already because of negative votes by the population, but overall more have been accepted than refused: the known plans for Alpine installation already add up to about the subsidized capacity.

It is still likely that some of the planned projects will not be realized in the end because the investment costs turn out to be higher than initially planned. This is due to a combination of constraints such as height above the ground, wind load, snow accumulation, and PV module resistance to the more extreme environment (thermal cycling, ice, higher UV doses, snow load from accumulation etc), resulting in many unknowns with respect to the reliability of such Alpine systems and potentially incurring additional financial risks for those projects that receive authorization. Furthermore, the projects are under tight timing as they must be partially operational before the end of 2025. An overview of the projects and their current status can be obtained from the official site, which shows them as soon as public inquiry is started (BFE, 2024); see Figures 4.2 and 4.3. Alternatively, a consortium of universities of applied science show the status for the around 50 solar parks announced so far (ZHAW et al., 2024) . At the time of writing, four building permits had been approved by the authorities, with two of them entering into force. An example of such a project is Morgeten[4]. Less than 18 months before the first grid connection deadline, there is around ⅕ of the planned initial capacity which is now going through a legal process.

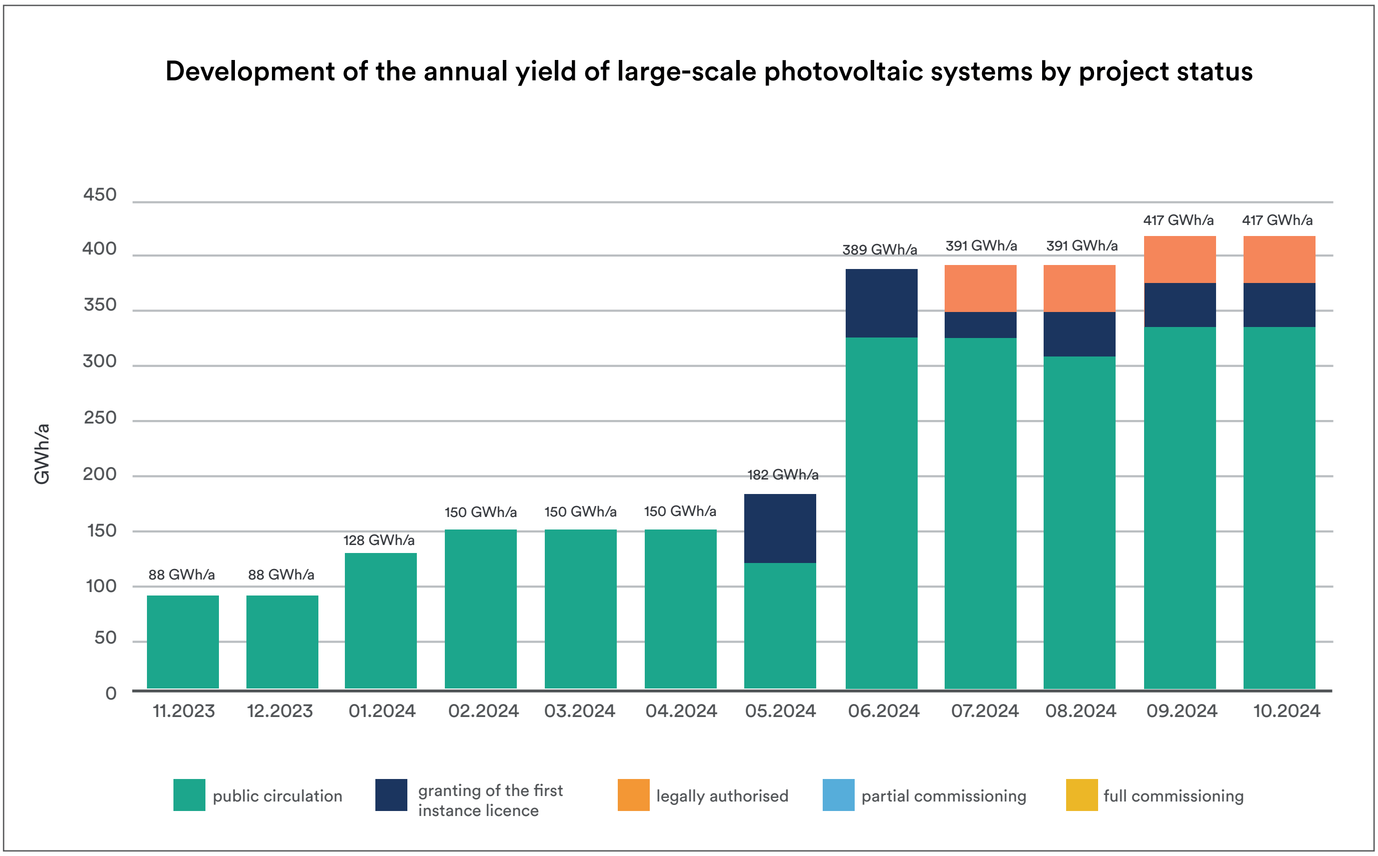

Figure 4.2 | **Status of deposited projects, BFE Large-scale photovoltaic systems (BFE, 2024), status 06.10.2024.**

4 https://www.morgeten.ch/solarprojekt-morgeten

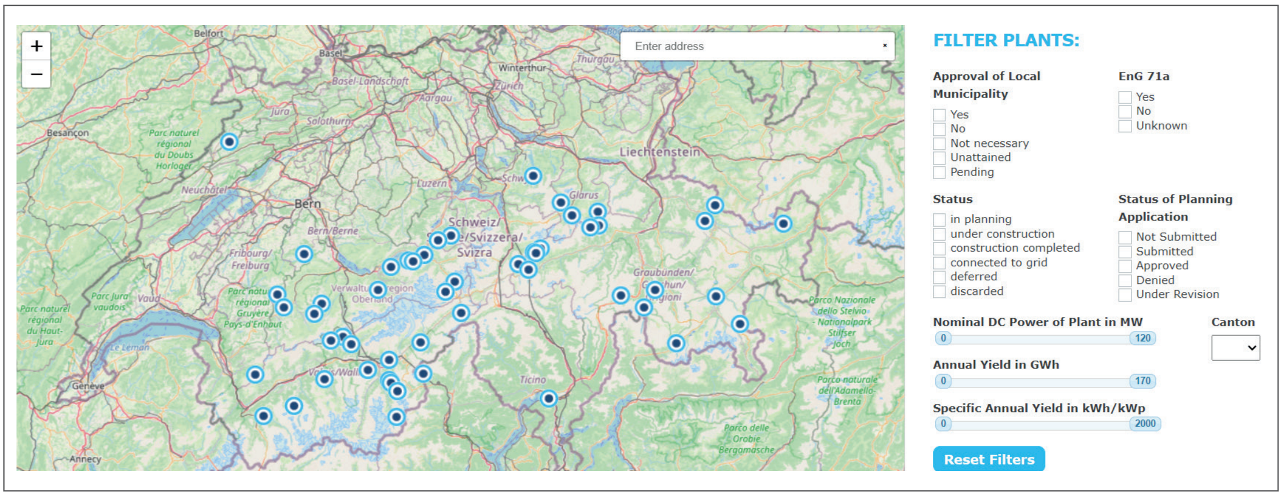

Figure 4.3 | **Overview of all initial "Alpine PV" projects (ZHAW et al., 2024). The development of each project can be followed by selecting the different sites on alpine-pv.ch**

There is no prioritization of solar parks within the framework of Solar Express (BFE, 2024) at either the cantonal or the federal level, but for all installations with a capacity of 5 MWp or more (excluding building-integrated installations), a study of their environmental impact (Etude d'impact sur l'environnement, EIE) is required by cantonal regulations (Fedlex, 1988). For example, in 2023 the Canton of Bern organized three roundtable discussions focused on solar initiatives, involving project stakeholders, relevant offices, grid operators, environmental associations, etc. The goal was to gain a more precise understanding of ongoing projects and identify those with limited chances of realization (insufficient network capacity, locations made unsuitable by natural hazard, proximity to protected zones, etc.). This process did not result in a full prioritization, but it provided a simple estimation of the likelihood of realization by categorizing ongoing projects as green, orange, or red. A document was created describing the authorization process for large PV installations (AUE Kanton Bern, 2023). A similar document exists for the canton of the Grisons (ARE and AEV, 2023). It stipulates that the environmental impact analysis should be published during the public inquiry process (as outlined on page 19 therein). However, that publication may be available only in paper form at the local municipality.

Overall, it becomes questionable whether the choice of large solar parks, which have the advantage of being considered of national importance, is the path towards Alpine PV. Their comparatively large minimum size tends to create a strong public debate and sometimes opposition, mostly about landscape preservation, as discussed in more detail in Chapter 6. The required minimum size also reduces the possible locations, often making it costly to connect them to the grid. In that sense, it would likely be less costly to consider smaller parks near existing infrastructures at high altitude. For example, ski areas may be suitable as they are often already impacted with partly denatured ground and usually close to a grid connection, likely allowing for lower electricity production costs and investments.

4.6 Wind energy and contribution to winter electricity supply

The practical potential for wind energy in Switzerland has been estimated conservatively at 30 TWh (Suisse Eole, 2020; Meyer et al., 2022), of which around 20 TWh could be produced in the winter. Deploying wind at full scale would allow Switzerland to become de facto autonomous in terms of electricity supply, and it would likely be the most technically and financially feasible.

Because of lack of acceptance (Gisler et al., 2024; Salak et al., 2024), and the complexity of procedures, the initial target in the Energy Strategy for 2050 translated to a rather modest electricity supply of 4.3 TWh (BFE, 2022b). Nevertheless, even this would represent an almost 25-fold increase from 2023 when (the very low number of) 43 wind turbines produced 0.17 TWh (BFE, 2023, 2022a). Such a target could be met even with moderate deployment in less critical zones. For comparison, in our neighboring country Austria, close to 1400 wind turbines produced 7.9 TWh in 2023.

As with Alpine PV installations, wind energy is very beneficial for winter supply (Kruyt et al., 2017). Winter productivity depends on many parameters, from the productivity profile of the varied locations in the complex mountain terrain to the size of the wind turbines: the general rule is "the bigger, the better". However, large turbines are cumbersome to transport and can be difficult to install, if not impossible at some windy sites. Some locations are particularly advantageous for winter supply, while installations in valleys such as those in Trimmis or Martigny may have higher summer supply. According to an analysis of the most promising locations for wind turbines in Switzerland, the electricity supply in winter is 66% of the total annual supply (Dujardin et al., 2021). Combined with seasonal hydro storage, PV and wind would allow Switzerland to balance its electricity needs between summer and winter very effectively (Kruyt et al., 2017).

Currently, the selection of sites in the cantonal development plans indirectly prioritizes some wind park locations. In 2023, the Conference of Swiss Environmental Protection Offices (KVU) published guidelines for conducting environmental assessment for wind park projects (Leutenegger et al., 2023). For example, the wind farm project in Tramelan/BE has a valid building permit. Local municipalities and the Federal Courts have validated the land use for seven additional projects, allowing them to benefit from the provisions of the Wind Express; the building permits are issued by the canton, and only two appeal instances are possible. An appeal to the Federal Court is only permitted for clarifying legal questions of fundamental importance. One project is awaiting a decision from the Federal Court regarding land use planning, while three projects are awaiting a decision from the cantonal court. All 12 projects have been approved by the local municipalities, with a total capacity of 270 MW.

4.7 The global challenge of winter electricity supply

Unless significant measures are taken in the coming years, Switzerland will have to meet its increasing electricity demand either by importing larger amounts of electricity in winter, or by using more fossil fuels for electricity supply; alternative supply based on hydrogen or other forms of chemical storage/transport might be possible by 2040–2050. The issue of winter electricity is further complicated by the lack of an electricity agreement between Switzerland and the EU; one is still under discussion. The possibility of import restrictions or of being forced to turn to the costly spot market for supply makes it a strategic necessity for Switzerland to reinforce its winter electricity supply as quickly as possible. As a result, the Swiss government is willing to support PV systems in the alpine environment (although only for a limited time), to speed up the administrative processes for wind parks (although only for existing projects), and to promote the creation of additional hydro storage capacity. Classical PV can contribute, but only if the installed capacity is massively increased and over-supply is either curtailed in summer, or used for other purposes (e.g. power-to-gas, thermal storage, etc.)

Of course, every effort to reduce energy use in winter will help reduce the imbalance between demand and supply. The Confederation's scenario calls for improved insulation of buildings, but that is challenging in terms of cost and workforce. Storing electricity from summer to winter, except in large hydro, is challenging and costly, especially when considering power-to-gas. Other limited options that can help reduce the imbalance include producing electricity or combined heat-electricity from waste and biomass, or installing seasonal heat storage to reduce the energy required by heat pumps in winter. We do not address the challenge and potential of biomass in this chapter. Noticeably biomass is still the second source of renewable energy in Switzerland behind hydro, but its potential is limited.

4.8 Direct and indirect impact of Alpine PV and wind turbines, potential of CO_2 avoidance

Alpine PV differs from conventional installations in that its PV elements are located higher above the ground to be above the snow, and widely spaced and at near-vertical angles to avoid shadowing under the shallow incidence angle of the winter season. Assuming the terrain does not need to be leveled, the direct ground impact can be made very small. The ratio between PV panel area and ground or ground cover ratio (GCR) area is likely to be in the range of 1 to 3 or even 1 to 4. Even though this can increase the overall visual impact, sunlight reaches the ground more easily in the summer due to the steeper angle of incidence. As the solar panels are tilted, the reduction of irradiance over the growing season is estimated to be smaller than the GCR and likely in the range of 15 to 20%, creating an irradiance change similar to the difference between south- and west-oriented slopes. As Alpine PV systems have not yet been deployed at large scale, it will be essential to closely monitor the first installed systems in order to understand the impact of new projects on ecological conditions and processes, using the before-after-control impact study design. At least some information on the impact of constructing in the alpine environment could potentially be gleaned by studying existing structures for avalanche protection or in areas with ski tourism. Studies at low altitude in managed landscapes in the UK suggest that ground-mounted PV systems tend to promote species richness (plants, insects, birds) through partial shading, renaturation and reduced management (Montag et al., 2016), whereas other studies report changes in ecosystem dynamics under agrivoltaic systems (Andrew et al., 2021; Sturchio et al., 2022). Small exploratory experiments at higher altitude in Switzerland suggested that shadowing from a single horizontal element 30 cm above ground did not change the above-ground plant biomass, but reduced below-ground biomass by 18%, with plants producing longer and finer stalks (Möhl et al., 2020). Yet, our knowledge of impacts of large-scale alpine PV is still very limited.

Shading effects of PV also lead to concerns of a reduced CO_2 capture in the vegetation and soil. However, if they replace traditional methods of electricity supply, the use of PV or wind turbines would still lead to a significant overall reduction of CO_2 emissions. For instance, a square meter of modules can generate around 300 kWh per year; its substitution for fossil fuels for transport or heating (a major goal of the energy transition) would lead to a reduction of CO_2 emission of around 200 kg per m^2 of PV module per year, i.e. over 5 tons per m^2 of module over the expected lifetime of 25 years. The ground impact (typically poles) will be only a few percent of the module area. Hence, there is very little negative impact due to loss of trapped CO_2 or non-captured CO_2 in the ground. Likewise, a 2.5 MW wind turbine, producing 4 GWh per year, would prevent the emission of 800 tons of CO_2 per year – 20'000 tons over 25 years. Assuming an impacted area of 1000 m^2 per wind turbine, this would avoid over 20 t/m^2 of affected ground (potentially more when considering only the area of the foundation after renaturing access roads etc.), several orders of magnitude more than what the same ground area can store. As similar calculations do not exist for alpine ecosystem carbon sequestration, caution is however needed until proper measures and comparisons are made.

4.9 Possible critical impacts

Apart from the impact on flora and fauna, the impact of Alpine PV or wind on otherwise pristine landscapes must be considered. Whereas the visual impact cannot be denied, it is ultimately a societal choice in favor of decarbonization and security of electricity supply.

As seen earlier, the most critical aspects of Alpine PV are hence not likely linked to surface usage, or modification of local CO_2 embedded in the ground, or even vegetation change to irradiance modification. Whereas suitable mounting structures limit the direct ground impact of PV, as shown in Figure 4.4, a larger surface area could be damaged during the installation of the systems, especially if it is carried out during rainy periods. Hence a strong recommendation, e.g. from the Morgerten Alpine PV Environmental impact assessment, is to perform tasks on the ground during dry (or drier) periods.

For wind turbines as well as for solar parks in remote areas, new or more frequented access roads put additional pressure on the fauna. In case of PV, a potential additional impact could come from fences that prevent animals from passing around PV areas, but as those are generally intended for security and to avoid vandalism, they may not be needed for remote installations. In the case of wind turbines, the main concern is birds and bats colliding with the turbine blades. Whereas overall bird deaths linked to wind turbines are per se not a critical pressure on bird populations, major risks to large predators are likely, and in some cases to bats (Ritchie, 2024); interference with migratory channels is also a concern. These issues can be mitigated by careful site selection (Vignali et al., 2022), implementing anti-collision measures such as painted blades, sound warnings, and automatic shutdowns when birds are detected, and by suspending operations during bird migration periods. Another possible mitigation measure is to create a pond at a certain distance, to attract bats far from the turbines. These are typically included in the guidelines for good practices and recommendations for the environmental impact of wind parks (Leutenegger et al., 2023). Recently the Swiss Academy of Natural Sciences prepared a document with suggestions for mitigating the conflicts arising between the preservation and promotion of biodiversity and landscape quality (note that these criteria are not considered in this chapter). These recommendations for spatial planning could help cantons, energy producers, and other interested groups (Neu et al., 2024). The white paper of the Speed2Zero consortium also provides recommendations on how to balance biodiversity, energy security, and landscape preservation (Brunner et al., 2024).

This chapter mostly discussed the impact on the environment. There are multiple other impacts, such as possible modification of the air mass behavior, including a possible heating of the environment (Barron-Gafford et al., 2016) or cooling of PV panel for higher positioning above ground (Prilliman et al., 2022). Also, for large PV parks, an impact on snow deposition and retention zone could increase (or decrease) the risk of avalanches, which could even cover and/or destroy parts of the PV plant itself due to wind accumulation zones. Such risk analyses are usually part of the process to obtain the building permit.

Figure 4.4 | **Example of bifacial Alpine PV systems with low ground impact. Top left: Simulation of the SolSarine Project (Impact Gstaad Association, 2024). Right: Prototype system to remove snow through a whirlwind effect (installed in Sölden, Austria, photography by J. Cattin). Bottom left: artistic view of the PV project in Samedan (Energia Samedan and TNC Consulting AG, 2024).**

4.10 Key messages

1. Even with major efforts in energy efficiency, a significant deployment of solar and, ideally, wind is required for Switzerland to make a successful energy transition. Technically a system based mostly on PV and wind, in addition to hydro, would be ideal to meet most of the future electricity demand of a decarbonized Switzerland. Beyond efficiency and clean energy, achieving net zero requires a strong and coordinated focus on sufficiency, leading to a reduction in the use of goods and services.
2. The demand for additional winter electricity would be particularly well served by an increased share of Alpine PV and wind, and an adaptation of the hydrosystems. In the short term, Alpine PV and some winter wind electricity would supplement standard rooftop PV systems, increasing the resilience and security of the Swiss electricity system.
3. In principle, the adoption of good practices and planning (e.g. installing PV when the ground is dry) could limit the direct ground impact of RE infrastructures. These installations should always be built in ways that minimize the overall impact on the site biodiversity. For example, sometimes, the impact in the immediate vicinity could be minimal, but could cause ecological changes at larger scale (e.g. in terms of species interactions such as seed dispersal by alpine grouse, chamoix, deer, or ibex).
4. In the alpine environment, sites should preferably be selected in areas that already have road access and in areas that have already been modified by humans. Care should be taken to avoid fences and increased traffic or other human presence after the installation, thus avoiding additional pressure on ecosystems. In the case of wind energy, avoiding harm to birds and bats should be considered essential additional site criteria, including site selection and anti-collision measures.
5. Large-scale projects must include environmental impact studies and possible nature compensation plans. Still, because there are few equivalent projects, e.g. in the case of Alpine PV, a detailed follow-up of the impact should be a priority after installation, which will be extremely useful in the event of any later extension.
6. Prioritization is currently impossible at the federal level, and each Swiss canton maintains a high degree of independence. Having a national deployment strategy would be helpful, and could make it easier to rapidly abandon the most problematic sites. Still, the situation encourages some competition and ensures enough projects are submitted.
7. Especially for Alpine PV, costly technical challenges and short deadlines might greatly limit the number of projects realized within the framework of the Solar Express legislation.
8. Adapting the Solar Express in the future to smaller parks located near existing tourism or skiing infrastructure would likely reduce both costs and the number of critical aspects because of the proximity to the electricity grid and to transport routes, and an already degraded environment.
9. To increase winter hydropower production by 2 TWh, a broad alliance has evaluated 15 projects. An important aspect of this evaluation must be the negative impacts of hydropower on aquatic habitats, such as fish migration, sediment transport, and hydropeaking, if biodiversity loss is to be counteracted.

Supports recommendations:

1 3 4 7 8

CHAPTER 5

CHAPTER 5

Developing Renewable Energy while Preserving Biodiversity: Impacts, Trade-Offs, and Synergies

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5.1 Introduction

The rapid phase-out of fossil fuels, besides serving the goal of achieving energy efficiency and sufficiency, might entail an intensification of land use for the installation of new electricity generation units to rapidly increase renewable energy (RE) capacity (Fthenakis and Kim, 2009). Ideally, most of this development should be carried out on existing settlements and other human infrastructure (Desing et al., 2019). Still, there is increasing pressure to expand the development beyond these areas to speed up the transition to net-zero emissions by 2050 (Chapters 2, 4). This poses a major threat to biodiversity, habitats, and landscapes of natural, social, and economic importance (some of them still nearly intact), especially those of high conservation value that are not currently protected by Swiss law (e.g. high alpine alluvial and periglacial zones for hydropower, and alpine grasslands for PV under the revised Swiss energy law; Chapter 3, 4). In Switzerland, this RE transition is foreseen to rely primarily on a massive development of solar photovoltaic (PV) and wind energy production, and secondarily on increased hydropower capacity (Chapter 4). Hydropower production already accounts for more than half of domestic electricity production (BFE, 2022c, 2022b; Boulouchos et al., 2022); while renewable, it is not necessarily sustainable, with current hydropower infrastructure already heavily impacting aquatic and alluvial biodiversity (Lange et al., 2019; Reid et al., 2019).

However, the potential for hydropower expansion in Switzerland is more constrained than for solar and wind energy (Altermatt et al., 2022b) (Chapter 4). Unlike in other European countries, wind energy and PV are currently lagging far behind their potential in Switzerland (Chapter 4), and both the negative and positive impacts of their deployment on biodiversity are largely unrecognized by energy developers and policymakers (Chapters 3 and 6). In light of impact uncertainties, a safe option to avoid or minimize biodiversity impacts would be to expand and develop new RE infrastructure primarily on buildings and other already existing human infrastructures (e.g. industrial areas) (Ismail et al., 2021; Salak et al., 2024) and on intensively managed, biodiversity-poor agricultural land (Spielhofer et al., 2023), even though this could also open up another set of land-use conflicts and social acceptance issues (Boulouchos et al., 2022; Kienast et al., 2017; Salak et al., 2024, 2022). From that viewpoint, development plans in high alpine ecosystems, which are currently targeted by many PV projects (Chapter 4), generate great environmental concerns, not only because these are among the most pristine ecosystems in Switzerland (giving them a unique conservation value), but because they are estimated to play a significant role as carbon sinks helping to mitigate climate change (Bai and Cotrufo, 2022; Rockström et al., 2021). As further hydropower development mostly concerns the Alps, mountain regions are at the core of the Swiss RE-biodiversity debate, followed by agricultural areas as alternative candidate areas for PV and wind developments (Spielhofer et al., 2023).

Given that land-use change, and associated habitat loss, have been the main causes of biodiversity decline in Switzerland (Chapter 3) and worldwide, with climate change representing a growing and tightly interlinked threat (IPBES, 2019; Pörtner et al., 2021; Schmeller et al., 2022), it is essential that energy transition does not add to this historical pressure. Hence, the main challenge is to decide how and where to select the best sites for RE facilities while preserving biodiversity and maintaining – or even enhancing – ecosystem services through habitat restoration (Bennun et al., 2021; Guisan et al., 2022a; Neu et al., 2024; Pellissier, 2022). An understanding of the potential impacts of large-scale deployment of RE infrastructure on biodiversity and the defining of acceptable trade-offs between RE expansion, landscape protection, and ecosystem service provision are prerequisites for any RE development plan (Popescu et al., 2020). This requires identifying the most sensitive species, communities, and ecosystems that might be affected (both currently and in the future; Ashraf et al., 2024), and then explicitly spatially delineating the most valuable areas (Niebuhr et al., 2022; Rehbein et al., 2020). Building upon a synthesis of the three previous chapters, this chapter describes potential trade-offs, synergies, and win-win solutions between the deployment of RE infrastructure and the protection and recovery of biodiversity.

5.2 Trade-offs between RE infrastructure development and biodiversity

The risks of environmental impacts of a fast energy transition towards more sustainable energy sources are multiple, and they manifest at different stages throughout the lifespan of any project (construction, operation, and decommissioning). All these aspects must be properly identified and understood before being accounted for in any assessment to balance RE-biodiversity trade-offs and synergies. Environmental impacts can be classified into three main groups: direct, indirect, and cumulative (sensu Bennun et al., 2021).

Direct impacts stem from the project activities or operational decisions of the project, so they can and must be recognized and anticipated during the project planning phase (Bennun et al., 2021). Habitat modification and disturbance induced by RE development will affect species, populations, ecological communities, and ecosystems, as well as the ecological functions and services they provide.

The most apparent impacts are the direct mortality of individuals. This is especially visible in wind energy: birds and bats may die from collisions with turbine blades (Drewitt and Langston, 2006; Lloyd et al., 2023; Serratosa et al., 2024). These effects are often spatially confined and can be avoided if, for example, key bird migratory flyways such as the Alpine valleys and passes are a priori excluded from development (Hirschhofer et al., 2024). Other undesired effects of RE infrastructure are habitat loss, degradation, and fragmentation (Gasparatos et al., 2017; Hastik et al., 2015; Hernandez et al., 2014) and the consequent functional connectivity loss (Radinger et al., 2022; Taubmann et al., 2021; Tinsley et al., 2023).

While these affect both terrestrial and aquatic ecosystems, they can be particularly acute in the case of hydropower (Radinger et al., 2022), which is renewable but not necessarily sustainable. Insufficient residual run-offs often result in water depletion and the deterioration of ecological quality (e.g. affecting connectivity, causing species extinctions and community simplification; see Chapter 3) (Altermatt et al., 2022b; Hastik et al., 2015; Kuriqi et al., 2021; Lange et al., 2019; Radinger et al., 2022; Reid et al., 2019).

Besides on-site impacts, the deployment of RE generates other direct off-site impacts that are less visible (Niebuhr et al., 2022). These include impacts linked to activities externalized to other countries, such as the extraction of raw materials such as silica for the production of PV panels (Shamoon et al., 2022).

Indirect impacts are by-products of project activities within the project area of influence. These are harder to anticipate than direct impacts, yet potentially easier to mitigate (Brosse et al., 2022; Peste et al., 2015). They relate to the expansion or new development of transportation infrastructures needed to deploy the energy equipment, and they further threaten flora and fauna (e.g. through poaching, overexploitation of resources, or invasive species) (Bennun et al., 2021). For instance, road constructions boost the spread of non-native species into mountain areas due to increased accessibility (Barros et al., 2022; McDougall et al., 2018). An example is the introduction of invasive fish into alpine lakes (Tiberti et al., 2014), leading to a consequent loss and impoverishment of the native species pool and the degeneration of natural food webs. These additional threats are especially problematic within already fragile mountain ecosystems characterized by slow dynamics and resilience capacity (e.g. alpine grasslands; Adler et al., 2022; Teng et al., 2020).

Cumulative impacts result from the incremental or combined effects of existing or planned infrastructure across the landscape or region selected for RE development (Gillingham et al., 2016), or even beyond its boundaries (Niebuhr et al., 2022). This encompasses impacts stemming from any interaction among RE projects, e.g. from wind turbines in the vicinity (May et al., 2019), and between RE projects and other existing human infrastructure such as ski resorts or forestry exploitation (Bennun et al., 2021; Roscioni et al., 2013). The risk of cumulative impacts at the landscape scale increases with an increased division of territorial governance – a challenge in Switzerland where environmental and energy responsibilities are in the hands of the cantons and not generally centralized at the federal level. For example, the environmental impact of a wind or PV park in one canton may be underestimated if the presence of a similar installation (or any other existing highly impacting human infrastructure) in a neighboring canton, on the other side of the administrative border, is not considered in the corresponding environmental impact assessment. The often trans-cantonal nature of species distribution ranges and landscape elements (e.g. large forests, pastures, mountain ranges) makes this challenge particularly important in a small and mountainous country like Switzerland. This challenge calls for expanding transboundary knowledge and inter-cantonal and international collaboration (Arduino et al., 2021; Chauvier-Mendes et al., 2024) and for implementing effective spatial planning that explicitly addresses all types of cumulative impacts (Whitehead et al., 2017).

5.3 Reducing aggregated pressure on biodiversity

To address the potential impacts of RE on biodiversity, the International Union for Conservation of Nature (IUCN) developed a **mitigation hierarchy protocol** tailored for the RE sector (Bennun et al., 2021). This protocol seeks to avoid and minimize biodiversity impacts of RE deployment (under the principle of "no net loss") and can be applied throughout a project life cycle, from early planning and design, through construction, operations, and eventual decommissioning and repowering.

Life cycle assessments are key tools supporting the application of this protocol (Schomberg et al., 2022). The most critical phase of the protocol is early planning: from the beginning, every project should set up a biodiversity goal, with four different levels envisioned depending on the environmental significance of the site: 1) no harm, 2) net gain, 3) no net loss or 4) reduced harm in areas of outstanding, very high, high, or low biodiversity significance, respectively. Substantial biodiversity impacts can be avoided from the outset of the project through adequate site selection (e.g., Dorber et al., 2020), particularly by avoiding the still most pristine areas of high conservation value (Rehbein et al., 2020) and giving priority to RE development into degraded land or areas of low conservation value (Xu et al., 2023) or where there is already other human infrastructure in place (e.g. ski resorts, rooftops, roadsides (Ismail et al., 2021).

To address this challenge at the Swiss level, a number of independent institutions (scientific, governmental, and non-governmental) have recently published a list of criteria to support spatial planning of suitable sites for RE production while minimizing or mitigating the negative impacts on species, ecosystems, and landscapes (Brunner et al., 2024; Neu et al., 2024; SLPF, 2023). These should be considered a mandatory starting point in current and future RE projects across Switzerland (Figure 5.1).

While a mere reduction of potential biodiversity harm can be seen as an acceptable trade-off solution (a "no regrets" choice), the IUCN mitigation hierarchy protocol requires "net gain" or "no net loss" for all areas of either "high" or "very high" biodiversity significance (Bennun et al., 2021). The protocol refers to "no net loss" when project-related impacts are balanced by effective mitigation measures, so that no losses remain, and to "net gain" when project-related impacts are outweighed by such measures, resulting in a net gain of the relevant biodiversity features. Merely reducing harm is not enough. The protocol also emphasizes the need to reduce existing pressure on ecosystems. In Switzerland, addressing biodiversity loss requires prioritizing conservation and restoration efforts targeting various key drivers (BAFU, 2023a). These include the following: intensive and industrialized agriculture, characterized by excessive nitrogen inputs and the use of biocides; large-scale expansion of road and energy transportation networks; urban sprawl, leading to soil sealing and habitat fragmentation (Nick, 2024); the unsustainable use of water resources in hydropower generation, resulting in insufficient residual water flows in rivers and streams; and the consumption of materials, which negatively impacts biodiversity both within Switzerland and abroad (Nathani et al., 2022; Schweizer Bundesrat, 2022). Thus, applying the IUCN protocol requires reducing these impacts as well as other activities that affect biodiversity, including all subsidies that lead to counter-productive effects (Gubler et al., 2020), so that the pressure on the environment arising for any new RE development will be adequately mitigated and compensated, for example, via ecological restoration (Leadley et al., 2022).

These and other measures could eventually help to disaggregate the cumulative pressures exerted on biodiversity by eliminating the most harmful impacts. Some examples of other measures include deconstructing the most damaging infrastructure, such as roads that

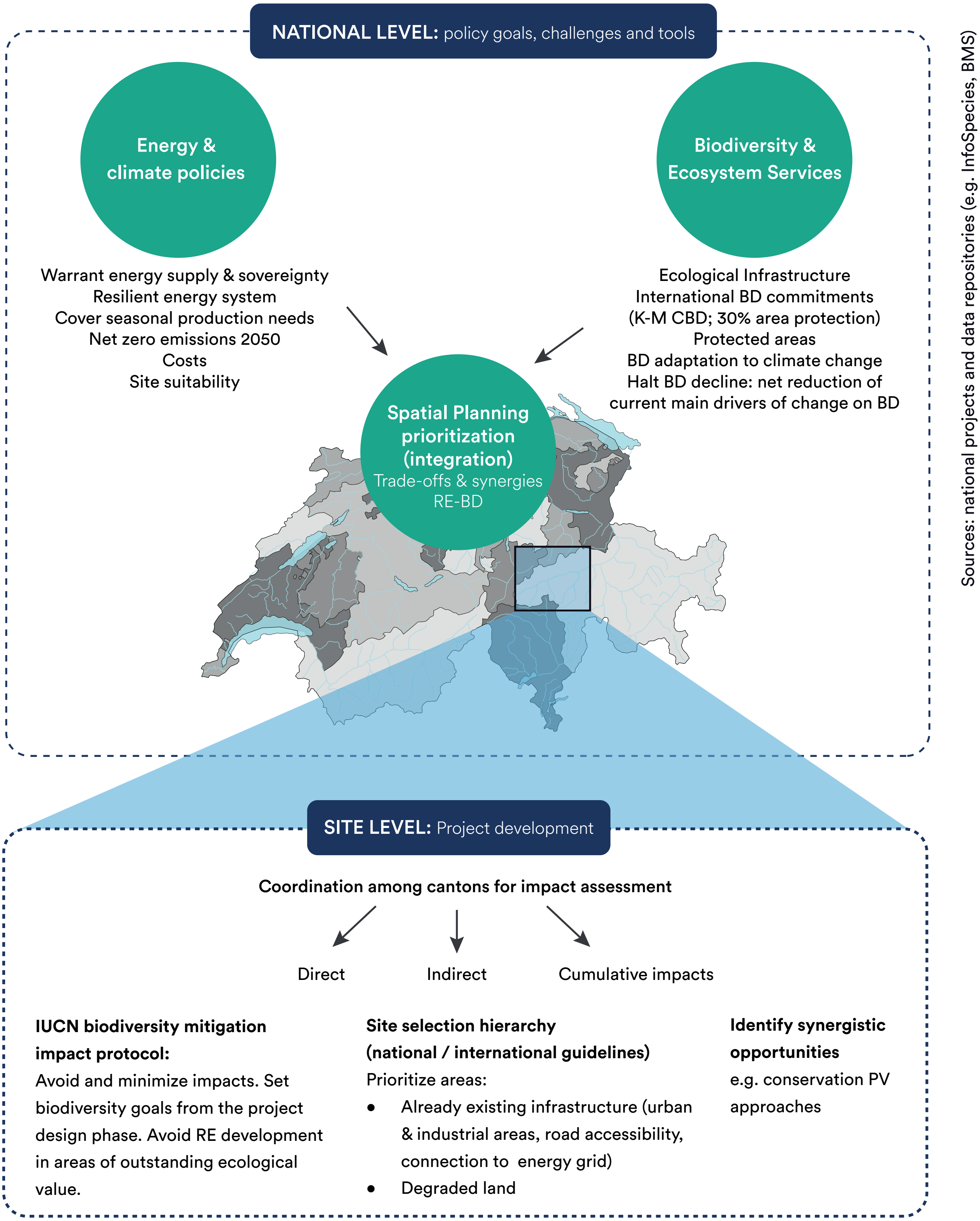

Figure 5.1 | Advancing RE development at the national scale requires the use of multi-objective spatial planning tools to integrate biodiversity and ecosystem service values and knowledge along with energy demands, costs, and production opportunities. These will allow the best locations across Switzerland for RE deployment to be identified so that trade-offs between RE and biodiversity are minimized and potential synergies maximized. At the local level, the guidelines of the IUCN mitigation protocol or those developed by private and public Swiss institutions show how to identify, avoid, and mitigate potential impacts from the onset of the RE project, as well as identify synergistic opportunities.

exacerbate ecosystem fragmentation (Jaeger et al., 2007), restoring connectivity of species populations, and mitigating the impact of linear infrastructure (van der Grift et al., 2015) (see also box 1), containing urban sprawl (Torres et al., 2016), or restricting high-altitude skiing infrastructure (Brambilla et al., 2016; Sato et al., 2013). Such measures should be envisioned within and beyond RE development areas (e.g. as compensatory restoration actions), if helpful for reducing the overall cumulative impacts described above.

In this regard, ongoing research in Swiss institutions already offers promising avenues for expanding basic knowledge to inform and support decision-making and action including spatial analysis or modeling tools (Adde et al., 2023; Jaligot et al., 2019; Vignali et al., 2022, 2021), landscape assessments (Salak et al., 2022; Spielhofer et al., 2021a), and multi-objective spatial prioritization approaches (Egli et al., 2017; Hermoso et al., 2023; Khiali-Miab et al., 2022; Kienast et al., 2017; Santangeli et al., 2016; Spielhofer et al., 2023). These approaches have already been used to support the design of a national network of ecological infrastructure and to evaluate potential conflicts and synergies between RE, biodiversity, and ecosystem service provision from local to national scales (Figure 5.1). However, science remains generally underused in Swiss policy and decision making, which still tends to be dictated by the tempo of political actors' engagement (Reber et al., 2022) and their personal preferences for policy instruments (Kammermann and Angst, 2021) (see Chapter 7). The energy transition offers a unique opportunity to make better use of the knowledge at hand to limit – if not diminish – the environmental impacts of RE expansion, to create synergies with biodiversity objectives, and develop new research at the interface between RE and biodiversity to cover knowledge gaps (e.g. impacts of PV on the structural and functional integrity of alpine habitats).

5.4 Synergies between RE development and biodiversity conservation

New theoretical and applied frameworks are emerging to promote more sustainable energy development while minimizing impacts on ecosystems, or even generating positive outcomes for biodiversity. For example, *conservation PV* approaches seek to apply ecological principles to co-prioritize energy production and ecosystem services during both the design and management phases of PV projects (Nordberg and Schwarzkopf, 2023; Sturchio and Knapp, 2023; Tölgyesi et al., 2023). Good solar PV management practice in degraded lands can foster vegetation recovery (Liu et al., 2019; Montag et al., 2016) and increase the diversity of associated species (insects, birds), including pollinators (Andrew et al., 2021; Blaydes et al., 2021; SEUK, 2023; Sturchio et al., 2022). The solar park can be designed from the outset of the project to promote the development of new habitats to support a variety of species. This requires various management interventions, such as setting aside natural vegetation, promoting and conserving field margins, or planting wildflower/nectar-rich meadows, i.e., measures that benefit both biodiversity and ecosystem service provision, for instance boosting pollination in near agricultural land) (Peschel et al., 2010; Randle-Boggis et al., 2020; Semeraro et al., 2018; Walston et al., 2018). Moreover, different settings and configurations of the solar panels themselves can promote small-scale heterogeneity in abiotic conditions, such as sunlight, water, and temperature; this may promote heterogeneous microclimates that offer micro-habitats for flora and fauna, potentially increasing local biodiversity and ecosystem function (Tölgyesi et al., 2023). Revegetation also promotes PV efficiency through the reduction of dust accumulation and general ambient cooling (Beatty et al., 2017; Hernandez et al., 2019; Macknick et al., 2013). Floating PV panels can also have a positive impact on biodiversity when installed on eutrophic lakes as they prevent UV rays from penetrating the water, limiting algal growth and therefore leading to an overall improvement in water quality (Al-Widyan et al., 2021). However, there is no evidence about whether these or any other benefits of floating PV could also be extended to oligotrophic lakes (i.e., dominant lakes across the high-alpine zones in Switzerland). There is also little – if any – evidence of potential synergies between biodiversity conservation and wind installations, as most studies so far that consider both have reported mainly negative impacts (e.g., Egli et al., 2017; OECD, 2024; Roscioni et al., 2013; Taubmann et al., 2021; Urziceanu et al., 2024). More eco-physiological experiments are still needed to understand the effect of RE installations on more natural ecosystems (Möhl et al., 2020).

However, most of these *conservation PV* frameworks are based on “agrivoltaic systems”, which seek to foster synergies between PV and agricultural production, and hence consider the role of biodiversity uniquely from the agronomic viewpoint (Sturchio and Knapp, 2023); besides, these frameworks also emphasize the principle of “no harm” in the placement of PV parks across the landscape. Therefore, it can be argued that their application (and potential benefits) is limited in (semi-) natural landscapes, and best in brownfields and abandoned and degraded lands (Hernandez et al., 2019; Lambert et al., 2021; Sacchelli et al., 2016), or in desert areas, where most of the environmental benefits of solar PV on biodiversity and ecosystem function recovery have been reported (and only in the short term) and from where the greatest amount of scientific evidence has been collected (Gómez-Catasús et al., 2024). Similar assessments for biodiversity-friendly deployment of RE infrastructure in grasslands or other natural and semi-natural ecosystems are lacking (Gómez-Catasús et al., 2024). These assessments would be of paramount importance in Switzerland, where many of the most pristine landscapes lack formal protection (e.g. habitats in proglacial zones), making them potential candidate areas for the deployment of RE infrastructure. Unfortunately, the final plan for a Swiss ecological infrastructure (i.e. ecological network; BAFU, 2021b) is not yet finalized (but likely will be in 2024; as e.g. produced by the Valpar.CH project[5]) (Reynard et al., 2021) and not yet available in a spatially explicit form for such RE impact assessments. Once this ecological infrastructure proposal becomes available, it will represent a key tool for optimizing RE-biodiversity synergies and minimizing trade-offs using a coordinated and nation-wide perspective that enables the simultaneous meeting of future energy demands and nature protection goals.

5.5 Conclusion

The challenge of balancing the rapid development of RE infrastructure with the preservation of biodiversity and ecosystem services is multifaceted and complex, including identifying suitable sites using multiple criteria, defining acceptable values for these criteria, finding ways to develop the selected projects to fit these criteria, engaging and obtaining acceptance of local communities, etc. (Neu et al., 2024). It requires using all available scientific evidence and expertise to develop an optimized, sound, and sustainable national strategy. Assessing the expected impacts of RE infrastructure on biodiversity – which span all stages of a RE project life cycle – necessitates a comprehensive and proactive approach to mitigate adverse effects. The IUCN mitigation hierarchy protocol offers a structured framework for minimizing biodiversity impacts. This protocol emphasizes the importance of accounting for biodiversity impacts from the very early phase of RE planning, notably by adopting strategic site selection approaches;

5 https://valpar.ch

it encourages the use of innovative solutions for integrating ecological principles into energy development, thereby fostering a synergistic relationship between energy production and biodiversity-friendly ecosystem conservation and management. Additionally, emerging theoretical frameworks such as *conservation PV*, and alignment with extant environmental frameworks are vital for ensuring a sustainable and ecologically responsible transition to the large-scale deployment of renewable energy across Switzerland. Yet, moving in this direction requires making systematic use of all the spatial information and management tools presently available at the Swiss level, fostering inter-cantonal and transnational cooperation, and rapidly developing the tools and knowledge that are still missing.

Box 5.1 Reducing already existing pressures on biodiversity: mitigating dangerous electric pylons

New RE sources, such as wind and photovoltaic electricity, are often considered environmentally friendly and green. However, a rapid and poorly planned expansion of RE infrastructure can harm biodiversity, adding pressure to existing threats to nature conservation, as shown in this chapter.

A typical example of extant threats related to energy is the electricity grid network, which includes medium-voltage poles and pylons that pose a high risk of electrocution for many species of vertebrates worldwide, particularly birds and mammals. In the temperate zone of the western world, these dangerous pylons take a huge toll on diurnal and nocturnal raptors. Note that high-voltage pylons rarely represent a risk of electrocution for perching birds because their electric lines are placed far enough from the metal, concrete, or wooden structure of the pylon or tower, rendering any shortcut between the power cable and earth impossible: rather, birds are killed when sitting on a structure connected to the earth, typically the pole or pylon, and touching a power line at the same time. Thus, along high-voltage lines, the main risk for a flying bird is not electrocution, but collision with the cables; however, this risk has repeatedly been assessed as being minor compared to the risk of electrocution generated by a shortcut (e.g., Schaub et al., 2010). Low voltage poles are also of minor concern because any shortcut might in such a situation represent a bad, but rarely deadly experience for a bird. In contrast, medium-voltage poles, because of the fairly short distance between the supporting structure and the power line, i.e. average insulation associated with a dangerous voltage, do pose a risk to large birds such as raptors and storks. In effect, with their large wingspan, these birds can easily connect the power line to the pole with their wings, generating a shortcut that will kill them instantaneously.

A recent systematic analysis has shown these pylons have a large impact on large-bird populations, more so than any other electricity source, and could lead to the local extinction of some populations (Serratosa et al., 2024); see Figure 5.2. Numerous studies in the western world have demonstrated the preeminence of this risk and called for systematic mitigation of all the dangerous medium-voltage poles and pylons (see Schaub et al., 2010 for a Swiss example of the Eagle Owl). In Switzerland, for example, there are thousands of these dangerous pylons scattered throughout the landscape. The Swiss national railway company (SBB/CFF/FFS) and some local electricity companies have begun implementing mitigation actions to address this issue (notably in the Seeland, the Grisons, and Valais). For years and until 2022, university researchers, along with the Association of Swiss Electrical Companies and Swiss nature NGOs, worked on developing a strategy to make mitigation of all existing dangerous pylons compulsory, under the auspices of the Federal Office for the Environment; however, this strategy was put on hold due to other priorities resulting from the Russian-Ukrainian war and subsequent energy crisis.

It is therefore essential to prioritize the mitigation of dangerous pylons of the Swiss electric grid. Although this would not account for the local impacts on biodiversity of the installation of new energy infrastructure, it may in the mid-term provide a net gain of survival for birds of prey and storks, with positive demographic effects far beyond the area of pylon installation, which may even over-compensate any new source of mortality triggered by the development of the renewable electrical production, in particular wind turbines.

Reviving and implementing initiatives targeted at reducing current biodiversity threats, such as the initiative described above, are key to achieving the phase-out of fossil fuels via the rapid expansion of RE infrastructure while conserving and promoting Swiss biodiversity.

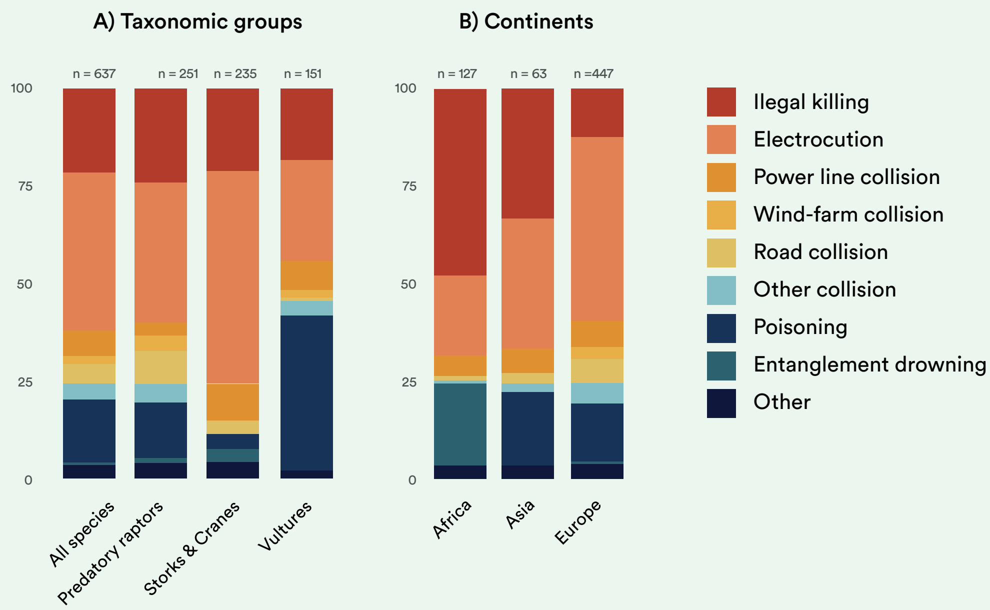

Figure 5.2 | **Percentages of human-induced causes of mortality on 45 migratory bird species in the African-Eurasian flyway by: A) taxonomic groups and B) continents, calculated from all known human-induced causes of mortality (n = 637 mortality events collected from literature). From Serratosa et al., 2024**

5.6 Key messages

1. The primary goals of large-scale deployment of RE are to mitigate climate change and secure energy supply at the national level.
2. Maintaining intact or partly intact ecosystems (e.g. mountain grasslands, peatlands) is essential, as biodiversity conservation and climate change mitigation are strongly interlinked.
3. Development of new RE projects should follow the principle of negative impact avoidance, prioritizing placing them in areas of already existing infrastructure. This means RE infrastructure should be avoided in areas of outstanding biodiversity value, such as near-intact ecosystems. In other areas, negative impacts of RE development should be minimized and projects must promote mitigation actions.
4. To create synergies between RE and biodiversity, IUCN recommends that all RE projects of "high" or "very high" biodiversity significance ecosystems target a "net gain" (via ecological restoration), "no net loss", or "no degradation".
5. Large-scale expansion of RE across Switzerland should follow an integrative approach where energy, climate, biodiversity, and social criteria are assessed jointly and the potential synergies and trade-offs among them, from the local to landscape and regional scales, taken into account. The use of modeling and spatial planning tools is key to achieving this integration, which should ideally be handled at the federal level.
6. Current RE conservation frameworks, primarily developed for PV, already incorporate ecological principles and evidence-based information to balance energy production, biodiversity, and ecosystem services. However, these assessments have mainly focused on intensively managed, biodiversity-poor farmland, and have shown some benefits for biodiversity. Similar balanced assessments are needed for intact and semi-natural ecosystems, key areas for Swiss biodiversity, where the effects of PV are less understood.
7. Finally, reducing the aggregate pressures on biodiversity must go beyond merely minimizing any additional negative impact generated by a given new RE project. Decision-makers and managers must understand that it is the sum and interactive effects of all these impacts that must be substantially reduced, to pave the way for a better-balanced coexistence of man and nature into the future.

Supports recommendations:

4 5 6

CHAPTER 6

CHAPTER 6

Community Engagement, Knowledge, and Capacity Building

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6.1 The importance of local communities in energy transitions

In this chapter, we present how local communities can become engaged in the debate regarding the necessary trade-offs to support energy transitions. We present examples and literature on how these communities can be promoters of energy security, technology innovation, sustainable development (Ahmed et al., 2024), and biodiversity conservation.

Note: *This chapter presents a stronger focus on energy than on biodiversity, based on identified community initiatives covered in literature. Therefore several aspects of the overall report are not covered in this chapter. Still the mechanisms outlined are essential for legitimacy of the transition, wellbeing and participation of affected communities, and ultimately reaching overall societal goals. As examples come from around the world, the communities described do not align with the Swiss political landscape. Adapting these learnings to the Swiss context should be the goal of the deliberative decision-making proposed in this chapter.*

Participation and deliberation in energy management contribute to the development of holistic strategies of energy transition, i.e., strategies that account for the different factors playing a role in these transitions, which include biodiversity protection, energy justice (Huttunen et al., 2022; IPBES, 2019; Qian et al., 2023; Schmidt et al., 2024), local practices (Jenkins, 2018), acceptance (Plaga et al., 2024), wellbeing (Sandifer et al., 2015) and self-reliance (Bashir et al., 2023). These factors indicate that meeting sustainable targets (Geels et al., 2019; IPBES, 2019) – like the Agenda 2030 (Schweizer Bundesrat, 2021) – and generating sufficient energy require systemic actions that reconfigure existing socio-economic systems (Geels et al., 2015). These include social practices (Olsson and Dawkins, 2022), production, consumption, knowledge, and values (Geels et al., 2019; O'Brien and Sygna, 2013).

In this chapter, we describe conflicts (6.2) and opportunities of the socio-technical transformation in energy systems by discussing participatory formats of energy management (6.3), means of deliberations for defining energy transition agendas (6.4), building knowledge and skills around energy management (6.5). We conclude with a list of recommendations (6.6).

With energy transitions transforming centralized energy infrastructure into decentralized points of production (Meister et al., 2020), there are associated socio-political system changes that allow local control leading to participation, and means for democratizing energy systems (Ahmed et al., 2024; Bauwens et al., 2022). We outline transformations that weight energy technologies' impact on communities and the environment and stimulate local economic benefits (Pestre, 2019). To discuss these, we will take as a general definition of community a group of individuals united towards shared objectives (Ahmed et al., 2024; Bauwens et al., 2022). In energy projects, we complement this definition with the following: a group of individuals involved in decision-making (*community as a process*), the benefits gained by members (*community as an outcome*), the degree of agency members have when interacting with other stakeholders (*community as an actor*), relationships between members that extend beyond a specific place (*community as a network*) and the members' shared values and way of thinking (*community as an identity*) (Bauwens et al., 2022).

Community as a network grounds and supports the ideas developed in 6.2, community as a process and outcome in 6.3, and community as process, actor, and network in 6.4 and 6.5.

6.2 Public acceptance in planning RE interventions

This section describes the conflicts that emerge with the planning of renewable energy (RE) infrastructure in landscapes. We discuss what factors of landscape use can influence local resistance to building RE infrastructure.

The wellbeing of every community and of society as a whole relies on well-functioning ecosystems, be it for clean air and water, food production, or recreation (Roberts et al., 2022). Protecting the stability of the Earth's systems requires a shift to RE; however, these transitions can have a negative impact on the landscape, the biodiversity within it (see Chapters 2, 3, 5), and local communities.

Regardless of the benefits provided by RE infrastructure in tackling future energy and climate challenges, the public's response to an increased use of RE varies according to the impact of its infrastructure on the landscape (Müller and Morton, 2021). It is important to understand the public's acceptance of RE because of the influence it has on the success of incrementing RE production (Scovell et al., 2024). For instance, in Switzerland, acceptance is very high at an abstract level, particularly for solar power, but falls sharply when the planning of proposed projects is more concrete (Sütterlin and Siegrist, 2017). Scovell et al. (2024) evidence that abstraction favors acceptance when the public has a positive view of using RE, such as the benefits it can bring to the environment. However, identifying a particular location for the planned RE infrastructure might challenge that acceptance. Acceptance for the installation of RE infrastructure in landscapes perceived as compatible (e.g., those used for touristic or productive purposes) and on existing infrastructure, such as roofs, is strong, but that is not the case for RE infrastructure planned within landscapes perceived as natural (Salak et al., 2021; Spielhofer et al., 2021a, 2021b). This is described by Müller and Morton (2021) and Ioannidis and Koutsoyiannis (2020) as co-existence with the presence (and visibility) of that infrastructure. Müller and Morton (2021) analyzed acceptance in relation to distributional (benefits), procedural (planning) and locational (landscape) issues and outlined that the unequal distribution of social and financial capital and the misalignment of timescales between planning and construction affect the perceived legitimacy of these projects. Scovell et al. (2024) studied how acceptance varies in relation to (1) beliefs about the consequence of a project, (2) trust in the industry operating a plant, and (3) attitudes towards the technology (e.g., will to use it). These factors revealed that a personal experience of RE plays a key role, and that acceptance decreases when RE infrastructure is associated with negative images or narratives.

Conflicts with landscape use can be mitigated by placing technologies such as photovoltaic

(PV) panels and solar thermal collectors on the envelope of existing buildings (Desing et al., 2019), or by combining these with green roofs, which increase biodiversity in urban spaces, cool buildings, and boost PV yield due to cooling effects (Fleck et al., 2022). Other infrastructure, such as parking lots or wastewater treatment plants, can increase PV potential with minimal impact on planetary boundaries, such as biodiversity and nutrient cycles (Desing et al., 2019). Scovell et al. (2024) and Müller and Morton (2021) reveal that acceptance is high for small-scale projects. In 2022, the increased popularity of solar panel installations on existing Swiss infrastructure – mainly by individual households and industries – more than doubled energy supply compared to 2020 – i.e. an increase of 128% (Hostettler and Hekler, 2023). For instance, installing solar panels on all suitable roofs would achieve the 2050 net–zero goals, but as discussed in more detail in Chapter 4, relying purely on rooftop installations would not yield sufficient electricity supply in winter. Thus, either strategies to minimize energy demand, especially in winter, or RE solutions to increase energy stability and winter capacity are still needed.

Unfortunately, RE technologies addressing the winter gap (i.e. large-scale wind turbines and Alpine solar parks) are not easily accepted by the public because of their scale and visibility in the landscape (Ioannidis and Koutsoyiannis, 2020; Les Vert.e.s Valais, 2023). For instance, in Switzerland, as of June 2024, 75% of Alpine park projects have been accepted and 25% refused locally (alpine-pv.ch); the Alpine solar park in the municipalities of Gondo, Grengiols, and Grimentz in Valais was rejected by a cantonal referendum (Arlettaz-Monnet and Sierro, 2023). Here, despite the communes' support, the cantonal rejection of an amendment to facilitate the authorization process for building PV infrastructure in the Alps jeopardized its feasibility. In Switzerland, very few RE projects are likely to reach the requirement for subsidies due to the time required to develop them: the project must generate 10% of the planned electrical capacity before the end of 2025 (Fedlex, 2023). Müller and Morton (2021) found that local activists in Germany used the timeline for approving a wind project as a means of opposition by trying to delay the process.

In Valais, the coalition leading the Alpine solar park opposition were groups with diverging missions, targets, or preferences – e.g., the Swiss People's Party (SVP), the Swiss Socialist Party (SP), WWF (Les Vert.e.s Valais, 2023) – that rallied behind Les Vert.e.s' cause of protecting the landscape. This was the narrative used to illustrate to cantonal voters the negative impacts of creating large scale solar plants in natural surroundings, which Scovell et al., (2024) describe as a parameter shifting opinions. However, as Müller and Morton (2021) outline, although a landscape is perceived as natural, in reality it is a socially constructed place. Talento et al. (2019) define *cultural landscape* as a territory directly or indirectly transformed by human action. A landscape is therefore a territory invested with different meanings that can change over time (Müller and Morton, 2021). It forms the immaterial heritage that provides economic livelihood influencing the local social structure (Bundesamt für Kultur BFK (Hrsg.), 2023; Taylor and Lennon, 2011). Through rituals and traditions, landscape and nature become tangible artifacts (Spencer-Oatey, 2012). For instance, UNESCO awarded the practice in Switzerland of "*alpage*" the status of immaterial cultural heritage (Porter, 2024), i.e., an expression of social and economic practices (Bundesamt für Kultur BFK (Hrsg.), 2023).

From the community's perspective, planning RE infrastructure in neighboring landscapes can impact those meanings, as it can be experienced as a loss of the jobs and practices that created that landscape (Brás et al., 2024). Scovell et al. (2024) suggest that communicating the benefits of RE installations can mitigate the negative image that might take hold in communities due to a change in landscape use.

In addition, despite RE installations having been shown to have a certain negative impact on nature (Marques et al., 2014; Vervloesem et al., 2022), there is not necessarily a trade-off between RE development and landscape preservation. It is possible to develop synergetic relationships between land management and RE provision (Santangeli et al., 2016). For example, installing solar green roofs (i.e. installing solar PV over a layer of vegetation on roofs) in cities cools their microclimate, brings back some biodiversity, reduces the need for rainwater drainage, and increases PV output, as evapotranspiration of plants cools the panels. This is implemented in the city of Hamburg, which specifically subsidizes solar green roofs, emphasizing the benefits for RE, biodiversity, and communities (BUKEA Hamburg, 2024). Yet, an effect of building RE in ways that yield synergies with landscape and communities is that energy supply does not necessarily meet current energy demand at all times (Desing and Widmer, 2022). Relying heavily on such synergies would thus increase the need to adapt demand to renewable supply.

Synergies can be also developed at a social level; defining a governance that integrates biodiversity protection, land management, and financing into energy transition discussions (IPBES, 2019; Plaga et al., 2024) can increase the public's trust and transparency on the procedures enabling these transitions (Scovell et al., 2024).

RE projects are transformative at an economic, social, political, and technological level; defining a governance for these transitions can support just processes that address negative responses to RE infrastructure in landscapes (Gisler et al., 2024; Sasmaz et al., 2020). Inclusive governance, i.e., governance models where local communities participate by expressing different values, knowledge, and practice, can increase the success rate of these transitions aimed at meeting energy targets (IPBES, 2019). Switzerland has the means to allow citizens to directly participate in the politics of the nation. On the subject of energy transition, integrating how energy transformations impact or benefit local communities in these instruments can inform deliberative forms of participation for the planning of energy policies (Schmid et al., 2020). It then follows that to participate in energy transition debates a community needs to understand how to benefit from RE infrastructure (Ioannidis and Koutsoyiannis, 2020) and use that understanding to participate in and support just transformations (Scovell et al., 2024).

6.3 The implementation of RE transitions through community–based energy cooperatives

In this section, we describe the formalization and characteristics of energy communities. As cooperatives that stimulate just processes of energy transition, these communities work together to manage energy production and consumption. We outline how these energy communities enable citizens of municipalities to become stakeholders, benefiting from local energy infrastructure and contributing to national energy targets. We discuss how these communities contribute to stimulating socio-technical transformations of energy systems.

Note: *This section includes several examples, which nicely illustrate the topic, but can be skipped without affecting the understanding of the whole chapter.*

Energy transitions are socio-technical transformations in which the introduction of new technology has an impact on the environment, society, and the economy (Qian et al., 2023); this impact comes from the reorganization of existing socio-economic systems. *Energy justice* can be defined as the fair distribution of the costs and benefits of energy services. The concept can serve as a decision-making tool for understanding how value is created by RE systems (Sovacool and Dworkin, 2015). Energy justice guides those involved in energy transitions to an understanding of whether benefits are distributed to any interested party and whether energy production promotes social equality (Gisler et al., 2024; Qian et al., 2023). This is key for achieving sustainability at a societal and environmental level (Bashir et al., 2023; Jasanoff, 2018). Understanding how and to whom costs and benefits are distributed, from the national to cantonal and local scales, makes it possible to define energy targets that adapt to different needs and contexts (Brás et al., 2024).

The decentralization of energy systems is a technical transformation that has helped stimulate the development of participatory management of energy (Lennon et al., 2019). Decentralization has meant that organizations that manage energy provision distribute the benefits created by energy production locally (Meister et al., 2020). These organizations give affiliated members, municipalities, and their citizens the procedural means to help shape the distribution of RE benefits and costs (Baldanov et al., 2020; Gezikol et al., 2019), while meeting national energy targets (Meister et al., 2020). With the Renewable Energy Directive, the European Union has formalized this participatory management in the concept of Renewable Energy Communities (REC) (European Parliament, 2018); through the Directive EU 2019/944 (European Parliament and Council of the European Union, 2019), it mandated that Citizen Energy Communities (CEC) use energy to deliver social, economic, and environmental advantages to its members (Ahmed et al., 2024). Members of these communities are citizens who can form any type of legal entity, including associations, cooperatives, partnerships, non-profit organizations, or limited companies (European Commission Decision, 2024). Members can also include public actors, such as municipalities (Schmid et al., 2020). Members of these CECs are expected to participate in the decision-making process, including deciding about investment or models for ownership (Ahmed et al., 2024).

In Switzerland, energy cooperatives emerged 150 years ago as voluntary associations that pursue common economic, social, and cultural needs (Meister et al., 2020). With the decentralization of energy infrastructure, and the need for more RE, the number and size of these cooperatives has grown. Switzerland has witnessed different development phases starting from the 1990s, with the largest increase between 2006 and 2012. That phase began in combination with the national schemes supporting the development of RE (Meister et al., 2020).

More recently, the Swiss federal administration has proposed to create energy communities to regulate the sale of RE across energy producers, consumers, and infrastructure managers (Fedlex, 2023). This is part of the Mantelerlass proposal to generate more RE, which was accepted in a national referendum in June 2024. This bill includes funding instruments and arrangements for producing, transporting, storing, and consuming electricity (Fedlex, 2023). It complements an instrument founded in 1991 that also supports the implementation of Switzerland's energy strategy, the Energy City Association. The role of this competence center is to guide and support Swiss municipalities in reaching their ambitions on energy policies and increasing knowledge transfer (Schmid et al., 2020). Its Energy Programme provides guidelines for "Energiestadt" certification; suggests and provides technical and financial support to implement measures such as building insulation, RE adoption, energy-efficient street lighting, and sustainable mobility; and provides monitoring tools for energy and GHG. Its members are citizens and representatives from the municipalities, public administration, and juridical persons. Its mission is to guide Swiss municipalities in maximizing the use of natural resources and introducing RE (Energiestadt, 2024).

Energy communities move the dialogue on energy management and production between national government and local population beyond acceptance (Lennon et al., 2019), focusing on defining a participative format of energy provision. Members of these communities are stakeholders benefiting economically from RE technologies (Ahmed et al., 2024; Meister et al., 2020; Nijkamp et al., 2023). Furthermore, as these communities are based on principles of transparency, they mitigate citizens' feeling of lack of agency and being excluded from the decision-making (Lennon et al., 2019; Meister et al., 2020; Schmidt et al., 2024; Würgler, 2024). Hence, these energy communities become a means for promoting energy justice, besides economic benefits; having studied 289 energy communities in Switzerland and 828 in Germany, Schmid et al. (2020) outline that some of these communities are legally defined as having a democratic membership control and limited profit. Within the Swiss sample, there are examples of municipalities requiring energy community members to have links with the local community to safeguard fiscal equivalency (Schmid et al., 2020).

With energy communities regulating the RE financial benefits in terms of both production and consumption (Lennon et al., 2019), members are no longer consumers but stakeholders (Alexander et al., 2022). Based on the principle of participation in energy management, these communities are means for defining distributional (as distribution of benefits and burdens), procedural (as fair decision-making procedures), and recognition (as recognition of needs) justice (Qian et al., 2023). This principle is favored by the decentralization of RE infrastructure, which allows energy community members and beneficiaries to tailor the parameters of energy production and consumption for their benefit (Geels et al., 2015; Lennon et al., 2019). In this regard, several European energy communities have been the subject of studies to understand their degree of participation. This analysis covers (1) their level of control, i.e. having a say; (2) their degree of ownership, i.e., having equitable ownership rights; (3) their potential, i.e., benefits beyond energy use and production (Lennon et al., 2019). Furthermore, studying energy communities' means of participation offers insights into how new socio-economic infrastructures can reduce national costs (Ahmed et al., 2024; Santangeli et al., 2016), or disrupt local practices (i.e., practical know-how and social objectives or meanings), agency (i.e., the ability to act in these systems regulated by rituals, conventions, rules, and habits) (Geels et al., 2015), and behaviors (Ahmed et al., 2024).

At a national level, these local energy communities are considered key players for the energy transition; this is because they are democratic organizations and often pioneers in their local municipality (Meister et al., 2020). These participative energy cooperatives are a means for local municipalities to contribute to national goals by using RE technology; as a consequence, RE becomes a means for energy self-reliance, having a positive impact on local life conditions (Gisler et al., 2024). Indeed, RE economic benefits can be directed to health, culture, or education (Baldanov et al., 2020). Municipalities play a key role in supporting the development of these energy communities, operating as shareholders, partners, investors, or buyers (Meister et al., 2020). The two Swiss federal programmes SuisseEnergie and the Energy Strategy 2025 help by providing training, advice, grants, and calls for projects to increase the local deployment of RE through Local Energy Communities (LECs) (Helvetica Energy, 2024). An example is the Quartierstrom project in Walenstadt, whose 37 households produce and store energy through a variety of technologies, including PV panels, batteries, and smart meters (Helvetica Energy, 2024). Another is the Community Power Energy (CPE) NGO in Australia, whose mission is to create fair and inclusive energy transitions through three strategies: (1) capacity building – working collaboratively with project developers to create tailored workshops, training, mentoring, and resource development on RE; (2) innovation – pioneering new business models in collaboration with government and developers at urban and regional level to help Australian households benefit from RE, independently of location and income; (3) advocacy – regularly advising government, business, and organizations on RE policies (Community Power Agency, 2019).

Energy communities are examples of socio-economic reconfigurations (Geels et al., 2015) that arise from distributional, procedural, and recognition energy justice (Qian et al., 2023). Indeed, the Australian NGO frames RE technologies as a means for fostering local development to lead to just transitions (Community Power Agency, 2019). The aim to satisfy local needs is a systemic one, intending to create improvement without causing deterioration in other parts of the system (Max-Neef, 1991); for instance, key to planning RE transitions is not to affect the landscape or hinder local practices. Analysis reveals that RE investment can be a means for fostering human development and reducing environmental degradation (Bashir et al., 2023; Santangeli et al., 2016). For Bashir et al. (2023), human development, RE investments, and healthy environments are interrelated parameters for pursuing sustainable goals. Hence, energy communities' participation in the decision-making offers them an opportunity to make local resources a means for ensuring social justice and wellbeing (EEA, 2023b; EEB, 2022; Jasanoff, 2018; Max-Neef, 1991; OECD, 2021). This is self-reliance, i.e. the ability of a community to satisfy its needs by using local resources (Grewal and Grewal, 2012). Some financial schemes for RE projects support self-reliance by funding those that have positive climate effects (e.g., Green Bonds), thus acknowledging that the use of natural resources to combat climate change offers economic returns (Haas et al., 2021).

Developing local RE infrastructure helps create economic independence (EEB, 2022; Max-Neef, 1991) provided it respects local ownership rights (Brás et al., 2024; OECD, 2021). Energy communities – which see the interaction of diverse actors, and opinions, in developing the processes required to shape technology configurations (Stirling, 2008) – offer the opportunity to create new local economies that are self-reliant with regard to their use of natural resources (IRENES Interreg Europe, 2024; Meister et al., 2020). In this section, we have shown that an inclusive and participatory practice of managing energy production and consumption can inform just processes of energy transitions that recognize and distribute benefits to every stakeholder participating in energy decision-making (Sovacool and Dworkin, 2015).

6.4 Processes of national deliberation engaging the public on climate issues

In this section, we present examples of national deliberative assemblies, where decisions are based on careful thought and structured discussion, developed to integrate the public into the decision-making that defines national climate agendas. These examples represent different models of deliberations – open or closed – that lead to different levels of agency for the community involved in these decisions. Such assemblies offer a forum for debating strategies for energy transitions at the national level.

The recent Swiss referendums on the climate in June 2023 (Schweizer Bundesrat, 2023) and solar parks in September 2023 (Arlettaz-Monnet and Sierro, 2023) were democratic processes through which voters expressed their position on subjects defined by those launching the referendum (Alexander et al., 2022). In an energy democracy – i.e., an energy governance made of different voices which can be contested and/or interpreted in diverse ways (Lennon et al., 2019) – citizens' participation in live debates, expressing their views, would increase the operational effectiveness of its governance (EEA, 2023b, p. 202).

Section 6.3 described participation in relation to energy communities; in this section, borrowing from the International Association for Public Participation (IAP2) definition, participation is framed as a process involving the public in problem-solving or decision-making to identify better and more democratic solutions (International Association for Public Participation, 2024; Stirling, 2008), and as a method to introduce different ways of knowing in scientific and political settings (EEA, 2023b; Jasanoff, 2018). Under the Arnstein's ladder framework (1969), an empowering participation that allows participants to learn and deliberate scientific evidence in the decision-making process of energy transitions is the basis for the development of institutional mechanisms of decision-making that reflect the way a problem is framed and discuss how it can be governed (EEA, 2023b).

The results of the integration of participation on climate issues into existing democratic processes have varied depending on how a government pursues its commitments to reach targets through public consultation (Stirling, 2008). For instance, the UK Climate Assembly (UKCA) (Climate Assembly UK, 2020) was a top-down national initiative created in 2020 to share with the UK Government the views of 108 citizens on predefined policies aiming to reduce UK greenhouse gas (GHG) emissions to net zero by 2050 (Cherry et al., 2021). In France, the Convention Citoyenne pour Climate (CCC) was a bottom-up process whereby 150 members of the public aimed to create just climate policies that would reduce GHG emissions by 40% by 2030 (Cherry et al., 2021; Convention Citoyenne pour le Climat, 2019). If the CCC is positioned at the higher levels of the Arnstein's ladder, the UKCA represents the lower steps.

In both assemblies, citizens discussed how climate policies impact everyday life and suggested alternative actions. Formats varied; the UKCA's included a presentation followed by a deliberation process and voting; the CCC aimed to use the assembly's collective decision-making to create new policies to be proposed to the government (Cherry et al., 2021; Sambrook et al., 2021). The different results these assemblies delivered reflect the different participatory structures; i.e., lower (UKCA) and higher (CCC) in the Arnstein's ladder. The UKCA's was an instrumental deliberation – designed to achieve better ends (Stirling, 2008). It allowed for only minimal variations to the policies. The CCC's was intended to be a substantial participatory process aimed at making governmental commitments coherent with values that are socially deliberated (Stirling, 2008). Its aim was to enable the development of innovative proposals that would shape new laws. Nonetheless, the French president's failure to keep the commitment he had promised when constituting the assembly disappointed CCC participants, as their proposals did not receive the governmental support for which they had hoped (Cherry et al., 2021). However, this assembly allowed members to actively engage in politics. They felt they had the agency to make a change by being subject rather than object of political aims (Stirling, 2008). The CCC was less technical than the UKCA (Cherry et al., 2021); its deliberation process was intended to empower action by integrating non-expert knowledge into the decision-making process with scientific knowledge. Its structure was an open type of deliberation that evaluated possible commitments the government should take (Stirling, 2008). Indeed, in open deliberations there is an opportunity for evaluating different perspectives (Stirling, 2008); participation allows participants to change the problem framing, the different opinions, conflicts, and disagreements for finding alternative solutions (Buchecker et al., 2023). Closed forms of deliberations orient themselves towards gaining the participants' consensus (EEA, 2023b; Jasanoff, 2018; Stirling, 2008).

To promote energy democracies, citizens' views of everyday life should be included in deliberation processes along with scientific and technical topics (Cherry et al., 2021; Jasanoff, 2018); this is to create energy transitions that meet the public's desire for transparent, just, and trustworthy policies (Cherry et al., 2021; Nijkamp et al., 2023) and a level of usability that tailors dialogue to the users' needs and capacity (Schmidt et al., 2024).

6.5 Local community knowledge and capacity building for energy transitions

In this section, we discuss the role that participatory energy management can play in stimulating knowledge and skill acquisition and increasing opportunities for deliberation about energy transitions. Participation stimulates members' learning and thereby prompts just energy planning that creates social and economic opportunities to address the needs of different stakeholders. We discuss literature and show what formats and approaches create learning that increases local participation in energy decision-making processes.

In the previous sections, we described how energy communities support democratic decision-making processes in energy transitions, to involve both private citizens and public actors in discussing and planning energy provision (Schmid et al., 2020). These communities foster the combining of practical knowledge (Huttunen et al., 2022), with scientific knowledge on ecosystem processes and energy systems, which has to form the basis of evidence-informed decisions (Lewandowsky et al., 2023). Within an energy community, there is space for discussing different goals, but also for learning. Learning enables members of a community to acknowledge other opinions, to develop knowledge and trust and/or to change their attitude towards a subject. This is described as social learning (Buchecker et al., 2023), an early definition of which was the capacity to learn from other behaviors when interacting with peers (Bandura, 1977).

The shift to local production and consumption has increased the need to develop local competence on energy provisions – e.g., the use of digital tools – that is based on evidence-based knowledge and scientific analysis (Nijkamp et al., 2023). Knowledge building can be incentivized through national programs (Schmid et al., 2020) or by organizations that provide training, like the Australian Community Power Energy, or Suisse Energy. Schmid et al. (2020) found that 54% of Swiss energy communities collaborate with others to exchange know-how, which is facilitated by the Swiss Association of independent energy producers (VESE). It must be noted that the Swiss federal system enables municipalities to develop and implement their energy policies and makes them responsible for energy provision. They therefore have local competencies and autonomy in the administrative, political, and financial organization of energy provision (Schmid et al., 2020).

The advantages of building knowledge by participating in energy communities are increased awareness of the topic (Huttunen et al., 2022) and a sense of membership, as individuals feel representative of a group with shared objectives, e.g., the negotiation of more favorable energy pricing (Lennon et al., 2019). Citizen science (CS) is a method that leverages knowledge transfer to engage participants in learning processes (Michel, 2020); this method aims at co-producing knowledge through practical activities, by acknowledging and benefiting from the local knowledge – e.g., local lifestyles and practices. Hence, CS is a method that makes activities a means for combining scientific with practical knowledge (Huttunen et al., 2022). For instance, Barbosa et al. (2022) used CS when co-creating a database of PV installations by inviting private and public entities to register the characteristics of their PVs; the goal of the research was to collect data on locations and characteristics of solar installations. Nonetheless, a CS activity for co-developing knowledge should move beyond data collection and aim at developing engagement that supports actions towards energy transitions. Furthermore, in these projects diversity is key to addressing the technical and social aspects of a problem (Barbosa et al., 2022).

Learning about biodiversity conservation supports the objectives of energy policies. In surveying Swiss and German energy communities, Schmid et al. (2020) identified different ambitions for the two countries' policies;

while in Switzerland municipal policies are informed by the Energy City label, in Germany they target climate protection. This difference can make the need to protect biodiversity in energy transitions less or more explicit. The Swiss Academy of Science project EnBiLa supports the spatial planning of RE facilities by providing criteria for identifying sites that impact biodiversity and landscape the least. This is directed at guiding the cantonal administration and actors in the energy sector (Neu et al., 2024).

Swiss natural parks are active in promoting knowledge transfer aimed at the protection of local landscape through land management. For instance, Le Parc naturel régional de la Vallée du Trient in the Swiss canton of Valais invites residents of the seven municipalities included in the park to propose activities that have three objectives: (1) to preserve, support, and value the quality of the landscape; (2) to create sustainable living and leisure while promoting local economy; (3) to develop knowledge on the cultural and natural value of the local territory. These projects are approved and financed at the cantonal and federal level (Parc naturel régional de la Vallée du Trient, 2024). The project IRENES uses interregional knowledge exchange and sharing on the relationships between RE and ecosystem services to identify gaps in energy policies across environmental, social, and governmental levels (IRENES Interreg Europe, 2024).

Games can be used to foster the stakeholders' comprehension of the effects that meeting energy targets through RE infrastructure can have on biodiversity (Garcia et al., 2022). In a game environment, players can take on different roles to gain an outside perspective and explore the system's reaction to a set of decisions. Within the simulation of the game, players can reflect on their decisions and increase their system-level understanding of trade-offs and strategies (Bos et al., 2020; Roca-Puigròs et al., 2024). Ultimately, these experiences may lead to better decisions using participatory methods.

In summary, learning through participation allows members and stakeholders engaged in decision-making about the energy transition to integrate and exchange scientific knowledge with practical knowledge. Furthermore, the activities of an energy community can enable the exchange of and learning about practical knowledge between stakeholders. Learning is also key for supporting and informing policymaking for the integration of biodiversity and landscape protection in energy transition policies. Here, gaming is a tool that allows different stakeholders to understand the consequences of decision-making at a system level.

6.6 Key messages

1. **Energy communities favor more just distribution and recognition of the benefits of decentralized RE plans through multi-stakeholder participation, which can include municipalities, energy utilities, and private actors. These communities are vehicles for national and local governments to encourage local participation in the decision-making of energy production and consumption.**
2. **The Swiss federal system is key for supporting and regulating the development of energy communities: financing, politics, and administration. Such support should recognize the social and economic value these communities bring to municipalities by managing RE provision. Through open deliberations, they integrate energy justice and biodiversity and landscape protection into energy policies.**
3. **Energy communities can act as vehicles and promoters of knowledge exchange on energy and land management to build skills in using science-based knowledge and managing and financing RE projects. This exchange can take the form of open deliberations, activities, or gaming, with the objective of identifying the trade-offs between RE planning and biodiversity/landscape protection and integrating non-scientific/practical knowledge, lived experiences, and local needs.**

Supports recommendations:

4 5 7 8

CHAPTER 7

CHAPTER 7

Legal Framework and Policy

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7.1 Introduction

As stated in the previous chapters, carefully integrating planning and decision-making about renewable energy (RE) is necessary to reach energy and climate goals while preserving biodiversity. The legal (international, constitutional, and legislative) framework is important as it sets the goals and shapes the decision-making process. It can hinder, or foster, synergies between seemingly competing goals. It can predefine certain priorities or set a process for a transparent and participatory balance of interest. In this chapter, we briefly present Switzerland's international commitments in the field of biodiversity conservation, climate action, and RE (section 7.2). We then move on to the Swiss constitutional and legal order in each of these areas (section 7.3), before discussing the federal rules shaping the interaction between RE and biodiversity conservation (section 7.4). Given the importance of planning and scientific knowledge in good decision-making, we then discuss ways to improve these two points in sections 7.5 and 7.6.

7.2 International commitments in biodiversity conservation, climate action, and RE

The international community has long adopted international policies and binding conventions in the fields of biodiversity conservation, climate action, and RE. These should guide the implementation of related policies at the Swiss level.

Switzerland is a signatory to a number of international conventions in the field of biodiversity conservation at the national level (e.g., the Convention on Biological Diversity (CBD) with its Global Biodiversity Framework (GBF), the Ramsar Convention on Wetlands, and the Bern Convention on the Conservation of European Wildlife and Natural Habitats). These conventions typically require the conservation of endangered species, the establishment of a system of protected areas, and the restoration of degraded ecosystems (see more extensively, Bowman et al., 2010). For instance, as stated in Chapter 2, in the GBF, the parties to the CBD committed to conserving 30% of terrestrial and inland water areas and to restoring 30% of degraded ecosystems by 2030 (Targets 3 and 2). The CBD and GBF also call for the integration of biodiversity concerns into other sectors and encourage countries to implement integrative spatial planning (CBD, art. 6 and 14; GBF Target 1 and 14).

Switzerland is also committed to reducing greenhouse gas (GHG) emissions and reaching climate neutrality in the second half of the century in accordance with the Paris Agreement under the UN Framework Convention to Combat Climate Change (UNFCCC). Rather than imposing intermediate reduction targets from the top down, the Paris Agreement requires the parties to set their own climate mitigation targets. However, these targets must be progressive and represent the highest possible level of ambition, taking into account the capacities of each country. As a rich country with considerable resources, Switzerland has a duty to adopt ambitious targets and trajectories.

Although there is no international convention on RE that legally binds Switzerland[6], there are nevertheless important political pledges. According to target 7.2 of the UN Sustainable Development Goals (SDGs), the share of RE in the global energy mix should be increased substantially by 2030. More recently, 123 parties to the Paris Agreement, including Switzerland, pledged during UNFCCC COP 28 in December 2023 "to work together to triple the world's installed renewable energy generation capacity to at least 11'000 GW by 2030, taking into consideration different starting points and national circumstances" (Global Renewables and Energy Efficiency Pledge).

Although the SDGs strongly emphasize their joint importance and interrelations, biodiversity and climate change concerns tend to be governed separately at the international level, as responsibilities are dispersed among numerous international organizations and isolated treaty regimes (Kotzé and Kim, 2022). Biodiversity is still insufficiently taken into account in the international climate change regime. Furthermore, international environmental law governance has long faced criticism for being weak, especially in a world in which states tend to be unwilling to accept strict top-down obligations (Pauwelyn et al., 2014). In addition, biodiversity and climate change conventions currently lack strong compliance mechanisms.

7.3 Swiss legal framework related to biodiversity conservation, climate change, and RE

Biodiversity, climate change, and energy constitute different policy arenas in Switzerland just as they do in international law, with different objectives, different institutions, and a different distribution of power between the Confederation and the cantons (Table 7.1). Below is a brief overview of the federal legal framework for each of these policy arenas. Alongside the Confederation, the cantons and municipalities play key roles in the adoption and/or implementation of the legislation.

In biodiversity conservation, although the cantons hold primary responsibility for nature protection, the Federal Constitution (Cst.), art. 78(4), grants the Confederation broad authority to legislate on the protection of flora, fauna, and the preservation of their diverse natural habitats (Zufferey, 2019). In addition, the Confederation has diverse competences in neighboring fields, e.g. water (art. 76 Cst.), forest (art. 77 Cst.), and fishing and hunting (art. 79 Cst.) that can influence the conservation of biodiversity. Based on these competences, the Confederation has adopted several national laws that concur with the conservation of biodiversity, such as the Federal Act on the Protection of Nature and Cultural Heritage (NCHA), the National Park Act, the Hunting Act, the Forest Act, and the Water Act. In particular, the Confederation has created several categories of protected areas to be designated by either the Confederation or the cantons, e.g. Swiss National Park, forest reserves, game and waterfowl reserves, inventories of biotopes of national, regional, and local importance, parks of national importance (Frigerio, 2021). Although these areas have different conservation objectives and protection regimes, they are supposed to represent the most precious ecosystems of Switzerland. In line with the executive federalism

6 The protocol on the implementation of the Alpine Convention of 1991 in the field of energy includes several broad commitments in terms of renewable energy, but was never ratified by Switzerland.

and the principle of subsidiarity (art. 43a al. 1 and art. 46 Cst.), the conservation and management of these areas, even those inventoried by the Confederation, mostly falls to the cantons (Joly, 2020). The protection of landscapes of national importance contributes significantly to the conservation of biodiversity (art. 5-6 NCHA). Outside of protected areas, art. 18 NCHA provides a general protection for biotopes worthy of protection. Encroachment upon these biotopes should be avoided, minimized, and compensated (according to the mitigation hierarchy). In addition, the Swiss Biodiversity Strategy (BAFU, 2012) and the accompanying Action Plan (BAFU, 2017b) (see Chapter 3) set out 10 targets that are intended to conserve and protect biodiversity and ecosystems directly (e.g. ecological infrastructure, protection of specific species or habitats) or indirectly (e.g. through collaboration with other (political) sectors).

However, as stated in Chapter 3, there are many deficiencies in the implementation of the legal framework and action plan for biodiversity conservation (BAFU, 2023b). First, the protected areas cover only 13.4% of the territory (BAFU, 2023a), whereas to be in line with international commitments and the recommendations of scientists they should cover 30% of the territory (Guntern et al., 2013). In addition, no national inventories exist for many habitats important for biodiversity, such as near-pristine rivers and streams and high-stem orchards (Petitpierre et al., 2021). In addition, many of the currently protected areas are too small, in bad condition, and poorly connected (BAFU, 2022c). Aware of the implementation problems, the Federal Council has instructed the cantons to plan the implementation of the ecological infrastructure by the end of 2024 through the financial program agreements in the area of the environment 2020–2024 (BAFU, 2021b, 2018).

Although the constitution does not define a specific head of competence relating to climate change, the Confederation can rely on its general competence for the protection of the environment under article 74 Cst. to adopt climate change legislation. In accordance with its international climate obligations, Switzerland has committed to halve emissions by 2030 (compared to 1990), and to reduce GHG emissions to net zero by 2050 (reaffirmed 2021 NDC and Climate Law). In addition, the 2011 CO_2 Law, updated in March 2024, sets a series of measures to reach these objectives (CO_2 Law modification project 2022). On 9 April 2024, the European Court of Human Rights ruled that Switzerland's intermediate climate targets are insufficient and that the country has not implemented adequate measures to mitigate the effects of climate change (ECHR, 2024).

Additionally, in accordance with art. 89 par. 1 of the Federal Constitution, the Confederation and the cantons shall, within the scope of their powers, "ensure a sufficient, diverse, safe, economic and environmentally sustainable energy supply as well as the economic and efficient use of energy". Alongside these constitutional objectives, the Swiss Energy Strategy 2050 promotes domestic RE to reduce dependence on imported fossil fuels and to meet climate change obligations. In line with these overall objectives, the 2016 Energy Law sets a series of indicative RE targets for 2030 and the overall legal framework to reach them. It is then up to the cantons to adopt detailed rules, the Confederation only having a competence on principles on the use of RE sources (art. 89 par. 2). In the aftermath of the war in Ukraine and the risk of energy shortages in the winter of 2022, the Confederation furthermore adopted a series of temporary laws to bolster the development of RE (the Solar Express and Wind Express laws) and in 2023 modified the 2016 Energy Law for the longer term (Mantelerlass), as described in Chapter 4.

Lastly, the Spatial Planning Act, its ordinances, and land use cantonal laws and regulations also shape decisions in these sectors, to the extent that they have important spatial consequences and need construction authorization.

<table>
<tr><th></th><th>BIODIVERSITY CONSERVATION</th><th>CLIMATE CHANGE</th><th>RENEWABLE ENERGY</th></tr>
<tr><td rowspan="2">Constitutional provision</td><td>ARTICLE 78:
The protection of nature is the responsibility of the cantons
The Confederation shall legislate on the protection of animal and plant life [...]
Strict protection of wetlands</td><td>No explicit head of competence, but basis in article 74 and 89</td><td>ARTICLE 89:
“Confederation and Cantons shall endeavor to ensure a sufficient, diverse, safe, economic and environmentally sustainable energy supply”
Competence of principle of the Confederation for RE</td></tr>
<tr><td colspan="3">ARTICLE 73:
The Confederation and the Cantons shall endeavor to achieve a balanced and sustainable relationship between nature and its capacity to renew itself and the demands placed on it by the population</td></tr>
<tr><td>Federal legislations</td><td>Nature Protection Act
Hunting Act
Forest Act
Water Act</td><td>Climate Law
CO_2 Emissions Reduction Law</td><td>Energy Law</td></tr>
<tr><td>Legal and political Targets</td><td>Political targets:
17% strict protection
13% additional zones for buffering or connecting protected areas
Total 30% protected
Establishment of an ecological infrastructure</td><td>Legal targets:
Reduction of GHG compared to 1990:
50% by 2030
64% on average between 2031-2040
75% by 2040
89% on average between 2041-2050
Climate-neutral in 2050</td><td>Legal targets:
RE excl. hydroelectricity:
35 TWh by 2035,
45 TWh by 2050

Hydroelectricity:
37.9 TWh by 2035,
39.2 TWh by 2050</td></tr>
</table>

Table 7.1 | **Legal and policy framework for biodiversity conservation, climate change, and renewable energy**

7.4 Interaction between RE and biodiversity conservation

Despite the fact that biodiversity and RE are the objects of distinct policies, the rules regulating the different protected areas and biotopes, together with the Energy Law and the Spatial Planning Act, govern the interaction between biodiversity protection and RE development.

Although the rules have changed, it seems important to briefly explain the system put in place by the 2016 Energy Law. The most strict form of RE restriction was the categorical prohibition of new installations in the stricter categories of protected areas (protection of wetlands, the Swiss National Park, the biotopes of national importance, and waterfowl reserves) (Largey, 2022; Tschannen, 2018). This exclusion applied to listed biotopes, but also to those that, although not listed yet, in practice meet the criteria for listing (Federal Tribunal, Case 1C_356/2019). The protection of key areas was therefore dependent upon the actual inventory and designation of these protected areas. Beyond these areas, a balance of interest must be conducted *in concreto* during each step of the renewable energy planning and authorization procedures (art. 3 of the Land Use Act, ATF 148 II 36 consid. 13.5). Accordingly, competent authorities must identify all relevant interests, then assess and prioritize the identified interests. Interests valued as equal should be optimized (Largey, 2022; Tschannen, 2018). In other words, RE projects must be made compatible with the biodiversity interests being encroached upon. In this assessment, the national nature of the interest at stake may be determinant (art. 6, par. 2 NCHA, art. 5 Forest law). According to art. 12 of the Energy Law, only renewable energy projects of a certain size were of national interest. Furthermore, measures to avoid, minimize, and compensate impacts must usually be considered (art. 6, par 1; art. 18 par 1ter NCHA). In addition, the cantonal structure plan had to designate suitable areas and stretches of water that could be used to generate renewable energies (art. 8a Spatial Planning Act).

As stated above, the Confederation adopted a series of temporary laws in the aftermath of the war in Ukraine, which have the potential to significantly undermine the protection of protected areas and species. In particular, the temporary and urgent Solar Express law places solar energy above all other national interests, including biodiversity (presumption of superiority) and removes the planning obligation (art. 71a LEne). This law has been highly criticized by the legal literature (Bühl, 2023; Griffel, 2023a, 2023b; Marti, 2023). First, there is broad agreement among constitutional law experts that the requirements for an urgent federal act pursuant to art. 165 of the Federal Constitution were not met. The justification for prioritizing the realization of large photovoltaic systems over other national, regional, and local interests is questionable against the background of a weighing up of interests in the specific case and the protection of biodiversity of art. 78 of the Constitution (Biaggini, 2022; Griffel, 2023b). Lastly, the exclusion of the cantons' planning obligation contradicts art. 75 BV (Griffel, 2023a). The Wind Express law, not adopted urgently, is more balanced, but restricts the type and number of appeals (art. 71c LEne).

The long-term modification of the Energy Law (Revision of StromVG and EnG) is also more respectful of biodiversity conservation than the above-mentioned Solar Express law, but still undermines conservation in many ways. On the positive side, it does not reiterate the presumption of superiority of RE over other interests of national importance that was included in the Solar Express law: these are equivalent. Furthermore, after debate, power plants in biotopes of national importance and in water and migratory bird reserves remained prohibited. However, newly emerging glacier forefields and alpine alluvial plains could be considered as locations of large solar power plants and hydroelectric dams. Additionally, the national interest of RE takes precedence over contrary interests of cantonal, regional, and local importance, which may be detrimental to biotopes of cantonal, regional, and local importance. Moreover, measures to avoid, mitigate, and compensate for impacts on natural landscapes of national interest are no longer required. Furthermore, the practice of reducing the amount of residual flow in the event of a power shortage is now provided for by law. Lastly, the new law facilitates RE in forest areas. These modifications could prevent Switzerland from meeting its international obligations under the biodiversity conventions mentioned earlier. In the implementation of these rules, it is therefore of utmost importance that cantonal authorities interpret them in accordance with their international obligations (Schmid et al., 2021).

7.5 Fostering integrated planning

As stated in Chapter 2, to address the climate and biodiversity crises jointly, and the related implications of renewable energy development, ecological and infrastructural components must be more systematically and jointly integrated in Swiss policy at all levels. For now, the cantonal authorities are in charge both of planning the ecological infrastructure and of designating in their cantonal structure areas and stretches of water suitable for generating hydroelectric and wind energy as well as ones fit for solar installations of national interest (Mantelerlass). However, these processes are separate. In the Mantelerlass, cantonal authorities must nonetheless take into account the protection of biodiversity and the landscape. It goes without saying that they have to avoid the strict protection areas (see section 7.4). In the other areas, the holistic planning of the ecological infrastructure should be taken into account when identifying suitable areas. In addition, the mitigation hierarchy that usually occurs at the project level should also guide this planning process (see IUCN and SCNAT guidelines in Chapter 5; Bennun et al., 2021; Neu et al., 2024).

The current framework lacks a coordinated approach at the federal level to address and solve the biodiversity, climate, and energy crisis. Coordination between the different RE sectors (solar, wind, and hydro) is also lacking. As proposed by some, a coordinated binding planning at the federal level, for instance through a sectoral plan, could show which interventions in nature and the landscape are ultimately unavoidable to meet our exorbitant energy requirements in a reasonably sustainable way (Griffel, 2023a). Such a planning instrument would also ensure a forward-looking legislative approach and could also avoid short-term actions and various constitutional conflicts. If well done, such a planning process furthermore reduces the risk of opposition and therefore speeds up the subsequent approval of individual RE projects. To date, however, there is no federal constitutional competence to adopt a sectoral plan in the field of RE and a modification of the constitution would therefore be needed. As an alternative, one could think of a roundtable at the national level for all RE and biodiversity issues, in the image of the hydroelectric roundtable (see Chapter 4). Although the results would be non-binding, they could guide the planning process at the cantonal level.

7.6 Fostering integration of scientific knowledge

The tremendous challenges of fighting biodiversity, climate change, and energy crises all together also highlight the need to rethink the interactions between scientists and policymakers across various sectors. Such reevaluation would aim to establish a different and more coordinated domestic science–policy interface able to fight such multi-scaled and cross-cutting issues.

Dunn et al. (2018) distinguish three theoretical models of science–policy interactions in political science: the “science push” approach (i.e. scientists transmitting knowledge to potential policymakers), the contrary “demand pull” approach (i.e. potential knowledge users asking scientists for specific information) and the intermediary “co-production” model characterized by a partnership approach (Jasanoff, 2004). Evidence-based policymaking (Hadorn et al., 2022) represents another ideal integrative approach, enabling policymakers to “digest” the knowledge they receive, and interpret the scientific outcomes into tangible policy measures. Additionally, other ideal-typical models incorporate factors such as organizational and cultural formats of the science-policy interfaces; the relevant knowledge actors; the styles, transparency, and visibility of the interactions; the level of trust in expert knowledge claims; and the scientific values and ethics associated with environmental and societal issues within the interface (see for instance Hermann et al., 2017; Jasanoff, 2004). Science-policy interactions should be conceptualized not as linear processes with inherent limitations, but as circular, involving iterative and reciprocal mechanisms of knowledge transfer (Vauchez, 2013). One proposal for achieving such knowledge dissemination is to install what Bourg et al. (2011) call a “College of the Future”, composed of researchers and experts, with a specific mandate of monitoring and informing the decision-making, alongside the traditional executive and legislative chambers.

The goals and measures of the Swiss climate policy are coordinated horizontally among the federal offices and departments, and vertically by the cantons and their conferences. The Environment Department relies on its own conferences and working groups (Casado-Asensio and Steurer, 2016). Switzerland also established an Interdepartmental Sustainable Development Committee (ISDC), which defines the priorities for action and oversees implementation and monitors progress. However, scientific findings represent only one criterion among several in the Swiss parliamentary decision-making process. Biodiversity issues, in particular, are especially subject to political dynamics and do not get constant attention on the national agenda (Reber et al., 2022). In comparison to other countries, Switzerland has been involved in institutionalizing science-policy interactions for some time. In 1996, ProClim established a Swiss parliamentary group on climate change, which remained active until 2019. This group organized lunch meetings thrice annually during parliamentary sessions, bringing together climate scientists and parliamentarians for presentations and informal exchanges (Hermann et al., 2017). In March 2021, a new inter-parliamentary group on climate change was initiated by the Climate Alliance group. In parallel, the lunch sessions have been replaced by several Klimadialogues supervised by ProClim, involving the leaders of the political parties and Swiss experts.

In several other European countries, national climate advisory councils comprising scientists are now increasingly prevalent (Weaver et al., 2019). However, to influence public policies effectively, such councils need stable public resources. Established in 2008 under the Climate Change Act, the UK Committee on Climate Change, with its substantial membership and development of prospective scenarios, has successfully worked toward the reduction of the GHG emissions of the country. In France, the Citizen Climate Convention in 2021, comprising 149 French citizens trained by experts, resulted in a comprehensive list of 150 measures to reduce national GHG emissions by 40% by 2030. This unconventional format was met with great enthusiasm by civil society and instilled hope for the future of national climate policy. Nevertheless, only a small fraction of the proposals were translated into law “without filter”, i.e., without any modification. Such examples of citizen assemblies demonstrate that when a diversity of people engage with these issues alongside more “conventional” political processes (such as climate advisory councils), they are willing to make significant and transformative choices regarding the societal model they envision. The democratic, participation, and control procedures are essential for the legitimacy of implementing coordinated cross-sector measures. Such principles should not be overstepped in the name of urgency.

7.7 Key messages

1. Switzerland must comply with international commitments in biodiversity conservation, climate change mitigation, and large-scale development of renewable energy concurrently. These commitments must be respected by both federal and cantonal authorities.
2. It is important to maintain a legislative prohibition on developing renewable energy in strictly protected areas and pristine habitats.
3. Until the ecological infrastructure is fully established, there is a risk under the current legal framework that many unprotected key ecosystems will not be sufficiently taken into account in the balance of interest to be conducted at the planning and authorization stages.
4. As seen in Chapter 5, following the mitigation hierarchy and aiming for a net gain of biodiversity can generate synergies between biodiversity and renewable energy. In this sense, the legislative decision to remove the obligation to adopt measures to avoid, mitigate, and compensate for impacts on natural landscapes of national interest is contrary to international best practices. Note, however, that this obligation is still maintained for biotopes worthy of protection under art. 18 NCHA.
5. The concurrent fulfillment of biodiversity, climate, and renewable energy commitments would benefit from a coordinated approach.
6. The democratic, participation, and control procedures are essential for the legitimacy of implementation measures. These should not be overstepped in the name of urgency, as they were by the Solar Express law.

Supports recommendations:

1 2 3 4 5 6 7 8

CHAPTER 8

CHAPTER 8

Conclusions, Urgent Recommendations, and Proposed Research Agenda

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8.1 Conclusions

Switzerland's transition to large-scale renewable energy (RE) can and must be carefully managed to prevent further biodiversity destruction. This requires a national plan that prioritizes low-impact RE projects and adopts best practices, stops and reverses existing pressures on biodiversity, and engages local communities, all while adhering to international biodiversity and climate commitments.

This is the conclusion of the CLIMACT-supported project "Towards new renewable energy developments in Switzerland that preserve biodiversity". Over 12 months, 45 scientists from 16 Swiss scientific institutions participated in collaborative workshops, extensive scientific literature reviews, and several rounds of writing and reviewing the assessment report, with a final round of whole-report reviews. The goal was to balance climate action, energy security, and ecological integrity, particularly in Alpine regions.

The executive summary in Chapter 1 provides detailed conclusions. Chapters 2–7 offer in-depth analyses. Chapter 8 presents urgent recommendations and outlines a future research agenda.

8.2 Urgent recommendations

This report presents numerous critical recommendations throughout each chapter. Here, we summarize the most impactful next steps, consistent with conclusions and recommendations in Chapter 1.

1. **Establish a regular dialogue:** Facilitate ongoing communication between Swiss scientific and policymaking communities working on biodiversity, renewable energy (RE), and climate. A permanent coordination unit, ideally hosted by SCNAT or a mandated Swiss university, would greatly aid this effort.

2. **Develop an integrated national plan** for large-scale RE implementation by engaging national and cantonal offices. This plan should be based on the best available scientific knowledge and ensure:

   a. **Minimization of additional biodiversity impact:** Integrate the best available current data on nationwide biodiversity status and conservation needs, and the provision of ecosystem services (for example the Swiss ecological infrastructure), taking into account potential synergies and trade-offs between biodiversity conservation, climate change mitigation, and deployment of RE infrastructure. This plan should follow existing guidelines on scientifically established best practices for a biodiversity-friendly RE transition developed by reference national bodies such as SCNAT.

b. **Reduction of existing biodiversity impacts:** Identify and map current pressures damaging biodiversity, and target areas for ecosystem restoration to guide cantonal implementation.

c. **Capacity planning for resilient RE supply:** Balance roof photovoltaic (PV), wind, hydro, and Alpine PV capacity to ensure sufficient and resilient RE supply year-round, meeting the needs of the current and future population without fossil fuels.

d. **Compliance with international commitments:** Ensure that the national plan aligns with Switzerland's international commitments to biodiversity conservation (CBD Global Biodiversity Framework) and climate action (UNFCCC Paris Agreement and the Global Renewables and Energy Efficiency Pledge at COP 28).

3. **Support local communities:** Initiate programs at national and cantonal levels to support local communities in engaging in deliberation, impact monitoring, and capacity building around RE and biodiversity.
4. **Conduct long-term impact monitoring:** Implement long-term monitoring of the before-after-control impact on biodiversity for any new RE projects (except PV on roofs or infrastructure).
5. **Implement the proposed research agenda** to address identified knowledge gaps.
6. **[Essential enabler beyond the scope of this project] National sufficiency strategy:** Even with further energy efficiency improvements, current efforts to develop RE and protect biodiversity will not ensure wellbeing for all within planetary boundaries unless current paradigms of economic growth are overcome and demand is better aligned with human needs.

These steps are essential to ensure a balanced approach that supports renewable energy development while preserving biodiversity. Full details on the rationales behind these recommendations can be found in the individual chapters.

8.3 Proposed research agenda

This report effectively identifies the key issues connecting RE development and biodiversity protection in Switzerland, offering actionable high-level recommendations grounded in published scientific literature. While the main findings and recommendations are established with high confidence based on the accumulated evidence, many relevant aspects would still benefit from further research.

Based on our analysis across the six previous chapters, we recommend prioritizing, funding, and enabling the following research questions (RQs), structured into three research areas:

1. **Understanding and protecting Swiss biodiversity, in the context of climate change** (this research area is independent of RE, but an important prerequisite for RQ2.x and RQ3.x)
   - **RQ1.1:** What are the specific impacts of climate change on Switzerland's biodiversity over different time scales, and how does climate change interact with other key threats to biodiversity?
   - **RQ1.2:** How do invasive species spread in Switzerland, and how do they interact with native biodiversity and ecosystem services, especially in the context of climate change?

- **RQ1.3:** Which Swiss habitats are the most pristine, and what is their conservation value in terms of biodiversity and ecosystem services, especially climate regulation and climate change mitigation and adaptation? Develop an inventory of important habitats like the most pristine high alpine alluvial zones, peatlands, and moors or high-value natural alpine grasslands. Which areas and corridors will be the most critical to protect or restore to ensure the conservation and recovery of Swiss biodiversity?
- **RQ1.4:** Switzerland officially protects only 13.4% (BAFU, 2023a) of its territory, and that only to a limited extent, far short of the 30% target by 2030 set by the Global Biodiversity Framework. Which additional biodiversity areas (OECMs) should be prioritized for protection, and which are most urgent to prevent further degradation? Beyond strongly protected areas, which partial protections are most effective? What would an effective national plan for ecosystem restoration and recovery be, including prioritization and annual targets?
- **RQ1.5:** Existing protected areas are often too small, degraded or in poor condition, and poorly connected. Which area reclassifications, new or improved connection ecological infrastructure, and additional protections are needed for optimal biodiversity protection, especially in the context of climate change?
- **RQ1.6:** Which existing pressures should be reduced or stopped most urgently? Develop an inventory of the most damaging human pressures on biodiversity, particularly from agriculture, soil sealing, urban sprawl, roads, ski areas, and other infrastructures. Identify the main enablers of these pressures, such as growth-oriented policies or harmful subsidies.

2. **Impact of renewable energy on Swiss biodiversity**
    - **RQ2.1:** How do large-scale PV projects impact ecosystem integrity, biodiversity, and climate change mitigation capacity, particularly in fragile alpine regions? Detailed environmental impact assessment and follow-up of the first projects is crucial (i.e. monitoring of before-after-control impact on ecological conditions and processes). This should include ground shading, and grid and road access, extending beyond the documented effects and benefits of PV installations on brownfields, degraded lands, and agrivoltaic systems. How can PV installations be designed with minimum footprint and ground impact?
    - **RQ2.2:** What is the feasibility and effectiveness of small solar parks near existing high-altitude infrastructures, such as mountain resorts for winter or summer activities (skiing, biking, etc.)? These could potentially offer lower costs and reduced environmental impacts compared to large-scale solar parks. Specifically, show how a strategy with smaller, distributed PV parks on non-pristine landscape could be deployed.
    - **RQ2.3:** What are the most promising conservation PV approaches that achieve both energy generation and biodiversity protection, reinforcing ecosystem services provision, especially in (semi-)natural landscapes? What is needed for effective implementation?
    - **RQ2.4:** What are the optimal locations for large-scale wind energy development across Switzerland to maximize winter energy supply and minimize impact on wildlife? What is the best way to implement automated stop mechanisms during migration times? How can wind installations be designed with minimum

footprint and ground impact?

- **RQ2.5:** Hydropower, especially residual water flows, exerts high pressure, affecting aquatic ecosystems, fish migration, sediment transport, and habitat connectivity. For current and future planned installations, what is the best way to restore fish migration routes and sediment transport processes while mitigating the effects of hydropeaking? Where can these measures be implemented to benefit freshwater ecosystems and biodiversity restoration and recovery?

3. **Integrated and holistic governance of biodiversity, climate, renewable energy**

- **RQ3.1:** What is the optimal mix of roof PV, wind, and Alpine PV capacity, offering adequate winter supply and excellent biodiversity protection?
- **RQ3.2:** How can national energy and climate policies ensure synergies between energy sufficiency, RE generation, and biodiversity protection, and how do these synergies compare to trade-offs in scenarios of production maximization versus biodiversity protection, in terms of energy economics and energy generated?
- **RQ3.3:** How can RE authorization procedures, especially for wind energy, be significantly accelerated while biodiversity protection and democratic decision-making are reinforced?
- **RQ3.4:** What is the best way to design, maintain, and regularly update a spatially explicit national planning instrument to coordinate RE projects and ensure biodiversity conservation across cantonal and national boundaries, engaging scientists, policymakers, federal and national offices, and local communities?
- **RQ3.5:** What would be adequate intermediate Swiss climate targets in light of the 2024 European Court of Human Rights ruling? Which policy measures will reliably ensure they are reached? Which laws and regulations need to be adapted, and how, to achieve the overall goals of biodiversity, climate, and RE?
- **RQ3.6:** How can local communities be effectively engaged in deliberative decision-making, ensuring community agency, high biodiversity protection, energy security, and overall acceptance? How to ensure knowledge and skill acquisition?
- **RQ3.7:** What are the power, agency, and political economy implications of a large-scale transition to RE? Who is affected by additional costs and benefits?

Implementing this proposed research agenda would ensure a solid scientific knowledge base to effectively develop Switzerland's large-scale renewable energy capacity and protect its biodiversity long-term.

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