Annex 5 - Drivers of large scale photovoltaic and wind power land-use change in alpine Switzerland

Marc Reusser, Jonas Schwaab, Jan Hartman, Adrienne Grêt-Regamey

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Abstract

This case study examines the drivers of land-use change linked to alpine photovoltaic (PV) development in Switzerland, a key component of the country's strategy to expand winter electricity production. Ground-mounted PV projects in high-elevation landscapes raise tensions among national energy goals, landscape identities, tourism, agriculture, and biodiversity protection.

Using a mixed-method approach combining stakeholder workshops, Photovoice, choice experiments, cognitive-psychological experiments, spatial analysis, and municipal voting data, we identify the structural, perceptual, and governance factors that shape decisions about alpine PV.

Developers prioritize cost-efficient and technically feasible sites, particularly those close to existing roads and grid infrastructure, while biodiversity considerations play almost no role in early-stage site selection. Municipal approval decisions, by contrast, depend mainly on local acceptance and governance conditions such as ownership models, economic benefits and voting formats. Across methods, landscape type strongly influences acceptance: infrastructure is tolerated in already modified landscapes but faces resistance in pristine alpine regions, where place-protective values are strong. Physiological data reveal that high-infrastructure scenarios trigger stronger emotional responses, highlighting an affective dimension that is not fully captured by stated preferences alone.

These findings show how structural conditions, values, emotional responses, and institutional arrangements jointly shape land-use trajectories. The Swiss case illustrates that sustainable energy transitions in mountain regions require the deliberate integration of biodiversity considerations and acknowledgment of landscape meanings, both factors that are currently not integrated in site-selection. The Swiss case also shows that governance arrangements must be designed that foster trust and local benefit. These insights are relevant for alpine and mountainous regions across Europe facing similar trade-offs.

1 Context + Framing of Land Use Change

The Swiss Alpine region represents a complex social-ecological technical system where national energy transition goals intersect with local livelihoods, cultural landscapes, and sensitive ecosystems. Switzerland's commitment to phase out nuclear energy and increase renewable electricity production has generated strong pressure to expand photovoltaic (PV) installations, including large-scale ground-mounted plants in high-elevation areas. These projects promise substantial winter electricity output that are crucial for closing a possible winter energy supply gap. However, higher-altitude alpine installations have a direct impact on land use in the Alps, where tourism, agriculture, and conservation of pristine landscapes and prone ecosystems are highly interconnected. As a result, decisions about installing PV farms depend not only on technical feasibility and economic viability but are also deeply embedded in land-use conflicts involving landscape services, biodiversity, and local perceptions of landscape change.

The land-use change at the centre of this case involves converting alpine open land into energy production zones through the development of ground-mounted solar parks. While these sites are chosen for their strong solar irradiation, especially in winter, they represent a transformation from traditional toward energy producing landscapes, altering both the visual and functional role of Alpine landscapes in Switzerland.

Several actor groups play a key role in shaping these land-use changes. Developers, predominantly national or regional energy companies, initiate projects and negotiate with local authorities. Landowners (including municipalities, cooperatives, or private alpine corporations) act as critical gatekeepers by leasing land or co-developing projects. Municipalities, through assemblies or referenda, hold the authority to approve or reject projects, making local citizens central actors in the decision process. Cantonal governments are increasingly influencing outcomes by drafting spatial plans and aligning projects with cantonal energy strategies, while the federal level provides overarching policy instruments, such as the "Solar-Express," which offers subsidies and streamlined approval until the end of 2025. Taken together, these actors can be grouped into four categories: developers, landowners, citizens, and public authorities (municipalities, cantons and state).

Policy goals at local, cantonal, and federal levels align on expanding renewable energy while ensuring compatibility with other land uses. At the federal level, the "Solar Express" aims to accelerate alpine PV deployment for projects submitted by the end of 2025, thereby aiming to secure winter electricity supply. Cantons are tasked with drafting spatial plans that balance the expansion of PV farms with environmental and landscape protection. Local municipal policy goals often relate to ensuring democratic legitimacy (through assemblies or referenda) and reconciling development with local economic interests such as tourism or agriculture. Together, these policy goals create both incentives for rapid PV deployment and constraints to safeguard other land-use functions.

The goal of the WP3 case study in Switzerland is to generate evidence on the drivers and motivations of land-use change linked to alpine PV development. By combining stakeholder workshops, photovoice, choice experiment studies, cognitive-psychological experiments, spatial analyses, and voting data, WP3 aims to systematically identify how socio-economic, perceptual, and governance factors drive the transition towards renewable energy landscapes in the Swiss Alps. With this approach, we aim to disentangle the structural and actor-specific drivers of land-use change linked to the siting and acceptance of alpine PV. Findings from this WP also feed into the MOSAIC Policy Lab to inform how energy transition policies can be better aligned with land-use values, and directly feed into the development of the Swiss SolarWind Explorer in WP5, a tool to support siting of renewable energy landscapes.

2 Methodology

2.1 Workshops to identify structural factors influencing land use change

To identify structural factors influencing land-use change related to renewable energy expansion, we organized a series of three stakeholder workshops between December 2022 and September 2023. The objective was to co-develop criteria for locating ground-mounted PV installations that minimize conflicts with landscape quality and biodiversity.

The first workshop (15 December 2022, 20 participants) brought together experts from federal and cantonal administrations and academia. Participants gathered and discussed existing legal constraints, planning instruments, and scientific evidence, focusing on exclusion criteria (where PV should not be built) and priority criteria (where expansion should be favoured). The collected criteria were refined after the workshop to clearly describe the requirements of potential development areas.

The second workshop (8 May 2023, 48 participants) expanded the group to include municipalities, the energy sector, and civil society. Through rotating group work across four thematic stations, participants revised and consolidated the draft catalogue of criteria, rated their usefulness, and highlighted disagreements between stakeholder groups. Participants were encouraged to propose new criteria where they felt the list from the first workshop did not meet their perspectives. The outcomes highlighted the need to consider solar and wind energy sources separately.

The third workshop (25 September 2023, 18 participants, online) focused on translating the criteria into practical parameters and datasets for cantonal spatial planning, with emphasis on PV installations. Discussions addressed implementation challenges and documented persisting divergences.

Across all workshops, the criteria catalogue was iteratively refined and validated, then circulated for consultation and final review. The process resulted in a consolidated, stakeholder-informed set of criteria to guide conflict-minimizing PV siting in Switzerland.

2.2 Photovoice experiment to identify drivers and motivation supporting land use change

To capture perceptions of alpine land-use change, we conducted a Photovoice exercise with stakeholders directly or indirectly affected by planned PV projects. Participants were invited to either provide their own photographs or select from a set of 17 images depicting existing or planned PV installations in alpine landscapes. Using these visual images, participants responded to a set of questions about their perceptions, hopes, and concerns regarding land-use change through solar infrastructure.

The sample included residents of a municipality where an alpine PV project is under discussion, as well as natural hazard scientists, climate and landscape NGOs, municipal administrations, federal authorities, energy companies, and farmers. Although not all groups responded, the diversity of perspectives provided a broad picture of how PV is interpreted across social, scientific, and professional domains. The guiding questions explored (i) first impressions and symbolic meanings of the landscapes, (ii) perceived risks and opportunities

of alpine PV, (iii) fears of loss (e.g. habitats, retreat areas, scenic value), (iv) conditions for acceptable development, and (v) the actors who should be central in decision-making.

The Photovoice method thus provided a qualitative, actor-centred view of how land-use change is perceived and negotiated in the Alpine context, as well as the motivations of actors involved, highlighting both potential sources of conflict and pathways for more accepted projects.

2.3 Choice experiment: to identify individual drivers and motivations to choose land use change

An online panel survey of Swiss citizens (N=844) was used to assess people's preferences for transforming the landscape with solar panels, windmills, and energy infrastructure (Salak et al., 2021; Salak et al., 2022). The questionnaire had two parts: (1) a discrete choice experiment (DCE) and (2) questions on meanings/experiences. Respondents completed 15 choice tasks comparing two renewable energy systems landscape scenarios, plus an opt-out option. Attributes were defined through literature and an expert workshop. Four key attributes were varied: landscape type, wind infrastructure, PV infrastructure, and high-voltage power lines. Fractional factorial D-optimal design (NGENE v.1.2.0) reduced 224 possible combinations to 30 alternatives across 15 randomized tasks. Analysis used a Multinomial Logit Hierarchical Bayes (MNL-HB) model. The model was estimated via Markov Chain Monte Carlo. Individual utilities from HB were then used as input to a Randomized First Choice (RFC) simulation. The two-stage approach (HB + RFC) produced estimates of the likelihood of choosing each scenario, enabling inference on Swiss citizens' preferences for renewable energy landscapes.

2.4 Cognitive-psychological experiment: to identify individual drivers and motivations to support land use change

To gain a spatially explicit understanding of the affective drivers underlying support for the implementation of renewable energy infrastructures within specific landscapes, we measured participants' physiological (electrodermal activity) and behavioural (landscape preference) responses to virtual stimuli depicting land-use changes across different renewable energy implementation scenarios (Spielhofer et al., 2021). The visual stimuli consisted of either a low or a high number of wind turbines and photovoltaic systems across seven landscape types of representatives of the main landscape types in Switzerland. The seven landscape types allowed to extrapolate the results across Switzerland. Participants were asked to choose their preferred landscape image from pairs of sequentially presented images while we recorded their electrodermal activity. The study recruited 101 young, mainly well-educated and environmentally oriented German-speaking students. Fourteen 30-second panoramic videos were created from 3D reconstructions of seven typical Swiss landscapes. LiDAR point clouds were coloured with high-resolution photographs and rendered in CINEMA 4D under constant atmospheric conditions. Each landscape had two versions, showing low- and high-renewable energy scenarios. Ambient sounds were recorded and standardised. Testing occurred individually in the Mobile Visual Acoustic Laboratory, a sound- and light-controlled aluminium cabin with three projection screens and surrounding sound. Skin conductance electrodes were attached to the non-dominant hand to record electrodermal activity (EDA). After consent and baseline measurement (reading a short story), participants completed one practice trial followed by three randomised testing trials comparing pairs of landscape videos (high–high, high–low, low–low RES). After each trial, they chose their preferred landscape. Post-experiment questionnaires measured environmental attitudes, neighbourhood perceptions, and socio-demographics. Results were analysed using nested linear mixed models and Spearman rank correlations (Bonferroni-corrected) related both dependent variables to the high- and low-level visual features of the stimuli. The results provided a Swiss-wide map of citizen preference levels for renewable energy systems.

2.5 Spatial analyses to identify drivers and motivations to implement land use changes

In this analysis, we aimed to examine the drivers and motivations of decision-makers involved in the implementation of renewable energy systems, rather than stated preferences or affective factors influencing preferences, as investigated above.

Several stakeholders are involved in the implementation process: developers aiming to construct the PV systems. Most often, the developers are energy companies. Second, there are landowners who cooperate with the developers to sell or lease their land for the installation of the PV systems. In some cases, the landowners themselves are developers. Third, municipalities can accept or reject projects planned within their administrative boundaries. As a fourth actor, the cantons will soon become highly relevant, as they are in the process of creating spatial plans that define where PV systems can be installed and where they cannot.

We used, on the one hand, the structural factors assessed in the workshops (see 1) that are relevant when selecting sites for PV systems. On the other hand, we collected spatially explicit data showing where the installation of PV farms has started, is planned, or where it was planned until it was rejected by a municipality (Fig.1). This data can be used in combination with the normative set of spatial criteria to assess whether the criteria influenced the decision-making process.

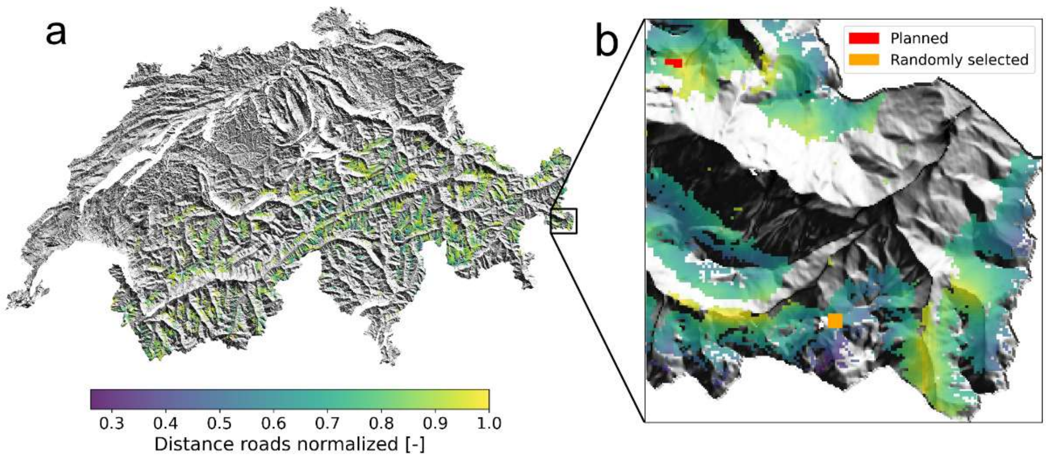

Figure 1: a) Map of Switzerland showing the distance to roads for all areas that are available for the installation of ground-mounted PV-farms. b) Clipped area of eastern Switzerland showing the patches of a planned PV farm (red) and a randomly selected patch for a PV farm (orange).

We combined this spatially explicit data to understand how developers selected sites for the installation of PV farms. We analysed the characteristics of each site planned for installation based on the defined spatially explicit criteria (e.g., "distance to roads" or "winter power production potential"). To better understand which criteria were taken into consideration when these sites were selected, we compared them against a set of randomly selected locations. To test for significant differences, we computed the distribution of the means and the medians based on bootstrapping (resampling 10'000 times with replacement) of the planned and the randomly selected sites.

Second, we used the data to determine whether some of the normatively defined spatially explicit criteria were relevant to municipalities' decisions on whether to approve or disapprove the installation of a PV farm on their territory. In our dataset, there were 26 sites on which the installation had been approved by the respective municipalities and 20 sites on which the installation had been rejected. For 5 municipalities, there has not yet been a decision. To test whether there was a significant difference between accepted and rejected sites, we again used a bootstrapping approach, calculating the distribution of the means and the medians (based on resampling 10'000 times with replacement).

2.6 Voting analyses to identify drivers and motivations to implement land use changes

A recent study led by Prof. Stadelmann (Stadelmann-Steffen et al., 2025) aimed at identifying how the type of decision-making (public vs. secret voting) and the ownership model (distant/private vs. local/public) affects acceptance for renewable energy systems. The study analysed 40 alpine photovoltaic projects in Switzerland that were subject to municipal votes between June 2023 and December 2024. Using cross-sectional Bayesian beta regression models, they examined the proportion of "yes" votes in these local decisions. The key explanatory variables were the type of voting (public versus secret) and the ownership structure (local/public versus distant/private). Additional control variables included project size, municipal support for a 2024 national energy referendum, and time trends. The models used non-informative priors and are estimated with the *brms* package in R (10’000 iterations with 5’000 burn-in), allowing the analysis of the entire population rather than a sample.

3 Structural external drivers for land-use change

Structural drivers shape the opportunity space for alpine PV development by creating incentives, constraints, and spatial feasibility conditions. In this case study, the major structural drivers can be grouped into (1) policy drivers, (2) market/technical drivers, (3) environmental drivers, and (4) social-environment drivers.

3.1 Policy drivers

At the federal level, policy incentives, such as the “Solar Express” act, serve as a strong accelerator of alpine PV development by providing time-limited financial and procedural support for projects submitted by the end of 2025. Cantons are increasingly relevant as they are developing spatial plans that define where PV systems can be installed and where they cannot. Local municipal processes (assemblies or referenda) create additional institutional constraints and opportunities by shaping how decisions are formally made.

In the voting analysis, time trends also mattered: support slightly decreased over 2023-2024 as the 2022 fear of winter energy shortages faded, showing that wider energy-supply conditions can act as a temporary policy-context driver of acceptance.

3.2 Market and technical drivers

Market- and feasibility-related drivers are particularly visible in developers’ site selection. Our comparison of 51 planned and 51 randomly selected PV farm locations shows clear differences in location characteristics. Developers’ siting decisions were significantly associated with proximity to roads and the electric grid, as well as with land-use intensity of open spaces and wilderness. These criteria reflect cost-efficiency and technical feasibility, such as easier grid connection, lower construction costs, and better winter power production potential.

Municipalities’ decisions to approve or reject PV farms showed fewer structural drivers. Only land-use intensity of open spaces remained significant for them, suggesting that once projects reach the municipal level, most technical site characteristics have already been pre-filtered by developers.

3.3 Environmental drivers

Environmental drivers operate both as motivation (climate/energy transition goals) and as constraints (biodiversity, ecosystem sensitivity). The alpine PV policy push is strongly linked to the goal of increasing winter electricity production and supporting the broader energy transition. However, biodiversity considerations were not relevant for developers’ site selection: randomly selected PV farm sites were significantly better for biodiversity than the planned sites (See Connectivity in Fig. 3). This indicates that, at present, ecological quality aspects such as biodiversity play little role in the selection of PV farm locations. This absence may stem from a lack of clear data, uncertainty about how to account for biodiversity, or weak incentives to integrate ecological values in early-stage planning and permit routines.

3.4 Social-environment drivers

Beyond formal policy, the broader social environment structures decisions through institutionalized arenas (e.g., municipal votes) and contextual conditions (e.g., local economic expectations and project scale). The voting analysis showed the role of project size: smaller projects received higher "yes" shares than large-land-use projects, echoing the general pattern that intensive infrastructure can face stronger resistance.

4 Factors influencing decision making

Building on the structural drivers outlined in Section 3, this chapter examines how land-use decisions are shaped by different stakeholder groups. While policy, market, environmental, and social-environment conditions define the general opportunity space, land-use change ultimately depends on how actors interpret these conditions and anticipated reactions. To make these processes explicit, the chapter is structured by key actor groups involved in alpine PV development.

Figure 2 shows a simplified representation of the land-use change process around alpine PV installations: developers anticipate public acceptance of projects, which is then also directly reflected in the municipal approval process. Pre-existing conditions, such as land-use intensity, and demographics mediate landscape valuation and place-protective attitudes. The ownership structure of a proposed project also impacts public acceptance.

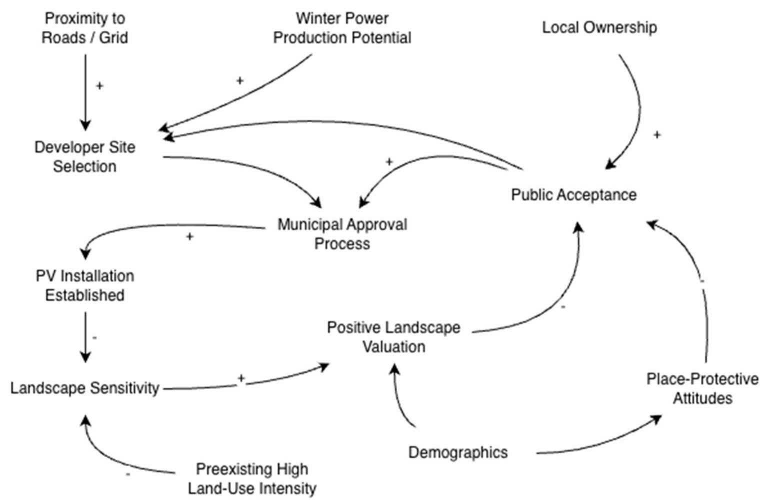

Figure 2: Land-use change processes for alpine PV

4.1 Developers and landowners

Figure 3 highlights how developers' site selection decisions are shaped by technical feasibility and market considerations, while also anticipating public acceptance and potential approval risks. Developers prioritize cost-efficient and technically feasible sites, particularly those close to existing roads and grid infrastructure, while biodiversity considerations play almost no role in early-stage site selection. Developers appear to internalize local preferences and avoid siting PV farms in landscapes perceived as sensitive, even though these landscape criteria are not directly related to cost-efficient energy production. As a result, municipalities mostly review projects that have already been screened for higher acceptance potential.

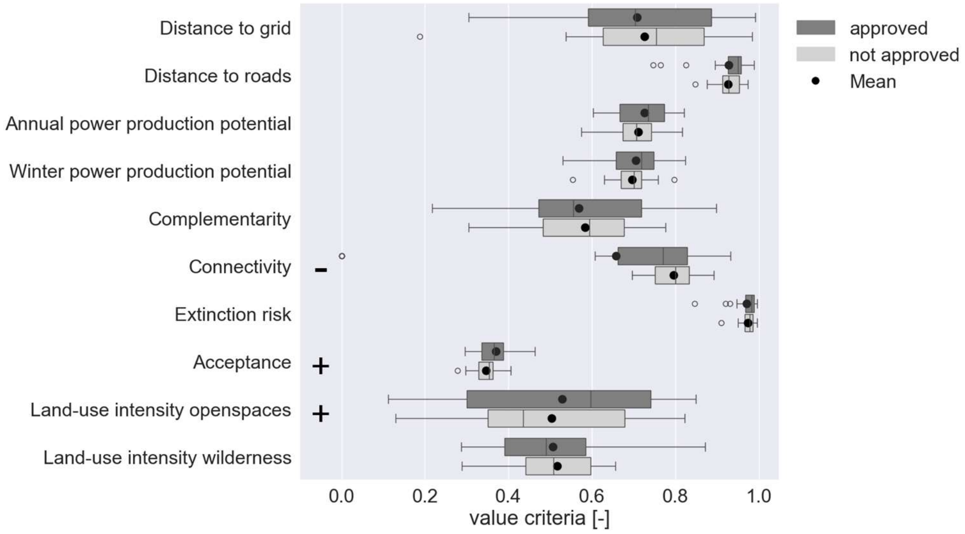

Figure 3: This figure indicates whether there are significant differences in the criteria between "approved" and "not approved" PV farms. The boxplots indicate the distribution of the "approved" and "not approved" sites for each criterion. The plus sign "+" indicates that PV farms were more likely to be approved by the municipalities if they were at locations where the criteria "Acceptance" and "Land-use intensity open spaces" were high. If there is no plus sign, it means that the criteria did not seem to be relevant for the selection of the sites. If there is a minus sign "–" it means that there was a significant difference between "approved" and "not approved" sites. However, this difference is negative, meaning that the "approved" sites even had a lower value for the criteria Connectivity than the sites that were "not approved".

In the spatial analysis (Fig. 3), acceptance already influenced site selection: projects were more likely to be planned in areas with higher expected public or political support, probably to avoid costly rejections later. This points to an anticipatory logic in which developers respond to perceived local acceptance and governance risk (e.g., likelihood of rejection), in addition to land-use intensity.

Landowners act as critical gatekeepers by leasing land or co-developing projects. In some cases, landowners themselves are developers. Their willingness to cooperate can depend on expected local benefits, perceived reputational risks, and whether governance arrangements are likely to be seen as legitimate.

4.2 Municipalities and cantons

As illustrated in Figure 2, municipal approval processes represent a key decision point where structural conditions intersect with public acceptance. Governance conditions such as ownership models, economic benefits, and voting formats also play an important role. In our dataset, municipalities' decisions to approve or reject PV farms showed few significant differences in spatial criteria; only land-use intensity of open spaces remained significant (Fig. 3). This suggests that, once projects reach the municipal level, most biodiversity or technical site characteristics have already been pre-filtered by developers and that municipalities judge projects primarily through the lens of social legitimacy and local fit.

Governance choices emerged as decisive. Municipal votes conducted in public assemblies were systematically associated with higher approval rates than votes held by secret ballots, reflecting the role of deliberation and the emphasis on the common good. However, public voting alone did not create majorities; it was most effective in municipalities where residents had already expressed support for renewable energy in previous national-level votes. Likewise, ownership mattered: projects owned exclusively by distant private companies were far less likely to pass than those including municipalities or local energy providers as co-owners. The highest "yes" shares occurred where both local ownership and public decision-making combined, indicating that governance factors jointly activate a collective-action logic (Stadelmann-Steffen et al., 2025).

Cantons will soon become highly relevant, as they are creating spatial plans that define where PV systems can be installed and where they cannot. This emerging planning layer is expected to shape municipal decision contexts by pre-defining feasible areas and formalizing the balance between expansion targets and protection goals.

4.3 General public

Across methods, landscape type strongly influences acceptance: infrastructure is tolerated in already modified landscapes but faces resistance in pristine alpine regions, where place-protective values are strong. Preferences for land-use changes during the energy transition are strongly shaped by factors such as the type of landscape and the characteristics of the infrastructure. Settlement-dominated areas, such as the Swiss Plateau, are the most acceptable locations for renewable energy systems, followed by agricultural areas and intra-mountain valleys, whereas pristine high-elevation Alpine regions consistently receive the lowest acceptance. Touristic mountain areas are tolerated only where tourism infrastructure already exists, and mid-elevation Jura and Pre-Alps elicit neutral reactions.

Infrastructure characteristics also matter: increasing numbers of wind turbines lead to a steady drop in preference across almost all landscapes, and high-voltage power lines are uniformly disliked. Photovoltaic installations display a more complex pattern; respondents rate scenarios without any PV lower than those with a minimum amount, but preferences decrease again as PV moves from medium to maximum levels. Across the board, a balanced, low-to-medium mix of wind and PV outperforms high levels of either technology, indicating that both the type of infrastructure and its quantity jointly drive acceptance.

Photovoice results highlight place-based meanings and motivations that help explain these patterns. Participants associated alpine landscapes with meanings such as home, identity, retreat, and untouched nature, and expressed concern that new infrastructures could undermine these qualities, especially in pristine alpine areas. At the same time, many participants welcomed PV installations when they were integrated into already-used landscapes such as dam walls, ski resorts, mountain passes, or agricultural zones, where the added impact was perceived as limited. Acceptance was closely tied to trust and legitimacy, with a preference for transparent and participatory decision-making and for local or public forms of project ownership.

Physiological data add an affective layer that is not fully captured by stated preferences alone. Skin conductance responses were significantly higher when participants viewed videos with high renewable energy infrastructure impact compared to low impact, indicating stronger physiological arousal to more intensive installations. This effect was consistent across six of the seven landscapes. Participants preferred low-renewable energy scenarios, especially in Alpine regions, whereas Plateau landscapes were the only landscapes where high-renewable energy scenarios received slightly more support. This indicates that although high-renewable-energy scenarios raise physiological arousal everywhere, the acceptability of that arousal differs across landscape contexts.

Respondents' own characteristics and perceptions also influence preferences. Many people display strong place-protective behaviour, rejecting renewable energy development in near-natural or culturally valued landscapes regardless of the infrastructure level. Landscapes perceived as strongly "arcadian" (natural, traditional) are judged to have a poor fit with renewable energy infrastructures and are less likely to be chosen, whereas landscapes viewed as "utilitarian" (already used) are more likely to be chosen. Respondents who see renewable energy systems as contributing to sustainability report a better fit between infrastructure and landscapes, while those who associate renewable energy systems with mechanisation report a poorer fit.

Perceptions of landscapes vary systematically with experience and demographics: living or recreating in a landscape increases the likelihood of seeing it as arcadian or utilitarian, depending on context. Urban landscapes are rated least arcadian and most utilitarian; near-natural Alps remain the benchmark for arcadian character. Swiss-Italian respondents perceive near-natural landscapes as less arcadian than Swiss-Germans do, and Swiss-Germans view them as more utilitarian than Swiss-French or Swiss-Italian respondents do. Men are somewhat more likely than women to rate a landscape as arcadian, and membership in an environmental organisation raises both arcadian and utilitarian perceptions. Exposure to renewable energy systems in one's living or recreational environment also alters the meanings attributed to them, lowering their mechanistic connotation and, in some cases, strengthening their sustainable connotation.

Integrated synthesis

Acceptance emerges as a key social driver across both public perception and municipal decisions. For municipalities, acceptance was one of only two significant criteria (alongside land-use intensity), indicating that local social or political sentiment strongly shapes the approval process. Developers anticipate these dynamics by strategically siting projects in areas where they expect greater political and social acceptance. The interplay between developers, municipalities, and public perceptions underscores how anticipated community reactions feed back into project planning and approval.

Figure 4 synthesizes how land-use decisions for alpine PV development emerge from the interaction of structural pressures and social dynamics. It illustrates a system of negotiation where technical feasibility and national energy policy collide with local identities and landscape values. Developers and authorities act within enabling but constraining frameworks, while municipalities and citizens infuse decisions with social legitimacy and emotional meaning. This interplay reveals a shift from purely rational planning toward value-laden governance, where acceptance and ownership become decisive drivers. Overall, the Figure portrays land-use change not as a technical outcome but as a collective socio-political process embedded in place and perception.

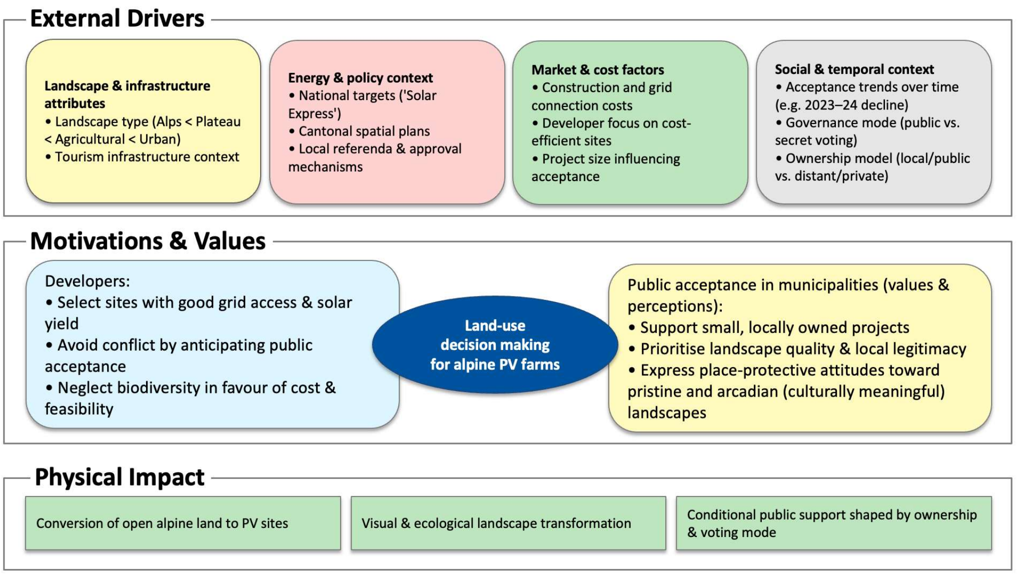

Figure 4: Mind-map for understanding land use decision making for alpine PV farms.

5 Discussion and reflection

5.1 Methodological reflection

Across the substantially different methodological approaches, a consistent picture emerges. Spatial modelling, Photovoice, discrete choice experiments, physiological data, and voting analyses all point in the same direction: acceptance, landscape meaning, and governance conditions collectively shape land-use trajectories. Each method contributes an additional layer of understanding of structural drivers, emotional reactions, social norms, and political processes, together providing a more complete picture than any single method could offer. This underlines the importance of a mixed-method approach for understanding socio-ecological transitions, as land-use change emerges from the interplay of technical feasibility, social legitimacy, emotional responses, and institutional structures.

One particularly interesting observation comes from the physiological and behavioural experiments. Participants' bodies reacted strongly to high-infrastructure scenarios even when their self-reported attitudes were relatively neutral. This highlights a hidden layer of affective resistance that may not be fully captured by surveys or stated-preference methods alone. Emotional and symbolic attachments to alpine landscapes influence responses to landscape change more strongly than people sometimes acknowledge, and these emotions can shape acceptance long before formal decisions are made.

5.2 Major drivers and motivations influencing land-use decision making

Across methods, a consistent pattern emerged: context matters. Landscape type, project ownership, and decision-making format jointly determine whether energy projects are embraced or rejected. Developers' site selection is primarily guided by economic criteria, whereas municipalities' decisions hinge more on social and political acceptance than on ecological or technical parameters.

Acceptance is highest where renewable energy infrastructures "fit" with the existing landscape, i.e. in already "infrastructured", touristic, or lowland landscapes, while pristine and culturally meaningful landscapes elicit strong emotional opposition. The data reveal conditional support for renewable energy transformation: people are willing to accept it if it is concentrated in already altered landscapes and designed as a balanced mix of technologies that align with their mental models of a fitting landscape.

The integration of ownership and governance dimensions is particularly decisive. Projects with local or public ownership and open, participatory decision-making received significantly higher approval rates than distant, privately driven projects. This highlights that collective benefit and procedural fairness are as important as technical performance for sustainable land-use transitions.

One of the most striking findings across most methods is the systematic absence of biodiversity considerations in both developer and municipal decision-making. Despite strong ecological concerns expressed in public debates and policies (e.g., the Biodiversity Strategy, Swiss Federal

Office for the Environment, 2024), biodiversity rarely influenced actual site selection. This points to a significant policy–practice gap: although biodiversity is a stated priority at the national level, it is not embedded in the practical routines of planning and decision-making for alpine PV projects. Poor accessibility of related data to decision-makers, inconsistent guidance, or limited incentives may contribute to this gap, and addressing it will be essential if future renewable energy development is to be aligned with broader environmental objectives.

A key implication of this gap is that biodiversity risks are not necessarily "rejected" in decision-making; rather, they tend to be invisible when decisions are made. When biodiversity criteria are not translated into decision-ready indicators, or when responsibilities for biodiversity assessment remain unclear across stages (developer screening, cantonal planning, municipal approval), biodiversity can remain marginal even when actors express general support for conservation goals. This suggests that integrating biodiversity is less a matter of changing values and more a question of operationalization of biodiversity goals across decision stages.

5.3 Role of specific context and relevance for other areas in Europe

While our study focuses on Switzerland, the underlying dynamics shaping land-use decisions, particularly the trade-offs between national energy goals and local landscape identities, are highly relevant for other Alpine and mountainous regions in Europe. Similar tensions between renewable energy expansion, landscape protection, tourism, biodiversity, and local identity are present across the Alps and other rural, landscape-sensitive areas. The conditional acceptance pattern we observe in Switzerland, where people are willing to support renewable energy only where it "fits" existing landscape character or builds on existing infrastructure, is likely to occur in many comparable European contexts as well.

Alpine regions across Europe likely face similar tensions between energy production, landscape protection, tourism, and local identity (cf. Iversen et al., 2021 for Norway). The symbolic value of alpine landscapes is often high, and the acceptance of new infrastructure is strongly influenced by how people perceive their landscapes, what they fear losing, and how fairly they feel included in the decision-making process. Acceptance increases when projects are built on or around existing infrastructure, when governance is transparent and participatory, and when benefits are shared locally. These principles hold beyond Switzerland and can inform European strategies to expand renewable energy in sensitive mountain environments.

While the Swiss case is shaped by specific political and cultural conditions, most notably Switzerland's strong direct democracy system and local voting rights, many of the underlying dynamics are relevant for other European mountain regions. In Switzerland, municipalities and local citizens play an unusually direct role in approving or rejecting energy projects. This can lead to very visible expressions of local acceptance or resistance. In other European countries, such direct local voting may be less common or less binding, and decision-making may rely more on administrative procedures and planning authorities.

Despite these institutional differences, the core insight remains the same: local acceptance is essential for the long-term success and social legitimacy of renewable energy development, regardless of national governance structures. Even where formal local vetoes do not exist, low acceptance can slow projects through opposition, legal appeals, political pressure, or reputational damage. Likewise, high acceptance can help stabilize the expansion of renewable energy and improve public trust in the energy transition.

Overall, the Swiss case shows that planning for renewable energy in sensitive landscapes requires more than identifying technically suitable sites. It requires acknowledging landscape meanings, addressing emotional responses, improving biodiversity consideration, and designing governance arrangements that build trust and local benefit. These reflections underscore the need for integrated approaches that recognise both the structural and psychological dimensions of land-use change.

5.4 Potential policy options

The long-term implications of our findings point to both opportunities and challenges for sustainable energy transitions in alpine environments. Projects that build on existing infrastructure, involve local ownership, and incorporate participatory processes demonstrate higher levels of legitimacy and are more likely to be accepted by the general public. This suggests that governance choices constitute powerful levers for supporting sustainable land-use change. At the same time, the systematic neglect of biodiversity in both planning and decision-making processes reveals a structural weakness that could compromise long-term national ecological targets.

Based on these insights, potential policy options include:

- **Strengthen participatory and transparent decision-making** to increase procedural legitimacy and reduce conflict, especially in landscape-sensitive regions.
- **Promote local and public co-ownership models** (or benefit-sharing mechanisms) to increase perceived fairness and collective benefits.
- **Integrate biodiversity assessments earlier in planning and site screening**, including improving accessibility and usability of biodiversity data for decision-makers and clarifying how biodiversity evidence should be applied in spatial planning and project evaluation.
- **Prioritize development on or near existing infrastructure** (e.g., ski resorts, dam walls, transport corridors, already modified landscapes) where acceptance is higher and added landscape impacts are perceived as lower.

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Project Partners

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WSL

ELO European Landowners' Organization

ESSRG Environmental Social Science Research Group

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Eurosite

ILVO Flanders Research Institute for Agriculture, Fisheries and Food

INRAE

KIT Karlsruher Institut für Technologie

KLIMASKOV FONDEN

NOVA FCSH Faculdade de Ciências Sociais e Humanas Universidade Nova de Lisboa

University of Amsterdam

University of Copenhagen

The University of Edinburgh

U Lisboa Universidade de Lisboa | Instituto Superior de Agronomia

ADRAL Agência de Desenvolvimento Regional do Alentejo

Vlaamse Land Maatschappij

Research Institute Nature and Forest

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MOSAIC

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