How landscape-technology fit affects public evaluations of renewable energy infrastructure scenarios. A hybrid choice model

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ABSTRACT

In response to the effects of climate change, many countries are realigning their energy systems to the principle of sustainability. An energy system change will lead to the development of substantial renewable energy infrastructure (mostly wind and photovoltaic) in landscapes with effects on perceived landscape quality and socio-political acceptance. Both direct perceptive effects of physical landscape structures and latent meanings associated with those structures potentially affect their acceptance.

This work evaluates the role of landscape-technology fit (derived from place-technology fit) representing the extent to which alternatives within each of these two components "fit" together (e.g., does a given type of renewable energy infrastructure fit well within some landscapes but not others?). It also evaluates the role of latent meanings ascribed to landscapes and renewable energy infrastructure within that mentioned "fit" decision as well as the role of prior experience (exposure) to both.

The study is based on a survey of Swiss citizens in a representative online panel (n = 1062). To estimate preferences for diverse renewable energy infrastructure scenarios across landscape types, a discrete choice model was implemented. Meanings ascribed to landscapes and renewable energy infrastructure were included in a second component of the survey. An innovative hybrid choice model approach facilitated integration of latent and observed variables in a hierarchy of predictors.

Results show that most effects were statistically significant. Landscape-technology fit functioned as a moderator between choice attributes and preferences; in turn, it is predicted by landscape and renewable energy meanings, which are predicted by relevant prior experience (exposure).

1. Introduction

Sustainable energy production is a challenge facing many European countries, including Switzerland, especially since the 2011 Fukushima nuclear power disaster. As a consequence, substantial expansion of infrastructure for the production of renewable energy (REI), mainly wind and photovoltaic (PV) needs to be implemented in landscapes. Some of that infrastructure will be located on exposed sites like mountain ridges, open plain fields or even on buildings. This may lead to important physical and social effects on the perceived landscape quality and affect socio-political acceptance of REI in landscapes [1–3]. Physical

effects are related to direct perceptual effects of physical landscape structures, whereas social effects relate to interpretations ascribed to those structures [4,5].

Many studies show that an REI-driven landscape transformation can lead to highly relevant visual-aesthetic impacts in the case of wind energy [e.g. [6–8], PV [e.g. [9–12] and high voltage overhead power lines [e.g. [13–15]. Many well-known landscape theories refer to the direct perception of physical landscape structures [5], since they influence the relationship between humans and nature. This effect also applies to REI, as they are placed in landscapes [16].

However, perceptions are heterogenous and may depend on where

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people are from, how they are socialized, where they grew up, where they live now, where they spend their leisure time, where they had specific experiences and so on.

Moreover, there may be heterogeneity with respect to landscape meanings. For some people, a steep rock face can be associated with fear and insecurity, while for others it can be seen as pure joy and freedom. Meanings are to be understood as feelings connotated to structures in addition to direct perceptive effects. Landscape meanings express how people think about landscapes, whether they are perceived as welcoming or threatening, and whether time spent in these landscapes would recharge or drain our "mental batteries." How people think (and feel) about landscapes seems to affect how people evaluate transformations happening in those landscapes, as this "psychological bond" between people and places can turn physical spaces into meaningful places [5]. This interdependence is comprehensively summarized by Lewicka [17], and also well-known as "place-attachment" [18] or similar concepts [19,20].

These local ties undoubtedly affect assessment of changes in the quality of landscapes, but they mainly focus on a local/individual dimension and lack a supra-individual dimension relevant for describing the bonds between people and landscapes. Societal meanings ascribed to landscapes in general are rarely found in the empirical scientific literature. People ascribe meanings to landscapes based on the values they hold for nature. Kellert [21] developed a gradient of types from a very strong relationship to nature (moralistic type) to a very loose one (dominionistic). Worster [22] differentiates two basic views of nature: arcadian and utilitarian, which can be seen as "edge points" of Kellert's ideal types [23]. Arcadian is understood as the ideal of simplicity, humility and peaceful human-nature coexistence, whereas utilitarianism refers to the desire to establish human dominance over, and utilization of, nature.

People also may ascribe meanings to REI, and how they think (and feel) about specific REI may impact the way people evaluate landscape transformations that involve those specific REI. REI may be connotated positively [24–26], but results from some studies question whether REI represents environmental friendliness [27] or other positive aspects [28–30]. Meanings ascribed to specific REI may be mostly based on what people notice from media (news, discussions), from personal experiences and from experiences of friends and family related to those energy sources. REI can be perceived as environmentally-friendly, clean and inexhaustible, safe and socio-economically beneficial (potentially leading to secure jobs) on the one side, but also associated with injustice, cost increases, yield limitations and loss of competitiveness on the other. However, it also depends on the scale of perspective [31]. REI can be perceived as contributor to sustainable development on a global scale [24,28,29], but, when it comes down to a local perspective, it may be perceived as a contributor to unwanted mechanization [32]. Thus, globally REI are preferably linked more to opportunities than threats, but REI may be viewed negatively at the local level [33].

The social acceptability of REI development may depend substantially on the interaction between these two sets of meanings – those ascribed to the landscape and those ascribed to REI. Dear [34] described *NIMBY (not-in-my-backyard)* as an expression of local opposition to transformation processes, but it turned out that its rather a psychologically justifiable reaction to local changes [32] and may be better characterized as expression of place-protective-actions [35–37]. In line with these findings, Devine-Wright [32,36] showed that REI can improve the perceived quality of places if they fit the character and essence of the place and exhibit temporal continuity. Transformations of places are processed by individuals [32,36,38], and this interpretation seems to be one stage in a tradeoff process which is coined by many authors as place-technology fit (PTF), meaning that individuals evaluate the fit of selected components (here place and technology) in specific situations [13,32,39,40]. The result of this PTF evaluation is an individual preference towards or against the evaluated transformation process. The PTF concept connects relevant aspects that so far have been

analyzed mostly separately. Its evaluation could be crucial for further REI development in countries like Switzerland. Place in the context of PTF is often interpreted as reflecting specific local places (areas), but it is important to also assess PTF at larger landscape levels. In this study, we modify the existing PTF concept to landscape-technology fit (LTF) to address the meta-level of landscapes.

Beyond meanings, Stedman [41] showed that exposure of people to transformation processes result in a higher likelihood of rejecting proposed interventions, and that people are more willing to commit if they identify with the affected places. Several studies describe how exposure affects how people think about landscapes and energy sources [42–46], which is evident through a number of repeated surveys in Germany [e.g. 47–49]. The psychological bond between people and places (landscapes) seems to have significant influence on the final decision of socio-political acceptance (or non-acceptance) of REI in landscapes, and this seems to persist across different attributes [5,32] in the context of human-nature relationships, including individual factors as well as cultural beliefs and practices [18,50].

This study focuses on public preferences in Switzerland for selected REI (wind energy, ground-, roof- and building-mounted photovoltaic and high voltage overhead power lines). The occurrence of REI in landscapes is not only examined in the context of individual existing energy technologies (only wind, only PV, only PL), but also in terms of technology overlaps (energy mix). The study contributes to the literature by including LTF as a core concept in modeling these preferences. Specifically, LTF evaluation is conceptualized as a moderator between scenario REI attributes (degree of REI presence in scenario landscapes) and preferences across scenarios. A hierarchical hybrid choice model is estimated in which landscape and REI meanings predict LTF, which then moderates the effect of REI attributes in scenario choice.

This study included the following research questions:

RQ1. What (simulated) REI characteristics across scenarios affect landscape preferences?

RQ2. Does landscape-technology fit moderate landscape preferences, and, if so, what types of Swiss landscapes – and potentially those with similar small-patched landscape types – are most sensitive to development of REI (exhibit poor landscape-technology fit)?

RQ3. Do landscape meanings and meanings ascribed to REI affect landscape-technology fit?

RQ4. Does landscape exposure (experience) affect landscape meanings?

RQ5. Does REI exposure (experience) affect REI meanings?

RQ6. How do demographic and other personal characteristics affect model variables?

Past research provides a foundation regarding the interaction of people with landscapes [5,21,22,51–55] as well as the interaction of people with REI [24,28,29,31,33,43,56]. It also shows that physical aspects of wind [8,57,58], PV [12,59,60] and power lines [13,14,61] affect landscape perception and evaluation.

To date, limited evaluation of landscape and REI meanings has been conducted. In addition, visual-aesthetic REI evaluations have focused on single types of REI rather than combinations, which is the present focus. Literature is often related to regions with climatic conditions and a landscape character that is not necessarily comparable with Swiss or similar small-patched landscape types. Also, it is unclear how changes in landscape quality are perceived and evaluated by the public.

Thus, for this study, a hypothesized meta model (Fig. 1) was developed which states a framework built on existing literature and contributes new knowledge. Hypotheses are streamlined to research questions (RQ1 matches H1) and are described briefly below:

H1. It is hypothesized that direct perceptive landscape structures like REI affect people's preferences about landscape quality with negative
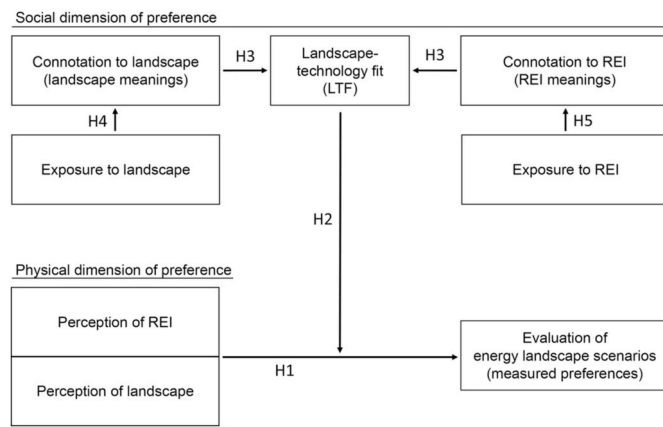
Fig. 1. Hypothetical meta model for REI-driven landscape evaluation processes.

impact [e.g. 57,58,12,13]. Developed landscapes (urbanized, agricultural) are hypothesized to show more positive signs, while negative signs are expected related to less developed landscapes (natural, pristine, alpine) [62–64].

H2. LTF is expected to represent the "fit" of REI (Wind, PV, power line) in a given landscape, with this fit expected to positively moderate the effect of REI on the evaluation of energy landscape scenarios [32,36,38, 40,41].

H3. Landscape meanings are expected to have negative effects for arcadian landscape perception [41,65,66] and positive for utilitarian [21,22]. REI meanings are expected to show positive effects if they are connotated as sustainable and negative if they are connotated as mechanization [13,32,67].

H4. Landscape exposure (experience) is hypothesized to predict landscape meanings [68,69].

H5. REI exposure is hypothesized to predict evaluation of REI meanings [32,47–49].

2. Material and methods

2.1. Study design

To address the research questions and hypotheses, a survey was conducted using an online panel of Swiss citizens. The survey included a choice experiment with relevant supporting questions. Responses were evaluated using a hybrid choice model (HCM). HCMs combine choice modeling and structural equation modeling to simultaneously evaluate choice and the factors predicting it, including latent variables within a hierarchical structure.

2.2. Data collection

2.2.1. Study area

This study was conducted in Switzerland, which is often referred to as the "heart of the Alps". Two thirds of the population lives in the central plateau (30% of the area) [70], whereas 70% of the area is considered mountainous. Switzerland's active nuclear power plants produce about one third of the country's electric power. Another half is produced by hydropower plants. New renewable energies currently play a minor role, but they are expected to expand considerably as the country intends to phase out nuclear power by 2050.

2.2.2. Study sample

An online panel survey was conducted from late November 2018 to March 2019 with a sample of Swiss citizen (N = 1062). Following

Hensher et al. [71], a pretest was conducted (N = 144) to provide data for estimating priors for generating an efficient experimental design for the main survey. Participants for both the main and the pretest study were accessed through Bilendi GmbH, a provider of "opt in" online panels. The present authors created the questionnaire, and Bilendi invited members of their Swiss panel to complete the questionnaire. Bilendi used quota sampling in the invitation process to ensure sample representativeness with respect to language, gender, age education and geographic area of residence. For example, the distribution of respondents across landscapes (near natural alpine areas, Jura ridges, Pre-alpine landscapes etc.) followed the distribution of the Swiss population across landscapes (e.g. Plat_agri = 12.09% of the sample respondents vs. 12.54% of the Swiss population, Alp_urb = 6.40% of the sample respondents vs. 7.03% of the Swiss population).

Data collection and handling were implemented in accordance with the social data gathering ethics regulations of the institution conducting this research.

2.3. Questionnaire

The questionnaire consisted of two major components. The discrete choice component involved multiple scenarios developed to understand preferences regarding REI across landscapes. The remaining component included questions covering meanings related to landscapes, nature and REI, including the "fit" of landscape/REI combinations.

2.3.1. Discrete choice component

Each respondent was presented with 15 choice tasks, with each task involving a choice between two "energy system transformation" (action) options or a neither (no action) option (see Fig. 2); options are also referred to here as alternatives or scenarios. Respondents were asked to make each choice assuming the presented options were the only available options.

Each option was visually represented by varying levels for each of four attributes (Table 1). For example, Option 2 in Fig. 2 is represented by landscape = Alp_val, wind energy = Wind max, photovoltaic = PV med, and power lines = PL_yes. Attributes were selected based on literature review and an expert workshop. The landscape attribute levels represent typical Swiss landscapes and are based on Swiss landscape typology [72]. The visual impact of each REI attribute level to the scenario was controlled by well-known visualization indicators like OAI_{SPP} [64,73] and others [16,74]. The visualization of choice attributes, relative to text-only attributes, helps present realistic scenarios of landscape transformation, enhance comprehension of complex choice content, and reduce fatigue [75].

Given the number of attributes and levels (7*4*4*2), 224 alternatives would be needed to cover all combinations. NGENE (v.1.2.0) was used to create an efficient (d-optimal) fractional factorial minimal overlap design of 30 scenarios [76,77], which were assigned to one fixed set of 15 randomly-ordered choice tasks (two scenarios per task, plus the neither option). This led to a total of 15,930 choice observations (1062*15) for the main study. Cleaning procedures reduced the number of respondents to 844 (12,660 choice observations), primarily from observation removal due to item nonresponse (see Sec. 2.4.1).

2.3.2. Choice predictor component

Development of model predictors beyond the choice attribute component was based on literature review and an expert workshop (January 22nd, 2018) with the project steering group. Questionnaire measures were as follows.

Landscape meaning for each of the seven landscapes was measured using the 10-item scale presented in [Data in Brief article, Table 2]. The items mainly reflect the perception of different nature concepts [21–23], but also include aspects of nature, wilderness and landscape perception from Rodewald [52], Stremlow and Sidler [78] as well as Abt [79]. Responses were measured on a 5-point scale ranging from 1 (strongly

If you had to decide between the following landscape developments as part of the energy transformation, what would be your decision?
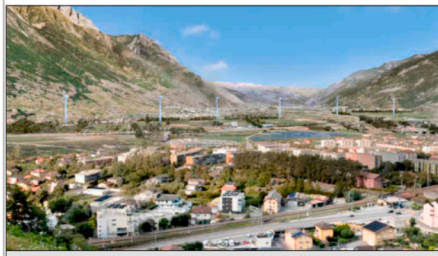Select the most acceptable option.

Fig. 2. Example of a choice task.

Table 1
Choice attributes and their levels.

Levels	Description
Attribute Landscape	
Alp	Near natural alpine areas
Pre_alps	Northern pre-alps
Alp_tour	Touristic alpine areas
Plat_agri	Agricultural plateau
Plat_urb	Urban plateau
Jura	Jura ridges
Alp_urb	Urban alpine valley
Attribute Wind energy infrastructure	
Wind no	No wind energy infrastructure
Wind min	Low level of wind infrastructure (3)[a]
Wind med	Medium level of wind infrastructure (6)[a]
Wind max	High level of wind infrastructure (10/15 in Jura ridges)[a]
Attribute Photovoltaic infrastructure	
PV no	No wind PV infrastructure
PV min	Low level of PV infrastructure[b]
PV med	Medium level of PV infrastructure[b]
PV max	High level of PV infrastructure[b]
Attribute Power line	
PL no	Absence of high voltage overhead power lines
PL yes	Presence of high voltage overhead power lines

Note.
[a] Attribute levels of wind differ in number of wind turbines and VIWT [16, 74]. While the maximum number wind turbines per landscape euqals 10, in Jura 15 wind turbines were placed. The impact of wind infrastructure per pixel differentiates by average 38% between attribute levels (min-med, med-max).
[b] Attribute levels of PV differ in OAISPP [16, 64, 73]. Area covered by PV infrastructure differentiates between attribute levels and landscapes. The impact of PV infrastructure per pixel differentiates by average 40% between attribute levels (min-med, med-max).

disagree) to 5 (strongly agree).

REI meaning for each of the three types of infrastructure analyzed (wind, PV roof and PV ground) was measured using the 9-item scale shown in [Data in Brief article, Table 3]. The items were based on studies from Heras-Saizarbitoria et al. [56] and Ntanos et al. [80]. Responses were measured on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Landscape-technology fit (LTF) was measured for each of five types of REI (wind, PV roof, PV ground/agricultural, PV ground/other, power

Table 2
Measurement model for landscape meanings.

Variable	Description	Coeff	Coeff/ SE	R2
Arcadian Factor [CRA 0.95]				
LSM_scenic-beauty[a]	… represent scenic beauty.	1.000	–	0.730
LSM_intimicy	… offers sense of intimicy/ familiarity.	0.856	117.92	0.649
LSM_sense	… helps to recognize sense.	0.721	90.475	0.549
LSM_relax	… helps to can relax my soul.	0.992	167.667	0.784
LSM_comfortable	… makes me feeling comfortable.	0.854	120.285	0.685
LSM_authenticity	… is a symbol for an authentic landscape.	0.857	134.599	0.678
LSM_intact-world	… represents an intact world.	0.925	141.427	0.663
LSM_self-experience	… helps to experience myself.	0.919	142.139	0.738

Note: Coeff = coefficient, SE = standard error, Coeff/SE = z-score, CRA = Cronbach's Alpha, LSM = Landscape meanings.
[a] The loading of the first indicator was set to 1 to scale the latent variable and does not have a standard error or a z-score.

lines) in each of the seven landscapes ([Data in Brief article, Table 4]), based on the PTF concept [32,36,40,81–83]. Responses were measured on a 5-point scale ranging from 1 (very poor) to 5 (very good). The LTF values used in analysis were those matching the landscapes presented in each of the two options in a given choice task. For example, if Option 1 presented the Jura landscape, the respondent's LTF response for wind REI in the Jura landscape was interacted with the wind attribute level presented in Option 1.

Landscape exposure was measured by the existence of a match between the landscape type presented in the option and the landscape type in which they currently live (LS_Living), in which they engage in outdoor recreation (LS_Recreation), and in which they spent their childhood (LS_Childhood), considering their landscape exposure within a radius of 5 km. The variables were dichotomous; for example LS_Living was 1 if the presented landscape matched the landscape in which the respondent currently lives, 0 if not.

REI exposure was measured by respondents selecting whether they are currently exposed to any of the presented REI types (wind, PV roof, PV ground), separately for one's living (Exp_Living) and one's recreation environment (Exp_Recreation). The variables were dichotomous; for example Exp_Living was 1 if respondents indicated that they were

Table 3
Measurement model for meanings assigned to infrastructure of renewable energies.

Variable	Description	Wind			PV ground			PV roof		
		Coeff	Coeff/SE	R2	Coeff	Coeff/SE	R2	Coeff	Coeff/SE	R2
Factor Sustainable contribution.[CRA 0.82–0.85]										
REI_clean_energy[a]	… provide clean energy.	1.000	–	0.362	1.000	–	0.381	1.000	–	0.435
REI_create_jobs	… potential to create jobs.	1.186	50.245	0.377	0.875	45.704	0.311	0.952	41.65	0.329
REI_support_local_economy	… support local economy.	1.090	48.975	0.374	0.862	50.606	0.367	0.998	45.522	0.359
REI_progress_humans	… represent the progress of humans.	1.502	55.652	0.644	1.088	50.023	0.497	1.116	44.174	0.523
REI_solving_problems	… contribute to solving the most important problems of humanity.	1.535	54.621	0.492	1.238	60.723	0.416	1.205	41.232	0.515
REI_represent_awakening	… represents awakening.	1.693	57.486	0.692	1.292	62.451	0.632	1.315	50.763	0.640
Factor Mechanized contribution. [CRA 0.62–0.65]										
REI_no_replacement[a]	… cannot replace other energy sources in Switzerland.	1.000	–	0.552	1.000	–	0.503	1.000	–	0.573
REI_limited_yield	… deliver limited yield.	0.659	39.523	0.310	0.615	37.748	0.303	0.689	36.054	0.271
REI_distract	… distract from really important measures.	0.728	36.07	0.301	0.666	32.106	0.335	0.829	35.042	0.270

Note:Coeff = coefficient, SE = standard error, Coeff/SE = z-score, CRA = Cronbach's Alpha, REI = Renewable energy infrastructure.

[a] The loading of the first indicator was set to 1 to scale the latent variable and does not have a standard error or a z-score.

Table 4
Model summary comparison.

Model	Parameters	LL	AIC	BIC
Estimated model	340	−804592.117	1609864.234	1612395.943
Null model	233	−817862.952	1636191.904	1637926.869

currently exposed to wind, PV roof, and/or PV ground in their living environment, 0 if not.

Membership in an environmental organization (such as the World Wide Fund for Nature), was measured as dichotomous variable, with 1 indicating membership in one or more organization, 0 indicating membership in none.

Lastly, native language was measured as categorical variable (0 = Swiss-German, 1 = Swiss-French, 2 = Swiss-Italian) and converted to two dummy variables (Swiss_French and Swiss_Italian) with Swiss_German serving as the reference category. Thus, a Swiss-French respondent was represented by 1 in the Swiss_French variable and 0 in the Swiss-Italian variable, while a Swiss-German respondent was represented by 0 in both variables. Gender was a dichotomous variable (0 = female, 1 = male).

2.4. Data analysis and modelling

2.4.1. Data preparation
The data were screened following Kline [84]. A conservative listwise deletion approach was used for item nonresponse, meaning that observations with nonresponse on any model variable were removed from the dataset. No outliers were detected based on the criterion of mean ± three standard deviations. No variables suffered from substantial skew or kurtosis. Indicator variables demonstrated reasonable spread and approximated the normal distribution. Relative variances across variables fell within the guideline of 10 for the ratio of largest to smallest.

2.4.2. Hybrid choice modeling
Discrete choice models are used to model preferences across alternatives, to assess the importance of each attribute included in the alternatives, and potentially to estimate willingness-to-pay for goods and services characterized by such attributes [71,85]. Choice of a particular alternative is assumed to be based on (i) the characteristics of the alternative, (ii) characteristics of competing alternatives, and (iii) characteristics of the individual. A linear-in-parameters form commonly is assumed, with respondent preferences for an alternative represented as a weighted sum of their preferences associated with each characteristic of the alternative.

Hybrid choice modeling represents an extension of choice modeling to allow the inclusion of latent variables (not just observed variables) and hierarchical relationships between variables. As noted by Kline [86], observed variables represent the data itself, such as survey responses in the present study. Latent variables (factors) correspond to psychological constructs (values, meanings, attitudes, and so on) that are not directly observable. Observed variables are used as indicators of each psychological construct (latent variable).

The inclusion of latent variables represents a milestone in choice modelling. It provides a more realistic and comprehensive understanding of why a choice has been made, which illuminates what has been described as a respondent's black box of decision making [87,88]. In addition, it can provide greater explanatory power than basic choice models [88,89]. This supports a more accurate assessment of how latent constructs influence people's choice behavior.

The present analysis uses hybrid choice modeling – the integration of choice and structural equation modeling – to incorporate latent variables [90–92]. The hybrid choice model was estimated using the MLR estimator in Mplus 7, with default settings except that 5000 Monte Carlo integration points were used. Because the choice alternatives were unlabeled, the attribute coefficients were constrained as equal across the two alternatives. Choice was specified as nominal (unordered categorical).

2.4.3. Measurement models
Structural equation models and hybrid choice models can be seen as combinations of 1) measurement models that reflect the relationship between latent variables and their indicators and 2) structural models that reflect the relationship between latent variables and observed variables beyond those serving as indicators of latent variables (e.g., scenario attributes and scenario choices). Measurement models were evaluated first to ensure adequate fit for the latent variables. Results from that preparatory evaluation are presented here.

For landscape meaning, exploratory factor analysis results indicated two factors, with the first reflecting an arcadian perception of landscapes and the second a utilitarian perception. Because only two survey items loaded on the utilitarian factor, the mean of the two items was used for analysis, rather than creating a utilitarian latent variable. For the arcadian latent variable, all items were highly significant and had R^2 values of at least 54% in the hybrid choice model (see Table 2).

For REI meanings, exploratory factor analysis was conducted separately for each of wind, PV ground and PV roof, with the same two factor solution found in each case. The first factor can be labeled as "contribution to sustainability", whereas the second factor can be labeled as "contribution to a mechanized world" (see Table 3).

All indicators were highly significant and with R^2 values between 27% and 69%. However, Cronbach's alpha values for each latent variable (e.g., the latent variable for wind energy sustainability, as reflected in the six indicators) ranged from 0.85 (Wind Sustainable), 0.84 (PV ground Sustainable) and 0.82 (PV roof Sustainable) to 0.64 (Wind Mechanized), 0.62 (PV ground Mechanized) and 0.65 (PV roof Mechanized). There is no strict cutoff for alpha values, but 0.6 to 0.7 reflects the lower limit of acceptability [84,93–95]. Thus, results related to REI as mechanization should be interpreted with appropriate caution.

3. Model and expected signs

The present analysis is based on the model shown in Fig. 3. The labels E1 through E5 indicate types of effects (e.g., Effect 1), which are described below and match the hypotheses in Fig. 1.

3.1. Effect 1: Landscape and REI attributes as predictors of choice

Choice attribute levels were hypothesized to affect the likelihood of selecting an alternative (E1 paths). The attributes were analyzed as sets of dummy variables. For the wind, PV and power line attributes, the base level was the absence of that type of infrastructure (e.g., Wind No). Signs for the remaining levels were expected to be negative (e.g., Wind Min would be less preferred than the base of Wind No).

For the landscape attribute, the first landscape (Alp, near natural alpine areas) served as the base. Developed landscapes (urbanized, agricultural) were hypothesized to have positive signs relative to that base.

3.2. Effect 2: Landscape-technology fit interacts with choice attributes as a moderator of choice

LTF variables were expected to represent the "fit" of REI (Wind, PV, power lines) in a given landscape, with this fit expected to positively moderate the effect of REI attribute level on choice (E2 path). For example, relative to a respondent who believes that power lines fit poorly within a Plat_urb (urban plateau) landscape, a respondent who believes they fit well in that landscape (higher value for LTF) would be more likely to choose an option with power lines in that landscape.

3.3. Effect 3: Meanings as predictors of landscape-technology fit

Landscape and REI, meanings were hypothesized to predict respondent "fit" evaluations (E3 paths in Fig. 3). Landscape meanings were expected to have negative signs for the arcadian factor and positive signs for the utilitarian factor. Relative to others, respondents with a more protective view of a given landscape (higher on the arcadian factor) were expected to indicate a less positive fit for REI in that landscape (lower on LTF).

REI meanings were hypothesized to have positive signs for the sustainable contribution factor and negative signs for the mechanization factor. Relative to others, respondents who view a given REI (e.g., wind power infrastructure) as making a stronger contribution to sustainability were expected to indicate a more positive fit for that REI in a given landscape.

3.4. Effect 4: Predictors of landscape meanings

Paths E4 reflect predictors of landscape meanings. Landscape exposure (experience) was hypothesized to predict landscape meanings. To the extent that respondents are able to choose the landscape in which they live, it was expected that, for that landscape, they would agree relatively strongly with the arcadian and utilitarian survey items (LS Living).

The same logic applies even more strongly to the recreation environment (LS Recreation), as respondents voluntarily choose the landscape in which they recreate. Lastly, the living environment during childhood (LS Childhood) was hypothesized to positively predict landscape meanings insofar as one remembers childhood as positive, especially as it relates to landscape.

Landscape type was hypothesized to predict landscape meanings and therefore the level of agreement with arcadian and utilitarian characteristics. However, several outcomes could potentially occur. On the one hand, it was expected that developed landscapes (e.g. urban plateau) were likely positively predict utilitarian items and less positively predict arcadian items. On the other hand, strong positive signs for both the arcadian and utilitarian measures may occur (e.g., since the two measures are not mutually exclusive one can have arcadian connotation to a certain landscape and also feel it is suited for certain utilization, including for REI).

Respondent demographics were hypothesized to affect landscape meanings, but with no a priori expectations for coefficient signs given limited previous evaluation.
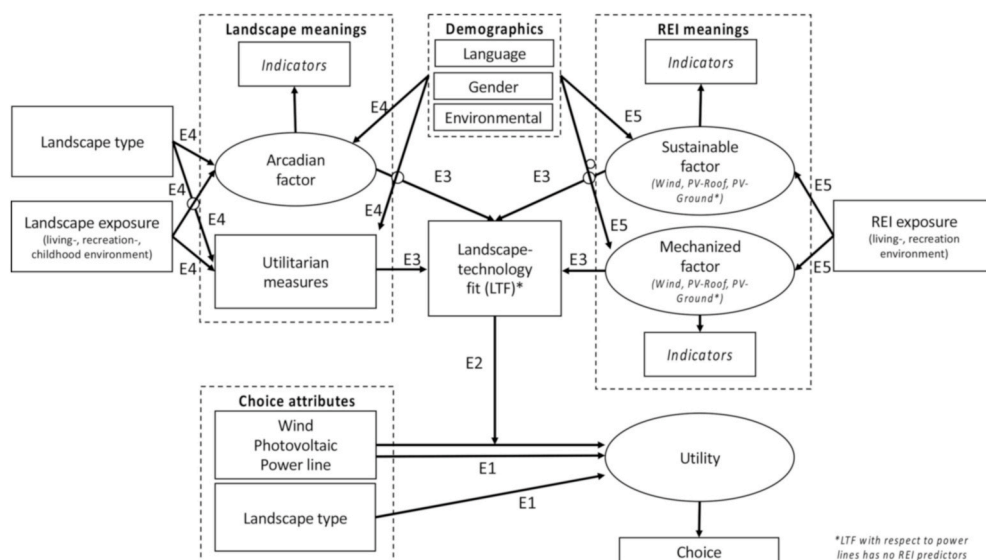

Fig. 3. Tested hybrid choice model.

3.5. Effect 5: Predictors of REI meanings

Paths E5 reflect predictors of REI meanings. REI exposure was hypothesized to predict evaluation of REI meanings. Previous exposure to REI in living and recreation environments (REI_Living and REI_Recreation) were hypothesized to positively predict REI meanings.

Respondent demographics were hypothesized to affect REI meanings, but with no a priori expectations for coefficient signs given limited previous evaluation.

4. Results

A single integrated model was estimated, but structural model results are presented below separately for each effect category shown in Fig. 3; measurement model results are presented above in Tables 2 and 3.

Traditional fit measures for choice models (e.g., McFadden R^2) or structural equation models (e.g., RMSEA, CFI, and SRMR) are not available for hybrid choice models. However, the additional explanatory value of the non-attribute content can be assessed by comparing the log likelihood (LL) value of the estimated model with the LL value of a base null-model in which all paths beyond those between attributes and choice (e.g., all structural model effects beyond E1) are constrained to zero. In practical terms, all the coefficients shown from Table 6 through Table 9 below are constrained to zero for the null model. Table 4 shows model summary data for the Estimated and Null models.

An MLR chi-square difference test was calculated, which indicated a statistically significant improvement for the estimated model relative to the null model (chi-square difference: 24894.710; degrees of freedom: 107; p-value: 0.000).

4.1. Effect 1: Landscape and REI attributes as predictors of choice

As presented in Table 5 all landscapes show significant positive signs related to the reference level (natural alpine areas; Alp). Given that respondents were asked to choose scenarios in the context of the energy system transformation, coefficients suggest that all landscapes are more suitable for REI development than the reference landscape (Alp). Landscapes of the urbanized plateau (Plat_urb) are by far most preferred

Table 5
Model results (E1): Effect of attributes on choice.

Variable	Description	Coeff	Coeff/SE
Landscape attribute levels[a]			
Pre_alps	Northern prealps	0.350***	4.022
Alp_tour	Touristic alpine areas	0.513***	6.054
Plat_agri	Agricultural plateau	0.419***	5.222
Plat_urb	Urban plateau	0.920***	9.382
Jura	Jura ridges	0.395***	5.666
Alp_urb	Urban alpine valley	0.525***	5.861
Wind energy infrastructure attribute levels[b]			
Wind min	Low level of wind infrastructure	−0.870***	−10.354
Wind med	Medium level of wind infrastructure	−1.987***	−20.755
Wind max	High level of wind infrastructure	−2.591***	−23.159
PV infrastructure attribute levels[c]			
PV min	Low level of PV infrastructure	0.259*	2.243
PV med	Medium level of PV infrastructure	−0.682***	−5.904
PV max	High level of PV infrastructure	−1.295***	−10.190
Power line infrastructure attribute levels[d]			
PL yes	Presence of power lines	−0.944***	−16.329

Note:Coeff = coefficient, SE = standard error, Coeff/SE = z-score.
Levels of significance: ***p ≤ 0,001, **p ≤ 0,01, *p ≤ 0,05.
[a] Reference level: Near natural alpine areas (ALP).
[b] Reference level: No wind infrastructure.
[c] Reference level: No PV infrastructure.
[d] Reference level: No power line infrastructure.

for REI developments (0.920), while all other landscapes have broadly similar coefficients (from 0.350 to 0.525).

Turning to wind energy, the absence of such infrastructure (the reference level) is significantly preferred to all levels of its presence (negative signs). Coefficients are consistently more negative as the level of wind infrastructure increases.

With respect to PV, a minimum level of infrastructure is unexpectedly preferred over the reference level of no infrastructure, though only at α = 0.05. Signs and relative magnitude are as expected at higher levels of infrastructure.

As expected, the reference level of no power lines is preferred over the presence of power lines.

4.2. Effect 2: Landscape-technology fit interacted with choice attributes as a moderator of choice

Most coefficients associated with LTF as a moderator of choice (Table 6) were significant, positive and with consistent coefficient magnitude (e.g., the moderating effect of LTF fit consistently increases as the wind attribute level increases from minimum (0.160) to medium (0.370) to maximum (0.514)). If an alternative's landscape and energy infrastructure were perceived as a match (fit together), respondents were more likely to select the alternative (or, put differently, they were less likely to avoid the alternative). The magnitude of this effect increases as REI intensity increases. However, this was not the case for roof mounted PV, where only a medium intensity showed a significant effect. In the case of power lines, the coefficient is significant and of expected sign, but there was only one level of presence relative to the base level of absence.

4.3. Effect 3: Meanings as predictors of landscape-technology fit

Coefficients for the predictors of LTF variables (Table 7) were all significant and mostly as expected.

Landscapes perceived as more strongly arcadian (Arcadian factor) were more likely to be reported as having poor fit between REI and the landscape (negative signs in first row of coefficients). This Effect 3 combines with Effect 2 such that landscapes perceived as more strongly arcadian were less likely than others to be selected in the choice task. For three of the four technologies, the opposite is true for landscapes perceived as more strongly utilitarian (Utilitarian measure) (positive signs for most of the second row of coefficients). If the landscape was perceived as utilitarian, it was more likely than others to be selected in the choice task.

Turning to REI meanings, respondents who viewed REI as making an important contribution to sustainability (Sustainable factor) were more likely to report good fit between REI and presented landscapes. Conversely, respondents who viewed REI as contributing to a mechanized world (Mechanized factor) were less likely to report good LTF.

4.4. Effect 4: Predictors of landscape meanings

Results for predictors of the meanings ascribed to presented landscapes (Table 8) show that no landscape was perceived as more arcadian (Arcadian) than the reference landscape (Alp). Likewise, no landscape was perceived as less utilitarian (Utilitarian) than the reference landscape. Urban landscapes (Plat_urb, Alp_urb) were rated as the least arcadian and the most utilitarian.

Experience living and recreating in the presented landscape was associated with a higher likelihood of perceiving the landscape as arcadian (significant positive sign) and (for current residence) of perceiving the landscape as utilitarian.

Swiss-Italian respondents perceived presented landscapes as significantly less arcadian than do Swiss-German (reference level) respondents. Swiss-German respondents perceived the presented landscapes as more utilitarian than Swiss-French or Swiss-Italian

Table 6

Model results (E2): Effect of landscape-technology fit as a moderator on the effect of REI attributes on choice.

Variable	Description	Wind		PV ground		PV roof		Power line	
		Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE
LTF_att_min	LTF-effect related to MIN attribute levels ('presence' regarding to attribute 'power lines')	0.160***	7.511	0.070**	2.663	−0.014	−0.575	0.168***	9.782
LTF_att_med	LTF-effect related to MED attribute levels	0.370***	16.152	0.191***	7.782	0.083***	3.511	NA	NA
LTF_att_max	LTF-effect related to MAX attribute levels	0.514***	19.837	0.302***	11.784	0.021	0.845	NA	NA

Note:Coeff = coefficient, SE = standard error, Coeff/SE = z-score.

Significance levels: ***p ≤ 0,001, **p ≤ 0,01, *p ≤ 0,05.

Table 7

Model results (E3): Effects of landscape and REI meanings on landscape-technology fit (LTF) for the landscape presented in the choice task alternative.

Variable	Description	Wind		PV ground		PV roof		Power line	
		Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE
Arcadian	Arcadian factor	−0.028***	−3.416	−0.191***	−24.934	−0.113***	−14.548	−0.193***	−23.395
Utilitarian	Utilitarian measure	−0.030***	−3.361	0.086***	11.682	0.122***	14.927	0.087***	10.905
Sustainable[a]	REI as contributor to sustainable development	1.027***	42.596	0.695***	39.204	0.631***	24.556		
Mechanized[a]	REI as contributor to a mechanized world	−0.066***	−8.868	−0.097***	−7.540	−0.171***	−10.310		

Note:Coeff = coefficient, SE = standard error, Coeff/SE = z-score.

Significance levels: ***p ≤ 0,001, **p ≤ 0,01, *p ≤ 0,05.

[a] No indicators were evaluated for meanings ascribed to power lines.

Table 8

Model results (E4): Effect of respondent characteristics and landscape exposure on meanings for the landscape presented in the choice task alternative.

Variables	Description	Arcadian		Utilitarian	
		Coeff	Coeff/SE	Coeff	Coeff/SE
Presented landscape[a]					
Pre_alps	Northern prealps	0.001	0.068	0.430***	14.976
Alp_tour	Touristic alpine areas	−0.636***	−24.547	0.932***	31.792
Plat_agri	Agricultural plateau	−0.748***	−30.620	0.857***	30.584
Plat_urb	Urban plateau	−1.237***	−46.456	1.228***	43.768
Jura	Jura ridges	−0.170***	−8.311	0.602***	23.944
Alp_urb	Urban alpine valley	−1.625***	−61.004	1.412***	50.308
Landscape exposure[b]					
LS_Living	Presented landscape matches landscape of current residence (5 km).	0.370***	20.866	0.067***	3.893
LS_Recreation	Presented landscape matches landscape of outdoor recreation (5 km).	0.488***	32.665	0.031	1.671
LS_Childhood	Presented landscape matches landscape of childhood (5 km).	0.125***	7.399	0.014	0.777
Demographics					
Swiss-French[c]	Swiss-French language	−0.029	−1.596	−0.189***	−9.698
Swiss-Italian[c]	Swiss-Italian language	−0.073*	−2.191	−0.121**	−2.963
Male[d]	Male respondents	0.053***	3.412	0.028	1.671
Environmental[e]	Membership in an environmental association	0.050**	2.712	0.068***	3.454

Note: Coeff = coefficient, SE = standard error, Coeff/SE = z-score.

Significance levels: ***p ≤ 0,001, **p ≤ 0,01, *p ≤ 0,05.

[a] Reference level: Near natural alpine areas (Alp).

[b] Reference level: Presented landscape does not match exposure.

[c] Reference level: Swiss-German language.

[d] Reference level: Female respondents.

[e] Reference level: No membership in an environmental organization.

respondents. Male respondents were significantly more likely to perceive a landscape as arcadian than were female respondents. Membership in an environmental association was positively associated with both categories of landscape perceptions (Arcadian, Utilitarian).

4.5. Effect 5: Predictors of REI meanings

The effects of the exposure to REI are presented in Table 9.

Respondents exposed to REI in their current living environment less strongly rated REI as contributing to sustainability and mechanization. All effects beside a sustainable connotation to wind and roof mounted PV are significant.

Respondents exposed to REI in their outdoor recreation landscape more strongly rated REI's contribution to sustainability and less strongly rated REI's contribution to mechanization. All effects beside a sustainable connotation to ground mounted PV and a mechanized connotation to roof mounted PV are significant.

Swiss-German (reference level) respondents generally were more restrained than Swiss-French and Swiss-Italian respondents in their ratings of REI contributions to sustainability and mechanization (first two rows of coefficients in the demographics section). Males generally were more likely than females to rate the sustainability contribution less

Table 9
Model results (E5): Effect of REI exposure and respondent characteristics on REI meanings.

Variable	Wind				PV ground				PV roof			
	Sustainable		Mechanized		Sustainable		Mechanized		Sustainable		Mechanized	
	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE	Coeff	Coeff/SE
REI exposure												
REI_Living[a]	−0.017	−1.622	−0.125***	−6.502	−0.043***	−3.246	−0.085***	−3.994	0.004	0.384	−0.175***	−8.885
REI_Recreation[b]	0.024*	2.306	−0.048*	−2.454	0.013	0.999	−0.047*	−2.307	0.049***	4.405	−0.011	−0.565
Demographics												
Swiss-French[c]	0.060***	5.325	−0.064**	−3.065	0.104***	7.665	−0.082***	−3.753	0.089***	7.368	−0.028	−1.295
Swiss-Italian[c]	0.124***	6.807	−0.244***	−5.791	0.177***	8.302	−0.280***	−6.806	0.161***	8.021	−0.307***	−7.601
Male[d]	−0.029**	−3.043	0.137***	7.645	−0.003	−0.283	0.076***	4.104	0.034***	3.354	0.067***	3.797
Environmental[e]	0.029**	2.621	−0.135***	−6.319	0.058***	4.360	−0.072***	−3.310	0.023	1.884	−0.052*	−2.527

Note:Coeff = coefficient, SE = standard error, Coeff/SE = z-score.
Significance levels: ***p ≤ 0,001, **p ≤ 0,01, *p ≤ 0,05.
[a] Description: Exposure of REI in living environment. Reference level: No exposure in living environment.
[b] Description: Exposure of REI in recreation environment. Reference level: No exposure in recreation environment.
[c] Reference level: Swiss-German language.
[d] Reference level: Female respondents.
[e] Reference level: No membership in an environmental organization.

positively and the mechanization contribution more positively. Membership in an environmental organization generally did not predict REI meanings.

5. Discussion

Hybrid choice models allow the integration of latent variables and a hierarchy of predictors into choice models. This functionality was used within this study to assess the role of LTF as a moderator of choice as well as to understand the hierarchy of factors (latent constructs) that predict LTF.

The results increase our understanding of how preferences towards or against REI-driven landscape developments are affected by LTF, which can be seen as a crucial in decision making. HCM helps facilitate understanding of the acceptability of potential landscape transformation initiated by the energy system change. It helps connect situational factors (represented by landscape and energy attributes of the choice model) and individual characteristics (represented by individual evaluations of (1) fit between landscapes and a mix of REI, (2) landscape and REI meanings and (3) landscape and REI exposure, as well as demographics).

To simulate a more realistic climate change driven landscape transformation, different landscapes and different penetration levels of selected REI were implemented. All situational factors were (highly) significant predictors of scenario preference. Most individual characteristics were (highly) significant predictors as implemented in the HCM.

This study showed that simulated REI characteristics across scenarios affect landscape preferences (RQ1). Scenario attributes were direct predictors of the choice (utility), which indicates that the presence of analyzed REI types (wind, ground/building mounted PV and power lines) affects landscape preferences (see H1/E1).

Landscape-technology fit (LTF) is shown to moderate the relationship between scenario attributes and choice (utility) (RQ2). If landscape and energy infrastructure were perceived as fitting together, respondents were more likely to select the alternative (see H2/E2).

Landscape meanings and meanings ascribed to REI affect landscape-technology fit (RQ3).

Both directly predict LTF (see H3/E3), and indirectly predict choice via a pathway that involves moderation (interaction) between LTF and scenario attributes (RQ2/E2).

Landscape exposure affects landscape meanings (RQ4), as it serves as direct predictor (see H4/E4). REI exposure affects REI meanings (RQ5) as it directly predicts meanings ascribed to REI (see H5/E5). Both

indirectly predict choice via a pathway that involves moderation (interaction) between LTF and choice.

In the following we discuss results in detail by effect category, and we link observations to relevant literature. Study limitations are listed at the end of this section.

5.1. Effect 1: Landscape and REI attributes as predictors of choice

Study results indicate that the public prefers REI development in urbanized landscapes more than in others, while such development is least preferred in near-natural alpine landscapes (E1).

With respect to the wind energy infrastructure attribute, the effect (less infrastructure if preferred over more) was expected and confirms results of several other studies [e.g. 42,56,57,63,96]. This suggests a stable view by the public that wind energy development perceptual costs outweigh potential benefit.

Positive feelings toward PV infrastructure [24] were confirmed insofar as scenarios with minimum PV infrastructure were more preferred than scenarios with no PV. However, the preference becomes negative as the presence increases to medium or maximum levels [97]. This is consistent with findings from other studies, which indicate that a positive perception of PV is not sufficient to generate public support for more intensive development [98,99].

The clear negative effect of the presence of power lines in energy scenarios confirms numerous studies showing negative connotation to this type of infrastructure [13,14,61,100].

5.2. Effect 2: Landscape-technology fit acts in interaction with choice attributes as a moderator of choice

Results indicate that evaluations of REI as fitting well within a given landscape increase the likelihood that alternatives containing that landscape will be selected. So, respondents not only selected their most preferred energy landscape scenario; they indirectly deselected landscapes they want to protect from such development. This passive place-protective behavior [41] intends to prevent place-disruption [66] which is known as a threat to place-identity [65]. It is based on a trade-off evaluation between places and REI (place-technology fit) [32,39,40]. This study scales the PTF concept to a larger, more general, landscape level and suggests landscape-technology fit (LTF) as a moderator of choice (in interaction with choice attributes), a relationship that previously had been hypothesized but not empirically evaluated [32,38,40, 83].

The significant positive effect (for each of wind, PV-ground, power

lines) becomes stronger as the intensity of implemented REI infrastructure increases. The exception is for PV-roof, which may reflect lack of perceptual intensity for this type of REI [64,73,97] or respondent perception that this infrastructure is generally beneficial, regardless of implementation intensity [9,101,102].

Previous studies also describe affective reactions as part of the PTF/LTF evaluation process [32]. Kaplan and Kaplan [54] and Ulrich [55] state that affective reactions can be modified by experience and cultural background. Although approaches to measure affective reactions reliably are lacking, such reactions may be partly expressed through the PTF/LTF evaluation as they impact our cognitive reaction.

5.3. Effect 3: Meanings as predictors of landscape-technology fit

All modelled predictor variables of LTF were significant (Effect 3) and underline the importance of meanings ascribed to landscapes and meanings ascribed to REI as relevant aspects in the PTF/LTF concept [32,40].

Respondents who perceived the presented landscape as arcadian were less likely to choose scenarios in which this landscape occurred. Respondents who positively evaluated an energy technology were more likely to choose a scenario where this technology was implemented [83].

When REI was connotated with sustainability strong positive effects were shown. Strong negative effects were shown when REI was connotated as mechanization (Mechanized) or the landscape was perceived as arcadian (Arcadian).

Overall comparison of coefficients between landscape and REI meanings show that meanings ascribed to landscapes showed a minor (but also significant) average effect on LTF.

While landscape related predictors of LTF show positive (Utilitarian) and negative signs (Arcadian) for LTF for PV and LTF for power lines, LTF for wind energy infrastructure is predicted negatively by both aspects. So, although the presented landscape is perceived as utilitarian (and less arcadian), an occurrence of wind energy infrastructures is not perceived as a match in this landscape (negative sign indicating a poor PTF). This negative connotation towards wind energy infrastructures seems to be manifested in social consciousness due to years of controversial public discussion and could result out of a general low acceptance (negative connotation) of this energy source in the public [42,43].

5.4. Effect 4 & effect 5: Predictors of landscape meanings and REI meanings

This study shows that landscape exposure (E4) and REI exposure (E5) affect how people think about both landscapes and REI. This has also been reported by recent studies [44,45]. In the bigger picture, exposure predicts choice via a pathway that involves interaction between LTF and choice attributes.

An arcadian landscape perception (positive Arcadian effect) is more likely if people have experience (LS_Living, LS_Recreation, LS_Childhood) with the landscape presented in the choice alternative. A utilitarian landscape perception (positive Utilitarian effect) is more likely if the presented landscape represents someone's living environment (LS_Living). This is well elaborated by Ströbele and Hunziker [68], who mention that people sometimes perceive what they want to perceive, which does not have to correspond to reality, since self-induced disturbances are often faded out. This so called cognitive-dissonance [103, 104] effect indicates that sometimes people do not accept reality as it is but as they desire it to be.

Most modelled predictor variables of REI-related meanings show a significant effect. Being exposed to REI in one's living (REI_Living) or recreation environment (REI_Recreation) reduces the likelihood that respondents perceived REI as a contribution to mechanization. Respondents exposed to REI in their recreation environment (REI_Recreation) were more likely to perceive REI as a contribution to sustainability.

It seems that people feel more positive about REI if the place of exposure refers to a location that can easily be substituted with a new location which usually refers to the place of recreation rather than the place of living. For example, if REI is being developed in people's recreation environment, people potentially can move and find another place for recreation, which is less likely in one's living environment. This is shown by (stronger) positive effects respective the recreation environment (REI_Recreation) and overall negative effects respective the living environment (REI_Living), which also confirm findings from other studies [42,46].

5.5. Limitations

Choice experiment responses and resulting estimates can be viewed as reflecting "passive" rather than "active" actions [105,106]. They do not reflect "social acceptance" per se, but rather a stated preference towards or against a landscape-related transformation process. The landscape-technology fit evaluation in this study reflects evaluations of all possible combinations of selected attributes regarding the fit of REI in presented landscapes. Results are relevant for renewable energy decision-making, but the socio-political acceptance literature highlights additional factors beyond the scope of this study.

As always, results may be affected by the study context and the sampled respondents. Evaluations with other samples beyond the Swiss context are encouraged. Lastly, at the time of the study, ground mounted PV was legally not possible in Switzerland, but it was included given its potential for future legalization and implementation.

6. Conclusions

The results of this study allow several conclusions, which are presented in the following.

With respect to landscape-technology fit, REI-driven landscape development impacts perceived landscape quality and causes affective reactions by people [16]. However, this study shows that public preferences for REI options may be affected by factors such as past exposure to REI and affected landscapes, as well as the meanings people ascribe to both. The complexity of respondents retrieving and interpreting such information is represented by a so-called fitting component, which in this study is expressed by a landscape-technology-fit evaluation. This means that at some point one has to decide whether the combination of evaluated aspects "fit together" and whether there is enough information available to even make a decision rather than to opt out. DCM results indicate that LTF moderates these decisions. This shows that a sound site selection and environmental impact assessment is incomplete when relying on physical factors only. Moreover, much information exists regarding aspects that impact socio-political acceptance (or non-acceptance [107]), but it is rarely known how those aspects interact and the degree to which they impact the public's decisions. Present results indicate that meanings associated with energy systems determine to a large degree whether a project is accepted. What people know and how they think about landscapes and REI significantly impact LTF, which in turn impacts their preferences. However, it is unclear where this information is originated but it may be retrieved from multiple sources like media, friends, family and personal experiences.

With respect to landscapes preferences, this study highlights the visual-aesthetic sensitivity of alpine landscapes undergoing changes, in this case through REI development. The bigger picture reveals a preference gradient starting from urban developed landscapes (high preference, low need for protection) and peaking at near natural landscapes (low preference, high need for protection). This indicates that REI development in some areas potentially may lead to more social conflicts than in other areas. Planning authorities might consider this when elaborating or adapting energy strategies, as social conflicts can be seen as a form of increased non-economic costs. This does not inherently mean that alpine landscapes shall not be considered for REI development – or that REI

development is generally welcome in urbanized areas – but it highlights the need for justification and transparency in decision making, as people need to gain trustworthy and neutral information for their personal interpretation of landscape changes (fit).

The policy implications of this study are manifold. Essentially, the study leads to two major opportunities to inform policy and planning. The first would be development of a communication and planning toolkit in which residents of potential energy sites are (1) informed early on and (2) invited to participatory workshops that address REI meanings in addition to the usual visual scenarios. Based on (1) and (2), siting alternatives would be developed that include explicit information on what changes in meaning are associated with the prospective REI. The second avenue to inform policy and planning would be to mainstream the landscape aspects of REI as e.g., demonstrated by Albert et al. [108] using the example of nature based solutions. In the present case, this would imply introducing REI meanings (not solely visual aspects) to all REI-relevant policy areas and technical decision-making tools, especially those that are not yet landscape-focused. This implementation can best be done by supporting technical commissions, planning bodies and the political debates in regional parliaments concerning landscape aspects.

With respect to future model development, several avenues may be promising. First, integration of environmental attitudes and beliefs could broaden the approach and identify what factors (e.g. pro-green thinking) may lead to inclusion or exclusion of visually attractive scenarios for the sake of biodiversity. Second, as only two items loaded on the present utilitarian factor, future studies could improve model quality by further developing items representing utilitarianism. Third, future studies could benefit from a more detailed focus on photovoltaic energy infrastructure, such as separation of ground mounted PV versus roof mounted PV. Fourth, integration of traditional energy infrastructure, such as nuclear/fossil power plants, into energy scenarios could potentially draw a clearer line regarding what society's "real" alternatives to REI are.

Society has made clear its goal of transforming from fossil-based to sustainable energy systems, especially in alpine regions expected to be particularly affected by climate change. REI development plays an essential role, but it will impact perceived landscape quality. Given REI's potential contribution to climate change adaptation and mitigation, it is important for society to decide what costs with respect to perceived landscape quality are acceptable to slow climate change.

Credit author statement

Salak B.: Resources; Methodology; Conceptualization; Formal analysis; Investigation; Data Curation; Visualization; Writing - original draft. **Lindberg K.**: Methodology; Formal analysis; Writing - review & editing; Software; Validation. **Kienast F.**: Funding acquisition; Conceptualization; Writing - review & editing; Validation. **Hunziker M.**: Funding acquisition; Project administration; Conceptualization; Writing - review & editing; Validation; Supervision.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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