Assessing uncertainties in ecosystem services impacts of solar energy systems in Switzerland

Franziska Walther, Benjamin Black, Jonas Schwaab, Adrienne Grêt-Regamey

16. September 2025

International Mountain Conference

Energy transitions and their impacts in mountain areas (FS 3.222)

ENERGY TRANSITION

Mountain areas in Switzerland are increasingly being targeted for the installation of solar energy systems, *i.e. ground-mounted photovoltaic (PV) systems*

Swiss policy context

- **Paris Agreement**

climate neutrality by 2050

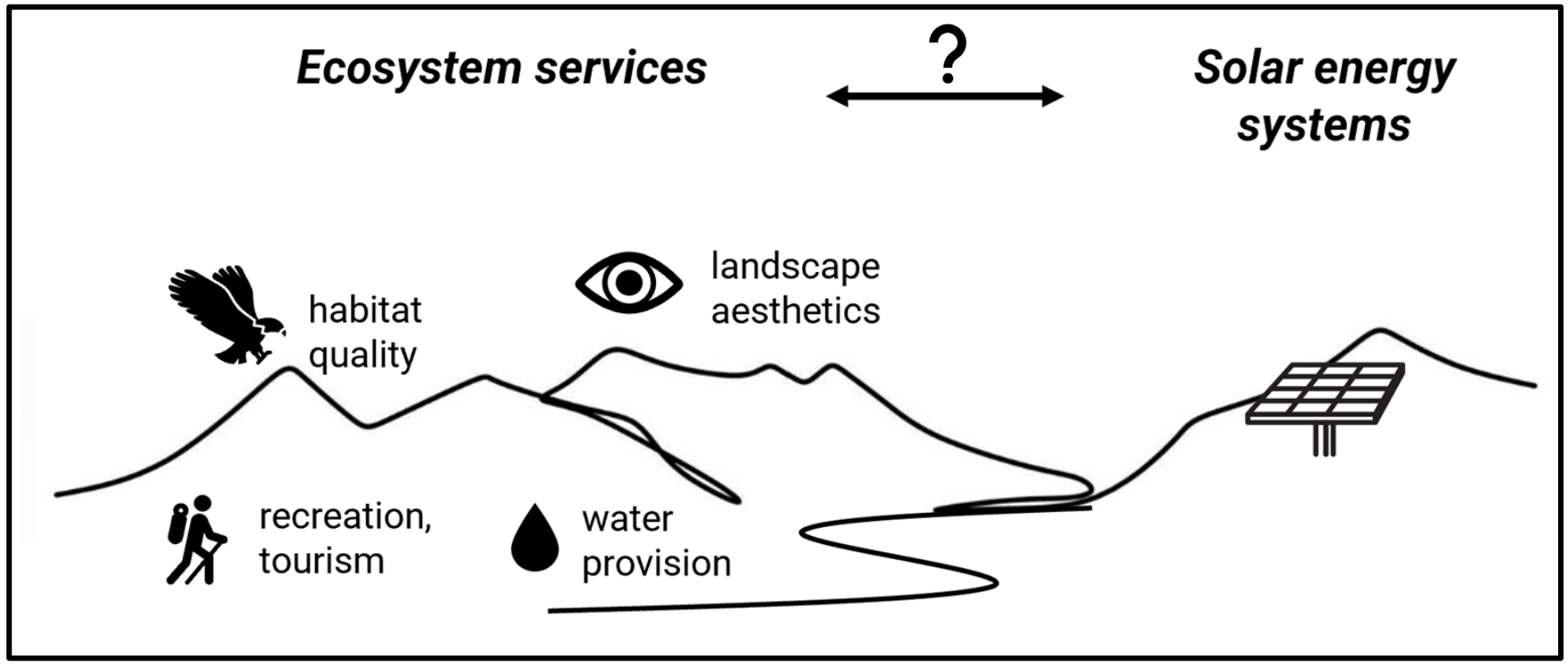
- **Solarexpress (Art. 71a EnG)**

financial incentive for large-scale solar systems in high alpine areas in Switzerland

Projected visualization: Madrisa Solar, Grisons, Switzerland
(currently under construction)

ENERGY TRANSITION & ECOSYSTEM SERVICES

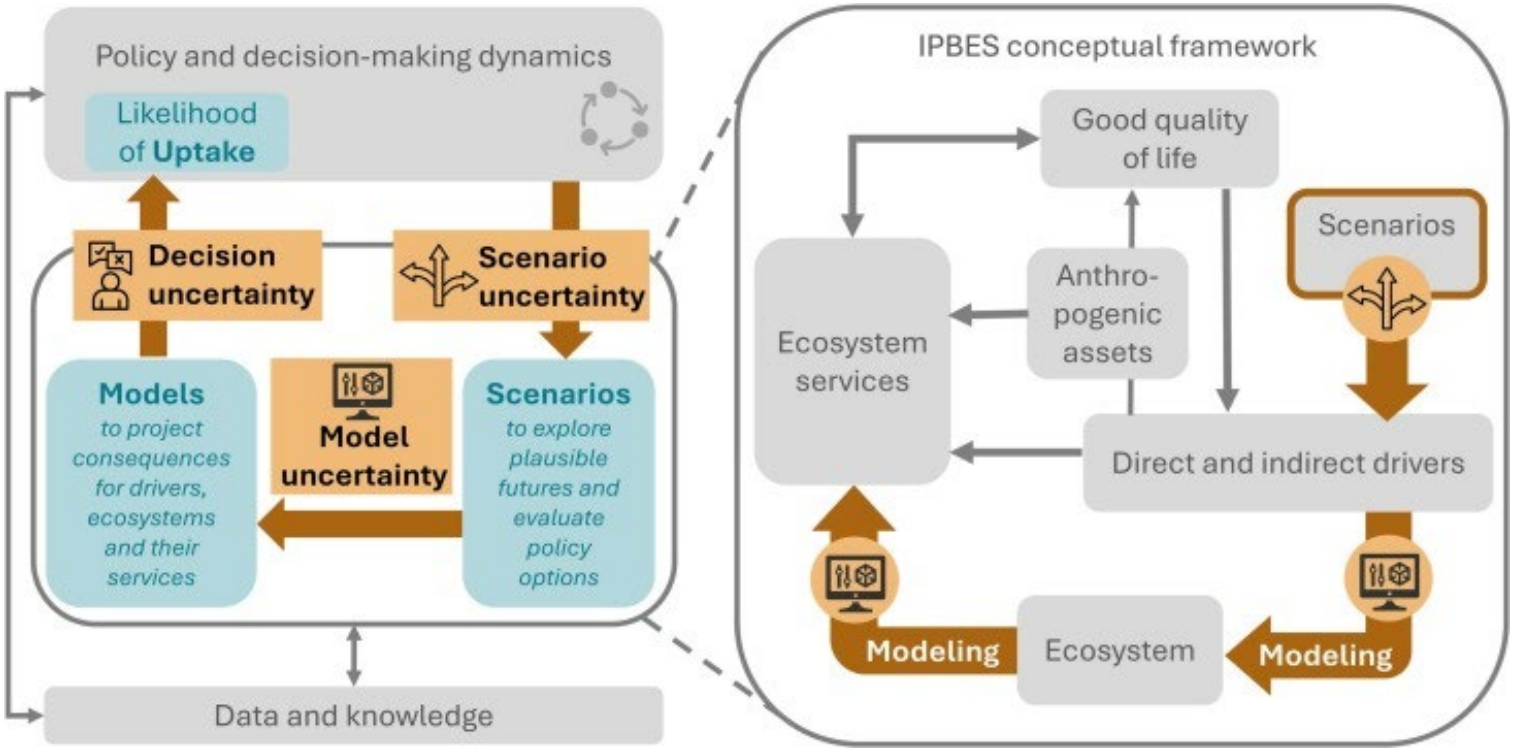
Mountain areas provide a multitude of ecosystem services that may be affected by the installation of solar energy systems



→ Assessing ecosystem services and PV impacts is essential for identifying suitable solar energy system sites

UNCERTAINTIES IN ECOSYSTEM SERVICES ASSESSMENTS

Uncertainties are inherent in scenario development *(scenario uncertainty),* modeling *(model uncertainty)* and the translation of results to decision-makers *(decision uncertainty)*



Literature review (n= 904 articles) has shown that:

Including the assessment of uncertainties can improve the potential for uptake*.

**Uptake = the potential use of ES assessment results by decision-makers.*

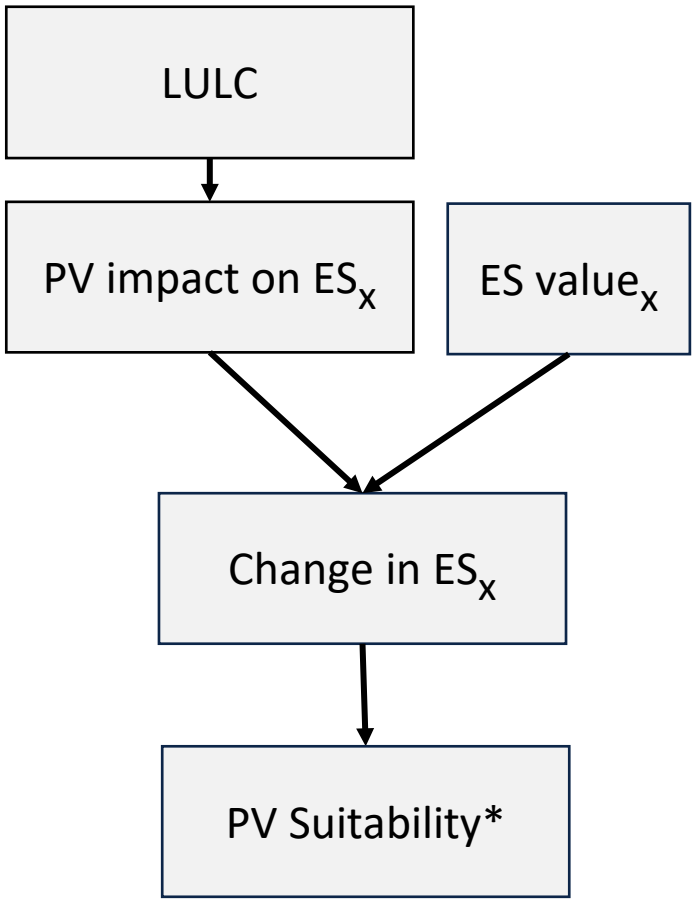
Walther et al. (2025)

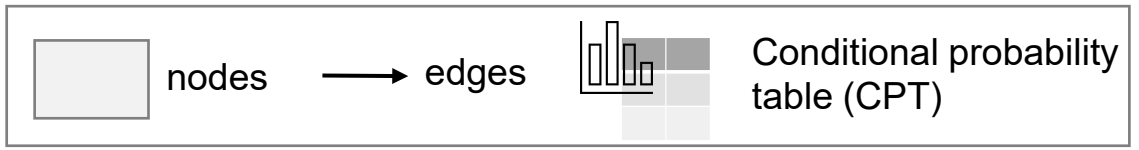
→ Assessing uncertainties makes ES assessment more useful for decision-making

Research question: How does the integration of uncertainties in ecosystem services (ES) assessments influence siting of ground-mounted solar PV systems?

Methodology: Spatially explicit, expert-based Bayesian network

Netica
NORSYS SOFTWARE CORP.





**Suitability = minimal decrease in ES, or potential increase, due to PV.*

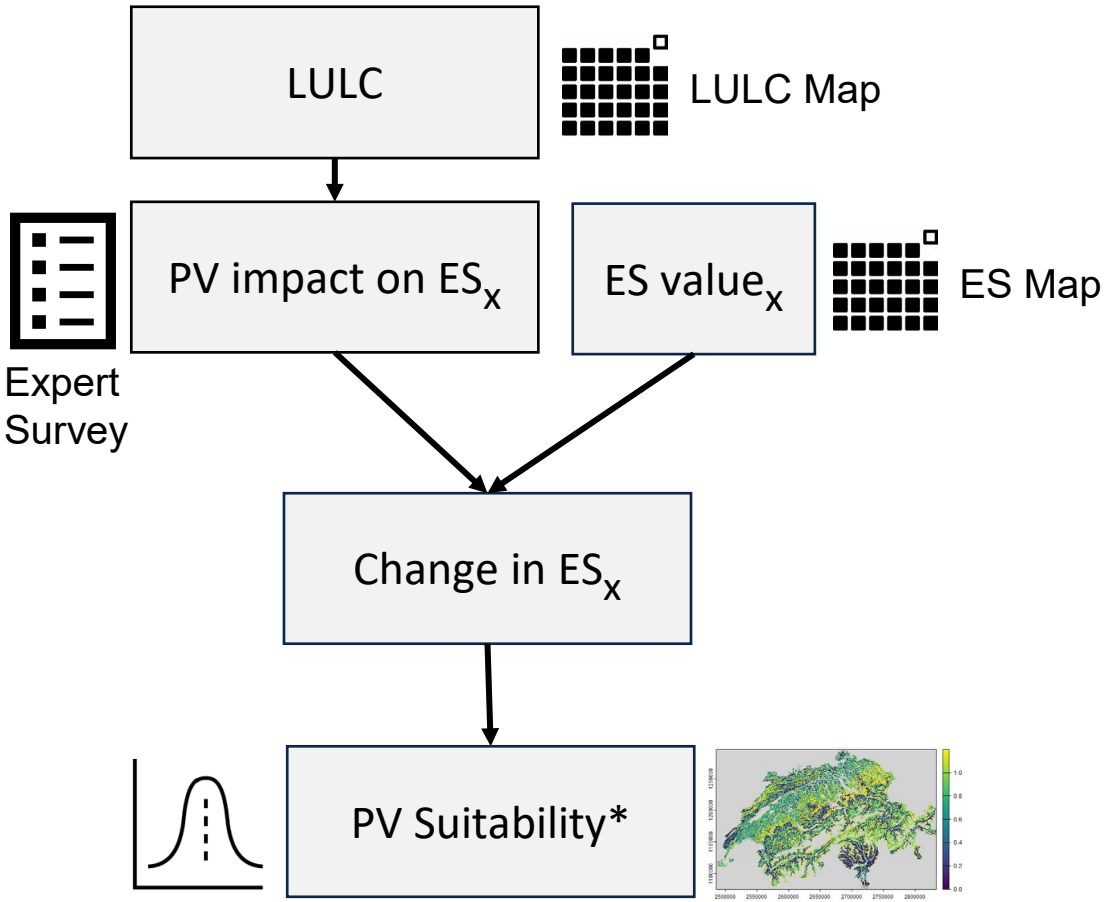
Research question: How does the integration of uncertainties in ecosystem services (ES) assessments influence siting of ground-mounted solar PV systems?

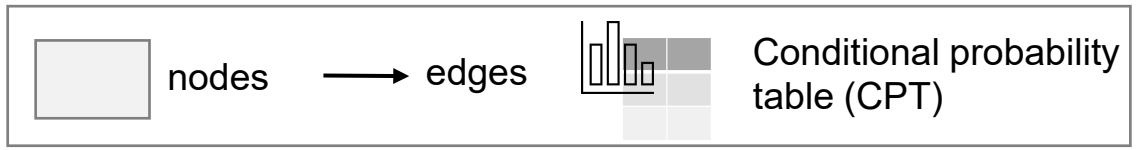
Methodology: Spatially explicit, expert-based Bayesian network

Netica

NORSYS SOFTWARE CORP.

gBay





Evidence

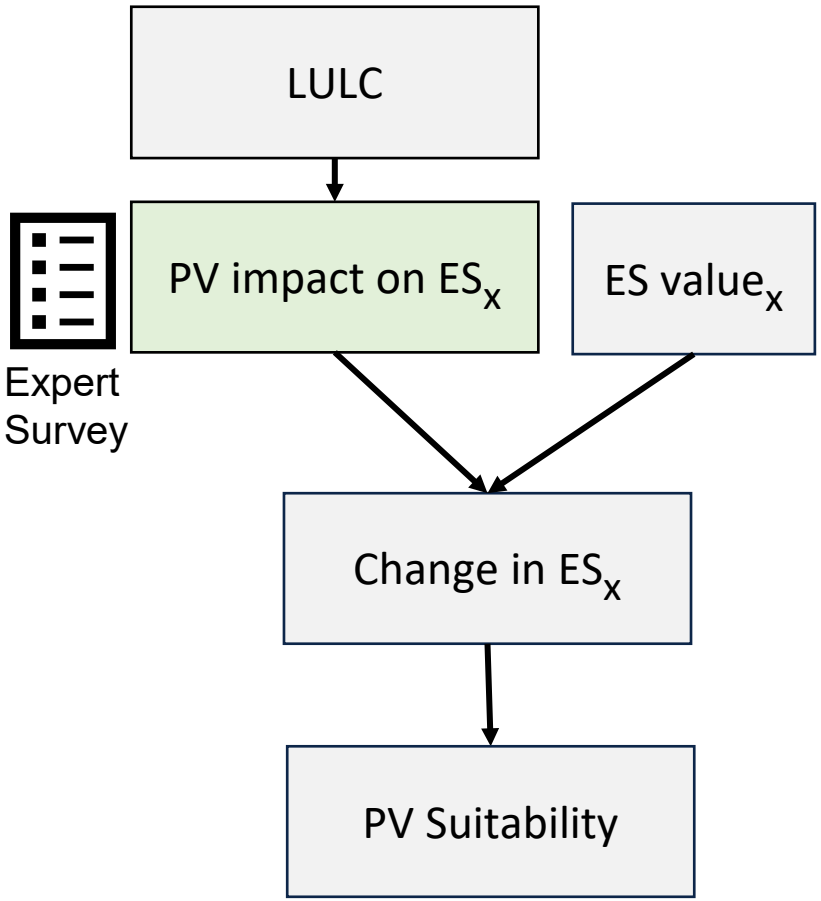
Spatial Data

Expert Survey

**Suitability = minimal decrease in ES, or potential increase, due to PV.*

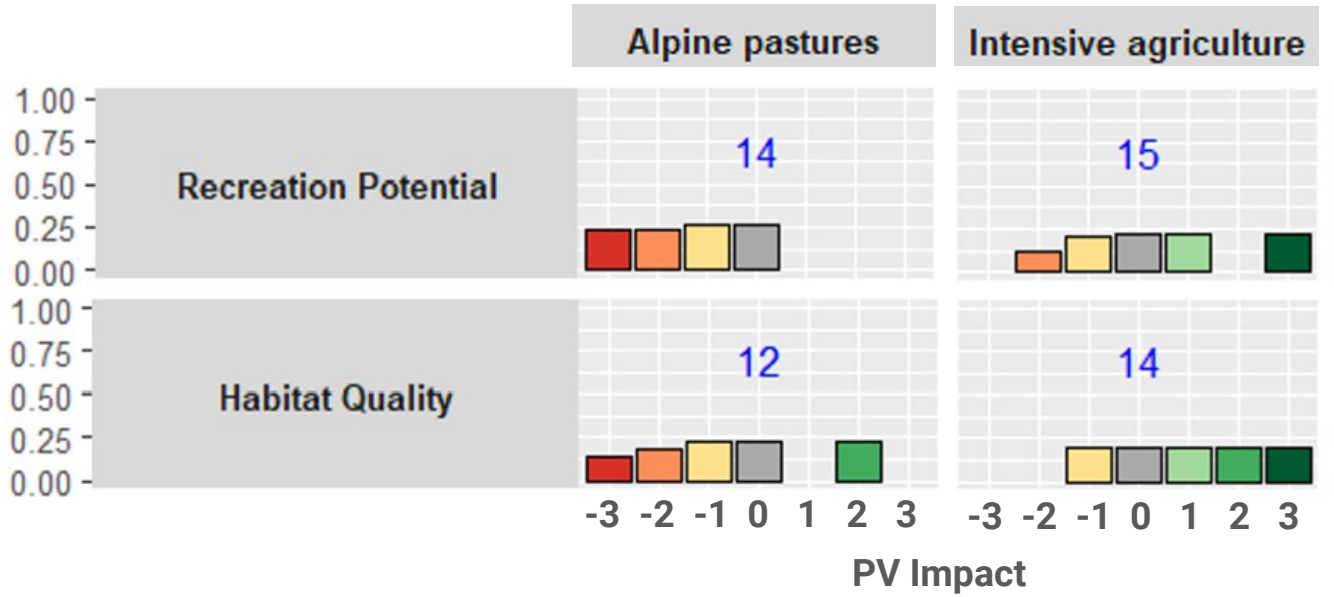
PRELIMINARY RESULTS

Methodology: Spatially explicit, expert-based Bayesian network



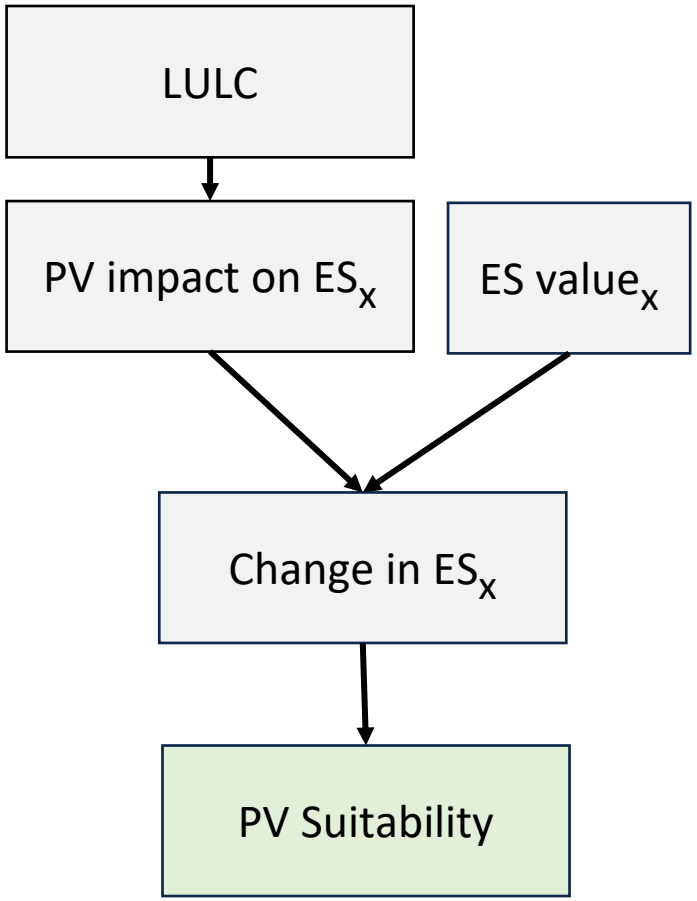
Expert Survey for CPT Elicitation of PV Impact

How do ground-mounted photovoltaics affect ES in Switzerland?

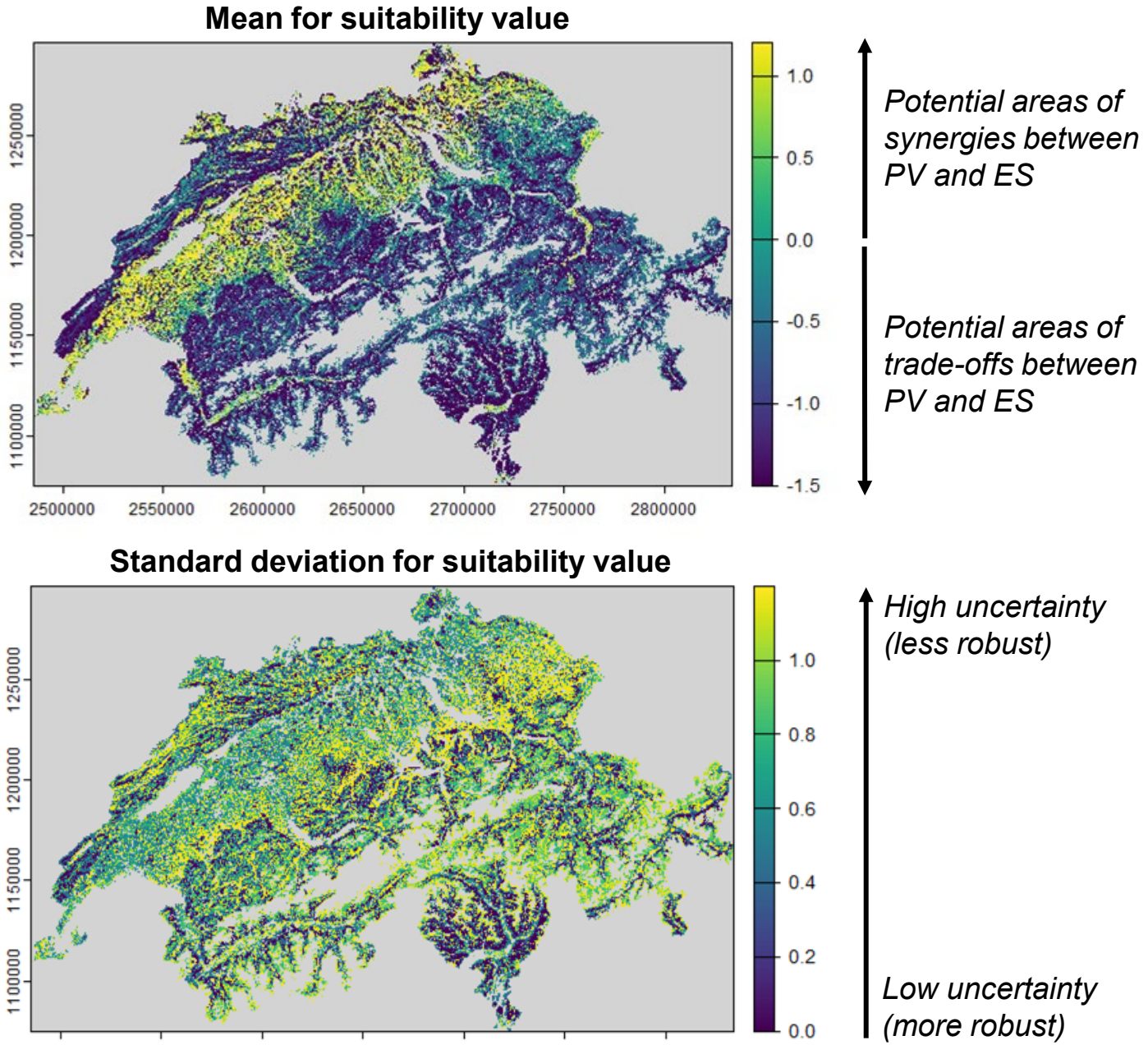


Average weighted response per Likert scale category (from strong decrease to strong increase in ES), differentiated by LULC class (amount of respondents in blue).

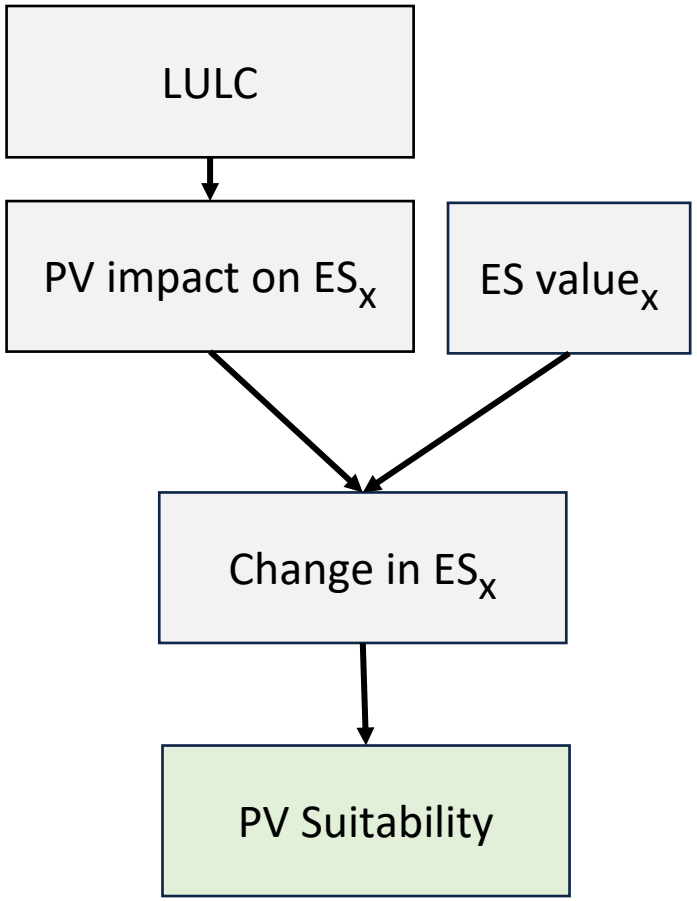
PRELIMINARY RESULTS

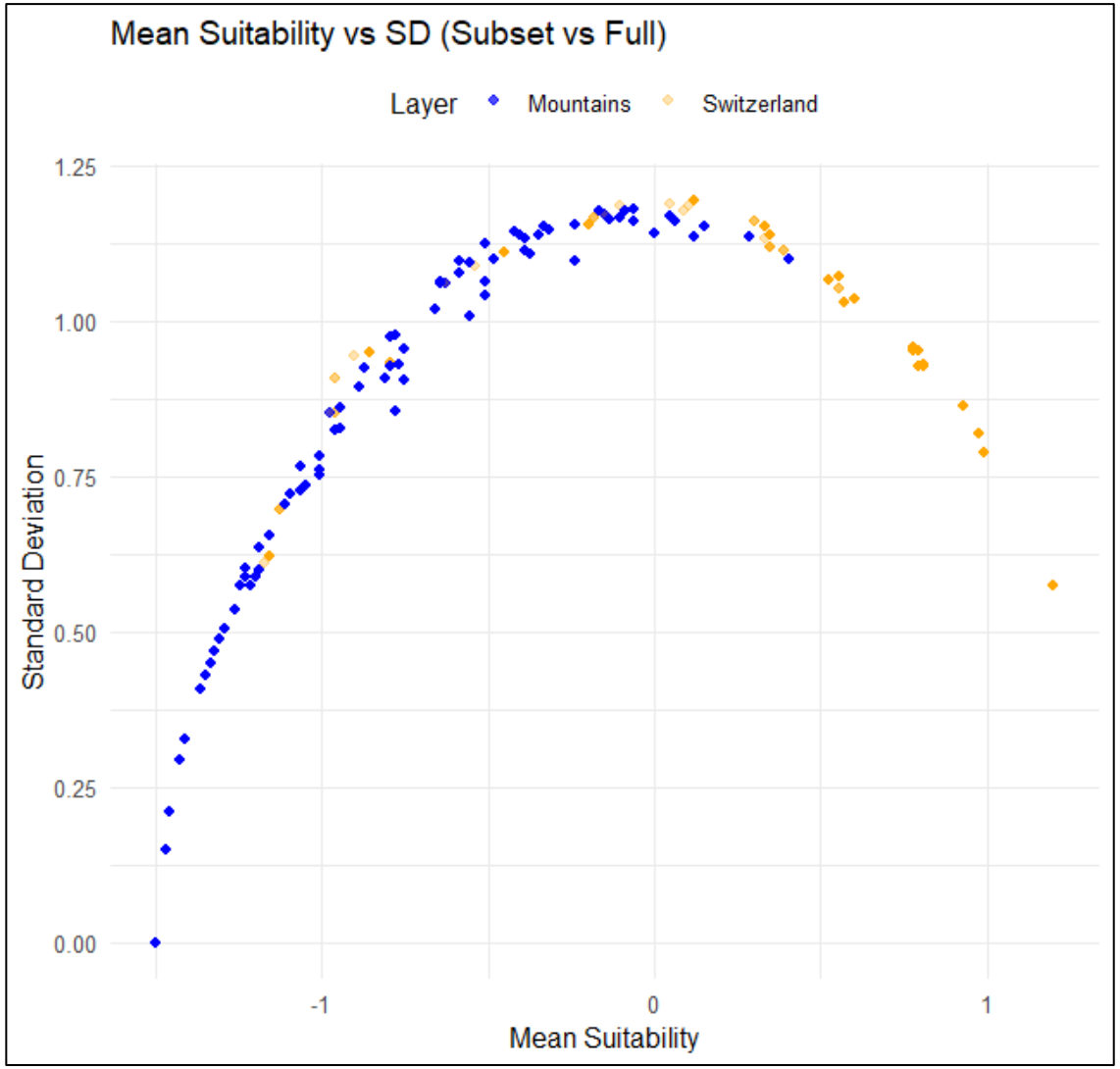


Ecosystem services included:
- Recreation potential
- Habitat quality
- Carbon storage



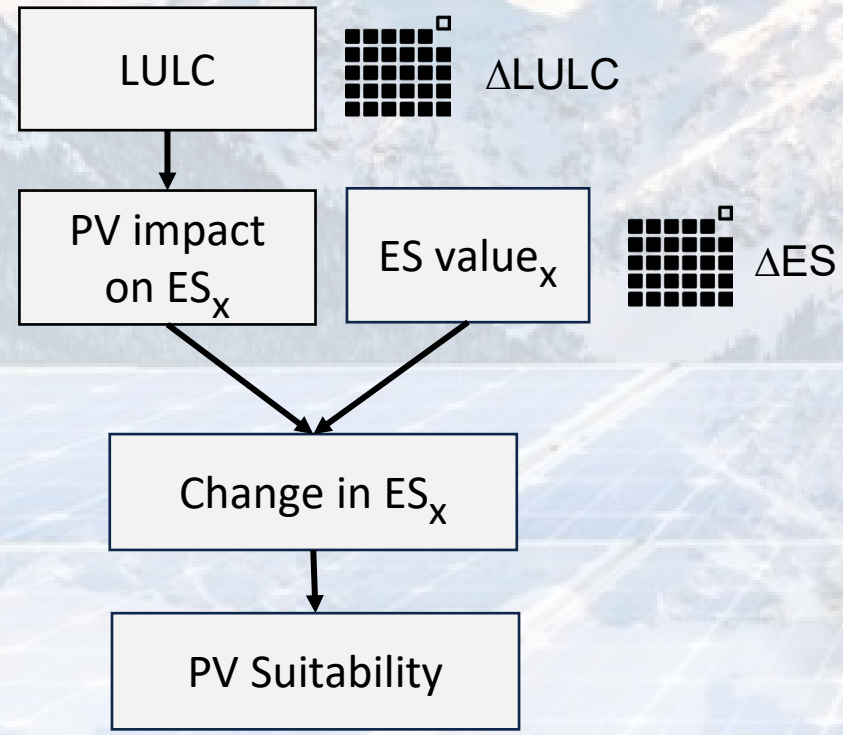
PRELIMINARY RESULTS





In mountain areas, trade-offs between PV and ES prevail, while synergies are at lower altitudes.

OUTLOOK *Future changes*



Would you like to participate in the SURVEY?

Enter your contact details to receive an email invitation:

Survey link:
https://pv-eco-survey.ethz.ch

THANK YOU FOR YOUR ATTENTION!

Franziska Walther
Contact: fwalther@ethz.ch

Would you like to participate in the SURVEY?

Enter your contact details to receive an email invitation:

Survey link:
https://pv-eco-survey.ethz.ch

Bibliography

Anderegg, D., Strebel, S., & Rohrer, J. (2023). Alpine Photovoltaik Versuchsanlage Davos Totalp: Erkenntnisse aus 5 Jahren Betrieb. ZHAW Zürcher Hochschule für Angewandte Wissenschaften, IUNR Institut für Umwelt und Natürliche Ressourcen

Black, B., Adde, A., Farinotti, D., Guisan, A., Külling, N., Kurmann, M., Martin, C., Mayer, P., Rabe, S.-E., Streit, J., Zekollari, H., Grêt-Regamey, A., 2024. Broadening the horizon in land use change modelling: Normative scenarios for nature positive futures in Switzerland. In press, Regional Environmental Change.

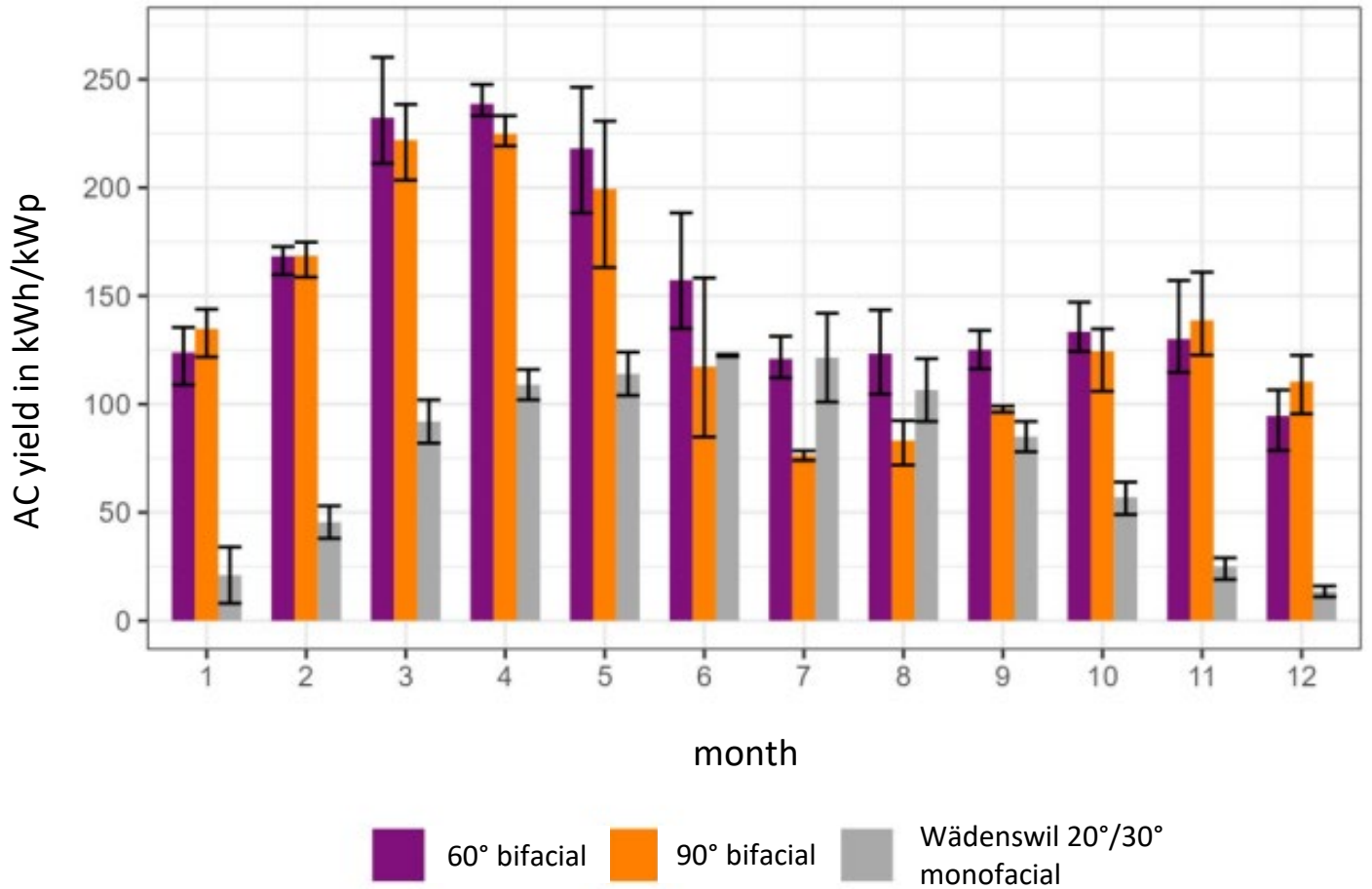
Mayer P, Rabe SE, Grêt-Regamey A (2023) Operationalizing the nature futures framework for ecological infrastructure. Sustain Sci. https://doi.org/10.1007/s11625-023-01380-7

Rounsevell, M.D.A., Arneth, A., Brown, C., Cheung, W.W.L., Gimenez, O., Holman, I., Leadley, P., Luj´ an, C., Mahevas, S., Mar´echaux, I., P´elissier, R., Verburg, P.H., Vieilledent, G., Wintle, B.A., Shin, Y.-J., 2021. Identifying uncertainties in scenarios and models of socio-ecological systems in support of decision-making. One Earth 4 (7), 967–985. https://doi.org/10.1016/j.oneear.2021.06.003.

F. Walther, D. N. Barton, J. Schwaab, J. Kato-Huerta, B. Immerzeel, M. Adamescu, E. Andersen, M. V. Arámbula Coyote, I. Arany, M. Balzan, A. Bruggeman, C. Carvalho-Santos, C. Cazacu, D. Geneletti, R. Giuca, M. Inácio, E. Lagabrielle, S. Lange, S. Le Clec'h, Z. Y. V. Lim, U. Mörtberg, S. Nedkov, A. P. Portela, A. Porucznik, T. Racoviceanu, P. Rendón, D. Ribeiro, J. Seguin, M. Šmid Hribar, V. Stoycheva, H. Vejre, C. Zoumides and A. Grêt-Regamey, 2025. Uncertainties in ecosystem services assessments and their implications for decision support – A semi-systematic literature review. Ecosystem Services. 73. https://doi.org/10.1016/j.ecoser.2025.101714.

ENERGY TRANSITION

Mountain areas in Switzerland are increasingly being targeted for the installation of solar energy systems, *i.e. ground-mounted photovoltaic (PV) systems*

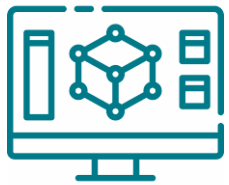


Average AC monthly yields as bars with respective maximum and minimum values shown as double-T. Test facility Davos Totalp compared with a facility in Wädenswil ZH. Observation period: October 1, 2020 to August 31, 2023.

Anderegg et al. (2023)

Sources of Uncertainty

(Rounsevell et al. 2021)



Model uncertainty

The representation of processes in models and how this is done.

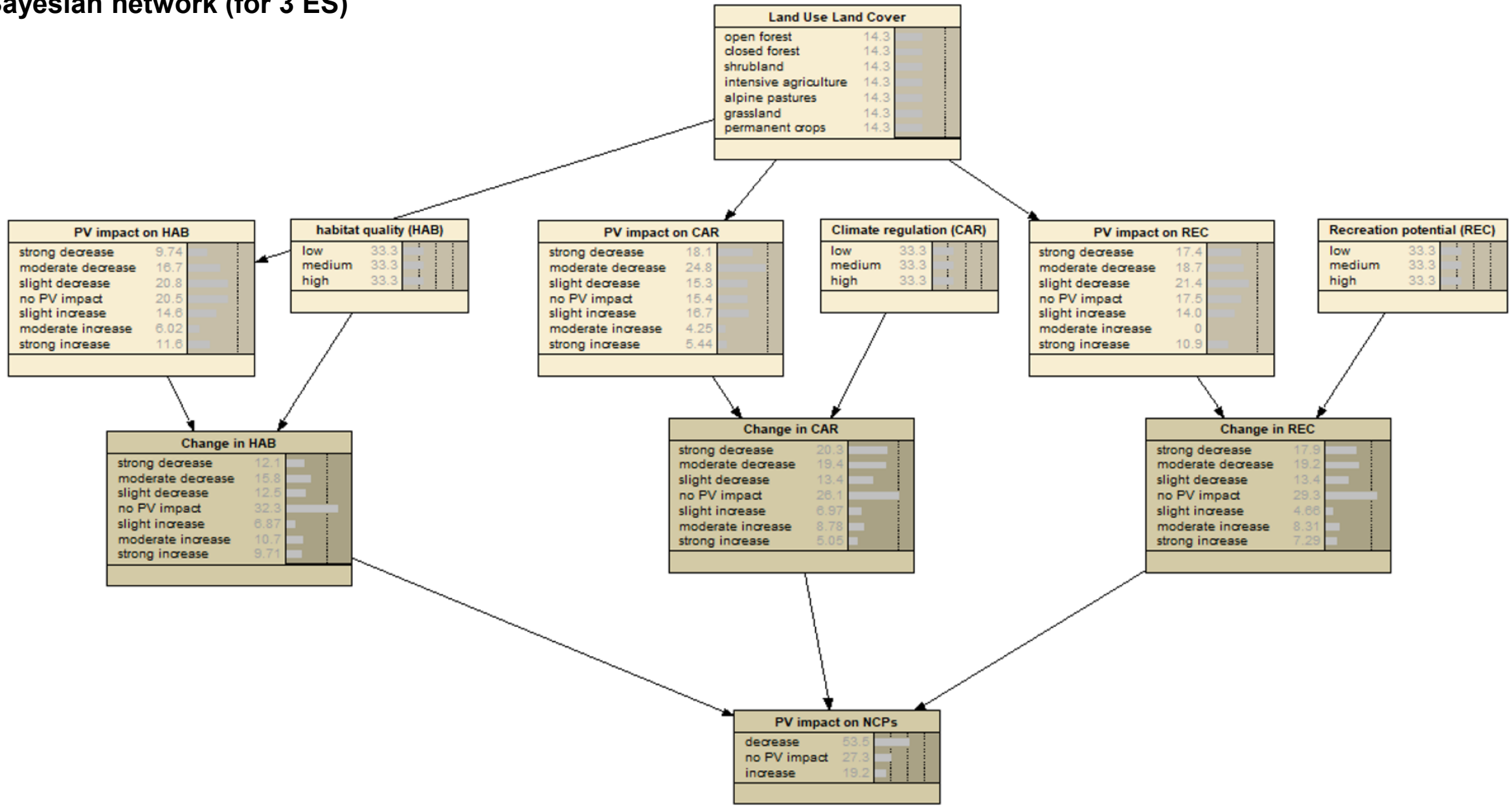
Scenario uncertainty

The qualitative description of alternative worldviews and their development into the future and the quantification of model input parameters that are conditional on these descriptions.

Decision uncertainty

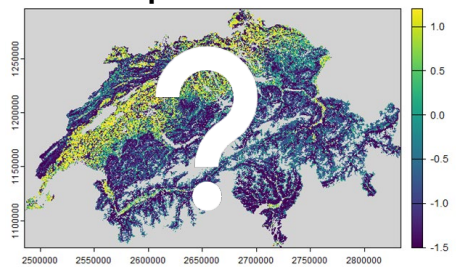
Communicating and translating the results of scenario and modeling studies into decision-making.

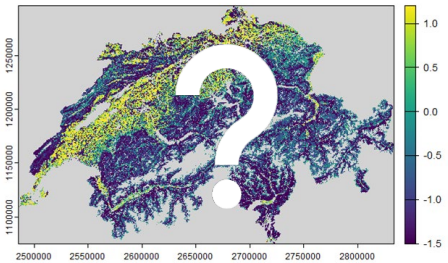
Bayesian network (for 3 ES)

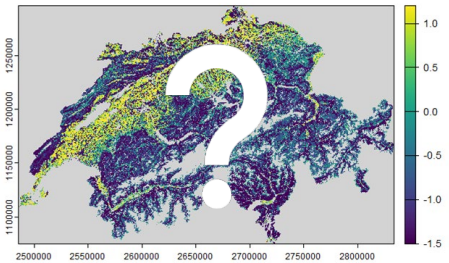


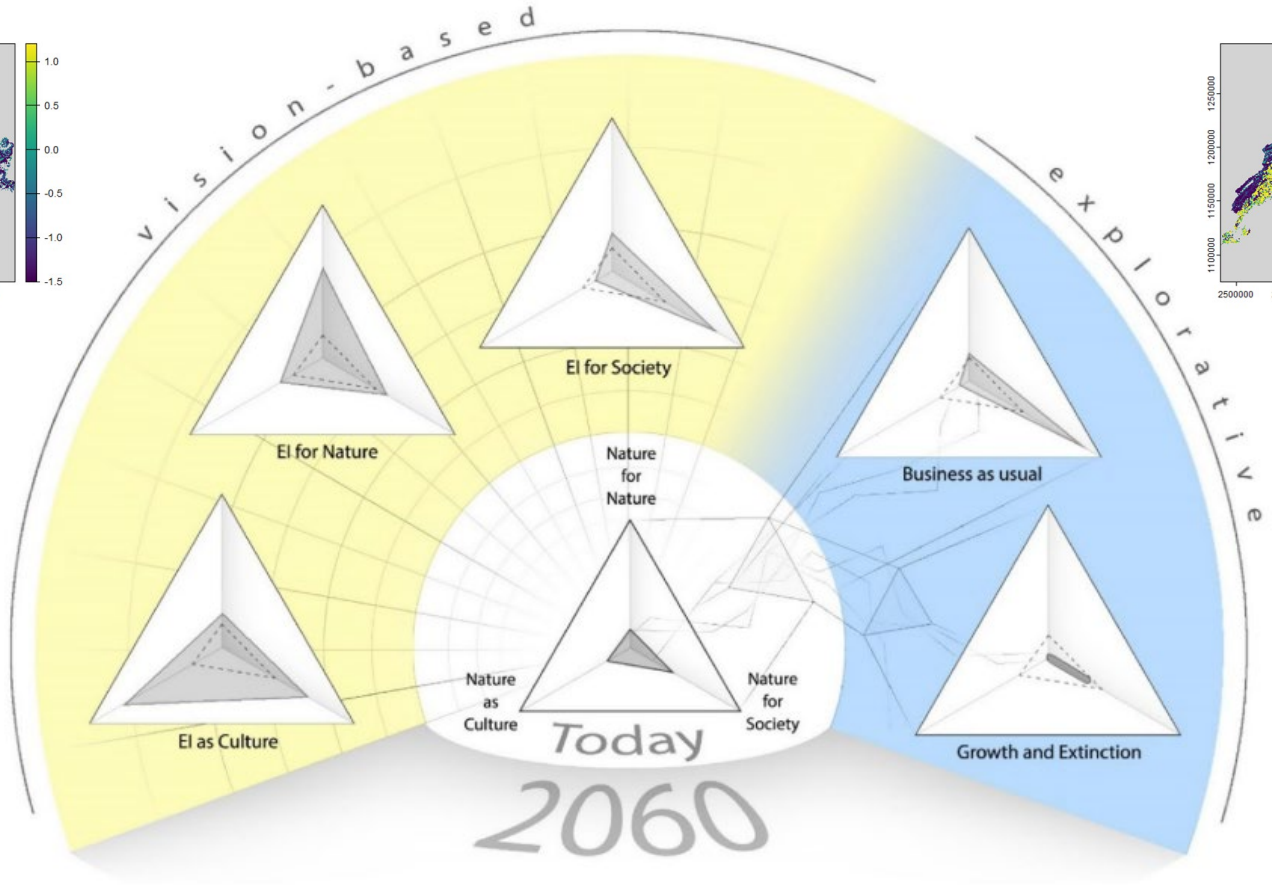
Outlook

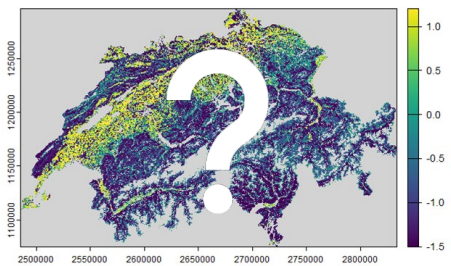
Addressing uncertainties in ecosystem services impacts of solar energy systems **under future changes**

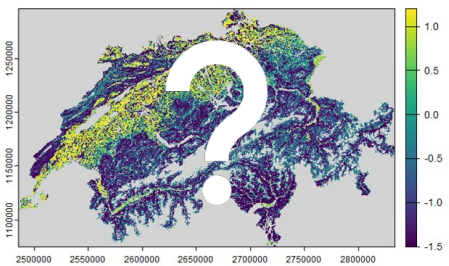






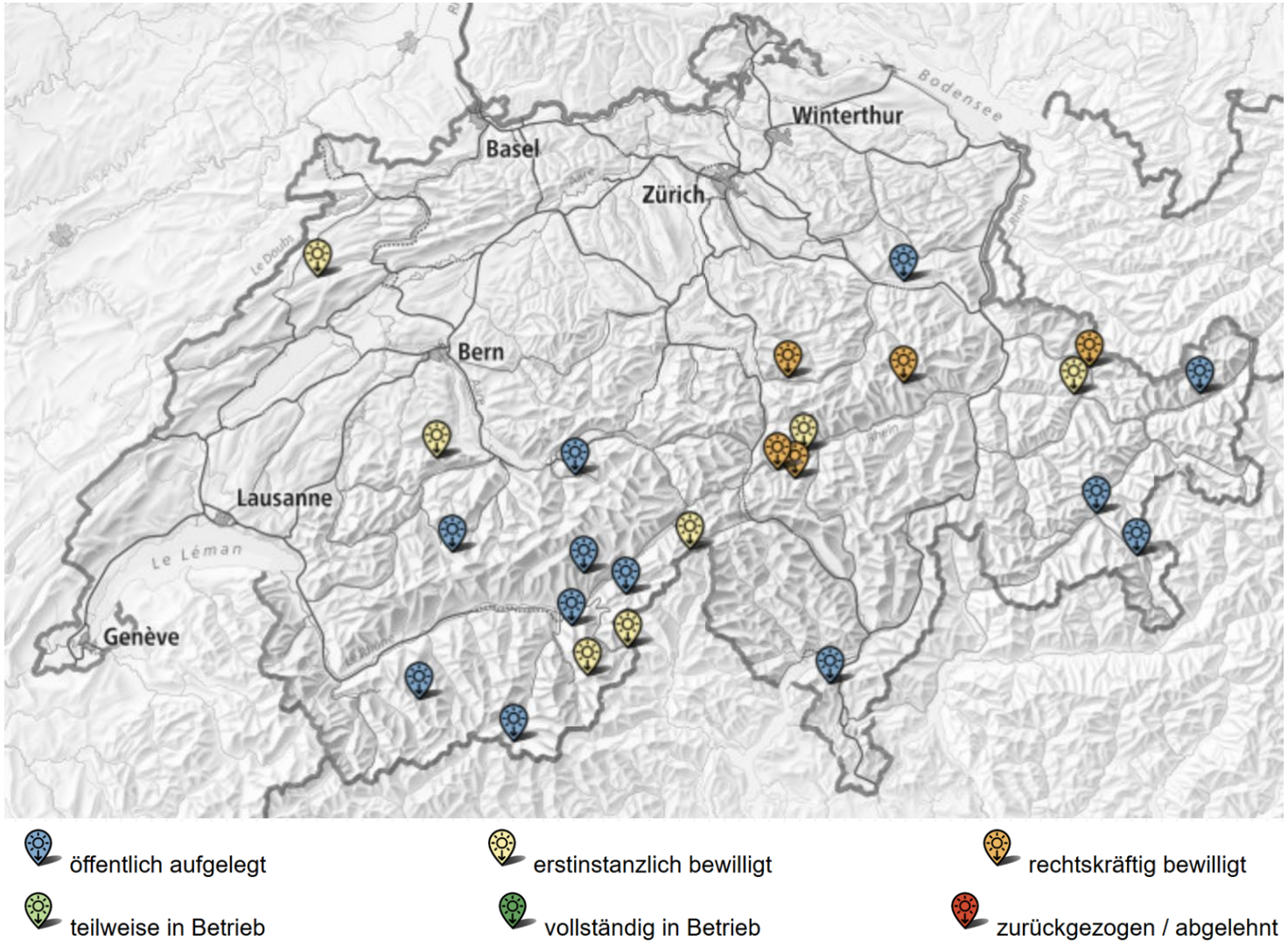






Meyer et al., 2023

Black et al., 2024



Ground-mounted solar PV systems in high-alpine areas, Switzerland
(https://www.uvek-gis.admin.ch/BFE/storymaps/EE_AlpineSolaranlagen/)

ES data

ES	Model	Description of input parameters (see sources in D.2: Tabel D.1 from Black et al., 2025)
HAB	InVEST	LULC inputs assigned parameter values (look-up tables): - Land use - Sensitivity table: habitat-specific sensitivity values indicating relative vulnerability of each land use type to different threats - Threats table: impact, maximum distance of influence, decay type of each identified threat affecting habitat quality - Half saturation constant: parameter representing the threshold at which habitat quality decreases by half
POL	InVEST	- Land use - Guild table: pollinator guilds, specifying nesting habitats, foraging habitats, flight ranges, and pollination activity patterns - Biophysical table: crop-specific data on pollination services and yield increases
CAR	InVEST	LULC inputs assigned parameter values (look-up tables): - Land use - Biophysical tables: carbon storage values by land use category, region and elevation
SDR	InVEST	LULC inputs assigned parameter values (look-up tables): - Land use - DEM USLE relevant parameters: - Erosivity: rainfall erosivitiy data) - Soil erodibility: soil susceptibility to erosion - Biophysical table: land-use specfic erosion parameters - Watersheds - Threshold flow accumulation - Borselli K parameter: parameter for sediment transport efficiency - Maximum SDR value: upper boundary for sediment export - Borselli IC0 parameter: Controls sediment connectivity - Maximum L value: Max slope-length factor
NDR	InVEST	LULC inputs assigned parameter values (look-up tables): - Land use - DEM - Nutrient runoff proxy (precipitation-based) - Watersheds - Biophysical table: nutrient load and retention parameters - Threshold flow accumulation: minimum number of upslope cells to generate a stream - Borselli K parameter: calibration parameter for nutrient transport

ES data

ES	Model	Description of input parameters (see sources in D.2: Tabel D.1 from Black et al., 2025)
PC	nSDM-based	Habitat suitability of 50 predator species of common agricultural pests
FF	FAO's Ecocrop model	- Land use - Monthly precipitation - Monthly average temperature - Soil pH
WY	InVEST	LULC inputs assigned parameter values (llok-up tables) - Precipiation (annual) - evapotranspiration (annual) - root restricting layer depth: soil depth limits - soil water available to plants - biophysical table: water balance parameters - Z parameter (for empirical calibration) - watersheds (hydrological bonudaries)
REC	ESTIMAP recreation model	- Land use - Naturalness score - Protected areas - Distance to lakes
ID	nSDM-based	Habitat suitability of 15 emblematic species (Schirpke et al., 2018)