

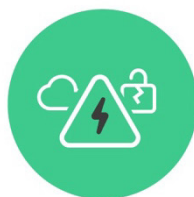


Report dated: 01.09.2025

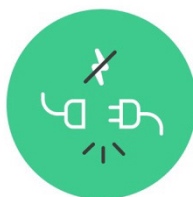
Reporting period: 01.11.2024 – 31.07.2025

Annual Report Year 1 – Public Part

RECIPE



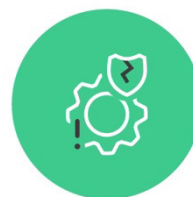
Hazards



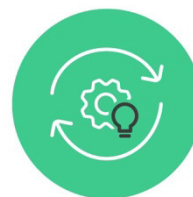
Criticality



Vulnerability



Impacts
& risks



Recommendations
to enhance
resilience



Hazards



Criticality



Vulnerability



Impacts
& risks



Recommendations
to enhance
resilience

Source: ©09 2025



Date: 01.09.2025

Location: Bern

Publisher:

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Bern
www.bfe.admin.ch

SWEET Call: 1-2023

Annual report template: v3.1

Subsidy recipient:

Eidgenössische Technische Hochschule Zürich (ETHZ), Reliability and Risk Engineering (RRE) Lab
Leonhardstrasse 21
8092-Zürich
<https://ethz.ch> , <https://rre.ethz.ch>

Consortium website: <https://sweet-recipe.ch>

Authors:

Coordinator: Giovanni Sansavini, ETHZ-RRE, sansavig@ethz.ch
Deputy Coordinator: Turhan Demiray, ETHZ-FEN, demirayt@ethz.ch
Integration Expert: Adamantios Marinakis, ETHZ-FEN, marinakis@fen.ethz.ch
KTT Expert: Johanna Zwahlen, Zoi, johanna.zwahlen@zoinet.org
Lukas Gudmundsson, ETHZ-IAC, lukas.gudmundsson@env.ethz.ch
Petra Sieber, ETHZ-IAC, petra.sieber@env.ethz.ch
Blazhe Gjorgiev, ETHZ-RRE, gblazhe@ethz.ch
Alexander Fuchs, ETHZ-FEN, fuchs@fen.ethz.ch
Tobias Reisch, ETHZ-KOF, reisch@kof.ethz.ch
Corinne Moser, FHNW-APS, corinne.moser@fhnw.ch
Gioia Hilpert, FHNW-APS, gioia.hilpert@fhnw.ch
Nicolas Schmid, INFRAS, nicolas.schmid@infras.ch
Braulio Barahona, HSLU, braulio.barahonagarzon@hslu.ch

SFOE project coordinators:

Nathalie Rüegg, nathalie.rueegg@bfe.admin.ch
Head of the monitoring panel: Michael Moser, michael.moser@bfe.admin.ch

SFOE contract number: SI/502897-01



The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.



Table of Contents

Executive summary.....	5
1 Work programme overview	7
2 Progress of activities.....	8
3 Highlights of outputs.....	10
4 References.....	11



Executive summary

RECIPE aims to foster a sustainable and resilient energy future for Switzerland, aligned with the country's energy and climate policy goals, by studying the risks associated with the energy transition and climate change that Switzerland can be exposed to in the coming 25-30 years. The RECIPE consortium will identify hazards to which the Swiss energy and ICT infrastructure can be vulnerable by engaging a transdisciplinary team of experts, from the academia and industry. The analysis will assess hazards from the evolving energy system, climate change, and socio-economic trends. The consortium will assess the criticality of energy infrastructures by examining the systemic impact of disturbances - such as energy supply disruptions or energy price volatility - on Switzerland's economy, society, resources, and ecosystems. RECIPE will (i) model today's as well as the future's energy system, covering all relevant infrastructures and operational paradigms, (ii) develop an integrated cyber security risk analysis framework, (iii) assess the influence of different climate change scenarios on hot and dry extremes, (iv) model the interactions among Swiss industrial firms, hence quantify how disturbances in the energy system propagate to the Swiss economy, (v) identify expected reactions of the population to energy disturbances, and (v) conduct an exhaustive review of relevant policy instruments and political decisions. Finally, RECIPE will propose ways to enhance resilience and will conclude with developing actionable recommendations for policymakers, authorities, infrastructure owners, and economic actors, closely working with them on selected real case studies.

Zusammenfassung

Das Ziel von RECIPE ist es, eine nachhaltige und widerstandsfähige Energiezukunft für die Schweiz zu unterstützen – im Einklang mit den energie- und klimapolitischen Zielen des Landes. Dazu analysiert das Konsortium die Risiken der Energiewende und des Klimawandels, denen die Schweiz in den kommenden 25 bis 30 Jahren ausgesetzt sein könnte. Ein transdisziplinäres Expertenteam aus Wissenschaft und Industrie wird die Gefahren für die Schweizer Energie- und IKT-Infrastruktur identifizieren und die Auswirkung des sich wandelnden Energiesystems, des Klimawandels und sozioökonomischer Trends analysieren. Zudem wird die Kritikalität von Energieinfrastrukturen bewertet, indem untersucht wird, wie sich Störungen - wie Unterbrechungen der Energieversorgung oder Energiepreisschwankungen - auf die Schweizer Wirtschaft, Gesellschaft, Ressourcen und Ökosysteme auswirken. RECIPE wird (i) das aktuelle und zukünftige Energiesystem unter Berücksichtigung aller relevanten Infrastrukturen und Betriebsparadigmen modellieren, (ii) einen integrierten Rahmen für die Analyse von Cybersicherheitsrisiken entwickeln, (iii) den Einfluss verschiedener Szenarien des Klimawandels auf heisse und trockene Extreme analysieren, (iv) die Interaktionen zwischen Schweizer Industrieunternehmen modellieren und quantifizieren, wie sich Störungen im Energiesystem auf die Schweizer Wirtschaft auswirken, (v) die zu erwartenden Reaktionen der Bevölkerung auf Störungen im Energiebereich identifizieren und (v) eine umfassende Analyse relevanter politischer Instrumente und Entscheidungen durchführen. Schliesslich wird RECIPE Wege zur Verbesserung der Resilienz aufzeigen und umsetzbare Empfehlungen für politische Entscheidungsträger, Behörden, Infrastruktureigentümer und Wirtschaftsakteure erarbeiten – in enger Zusammenarbeit mit diesen, basierend auf realen Fallstudien.



Résumé

RECIPE vise à favoriser un avenir énergétique durable et résilient pour la Suisse, en accord avec les objectifs de la politique énergétique et climatique du pays, en étudiant les risques associés à la transition énergétique et au changement climatique auxquels la Suisse peut être exposée dans les 25 à 30 prochaines années. Le consortium RECIPE identifiera les risques auxquels l'infrastructure énergétique et TIC suisse peut être vulnérable en faisant appel à une équipe transdisciplinaire d'experts, issus du monde universitaire et de l'industrie. L'analyse évaluera les risques liés à l'évolution du système énergétique, au changement climatique et aux tendances socio-économiques. Le consortium évaluera la criticité des infrastructures énergétiques en examinant l'impact systémique des perturbations - telles que les interruptions de l'approvisionnement en énergie ou la volatilité des prix de l'énergie - sur l'économie, la société, les ressources et les écosystèmes de la Suisse. RECIPE (i) modélisera le système énergétique actuel et futur, en couvrant toutes les infrastructures et tous les paradigmes opérationnels pertinents, (ii) développera un cadre intégré d'analyse des risques de cybersécurité, (iii) évaluera l'influence de différents scénarios de changement climatique sur les extrêmes chauds et secs, (iv) modélisera les interactions entre les entreprises industrielles suisses, quantifiant ainsi la façon dont les perturbations du système énergétique se propagent à l'économie suisse, (v) identifiera les réactions attendues de la population aux perturbations énergétiques, et (v) effectuera un examen exhaustif des instruments politiques et des décisions politiques pertinents. Enfin, RECIPE proposera des moyens d'améliorer la résilience et conclura en élaborant des recommandations exploitables pour les décideurs, les autorités, les propriétaires d'infrastructures et les acteurs économiques, en travaillant en étroite collaboration avec eux sur des études de cas réels sélectionnés.

Riassunto

RECIPE mira a promuovere un futuro energetico sostenibile e resiliente per la Svizzera, in linea con gli obiettivi di politica energetica e climatica del Paese. Questo sarà raggiunto studiando i rischi associati alla transizione energetica e ai cambiamenti climatici a cui la Svizzera è esposta nei prossimi 25-30 anni. Il consorzio RECIPE identificherà i pericoli a cui l'infrastruttura energetica e l'infrastruttura di telecomunicazione svizzere sono più vulnerabili, coinvolgendo un gruppo transdisciplinare di esperti del settore, provenienti sia dal mondo accademico e che industriale. L'analisi valuterà i pericoli derivanti dall'evoluzione del sistema energetico, dai cambiamenti climatici, e dalle tendenze socioeconomiche. Il consorzio valuterà la criticità delle infrastrutture energetiche esaminando l'impatto sistemico delle perturbazioni - come le interruzioni della fornitura di energia o la volatilità dei prezzi dell'energia - sull'economia, sulla società, sulle risorse, e sugli ecosistemi della Svizzera. A tal fine, RECIPE (i) modellerà il sistema energetico odierno e futuro, coprendo le infrastrutture e i paradigmi operativi rilevanti, (ii) svilupperà un quadro integrato per l'analisi del rischio di cyber-sicurezza, (iii) valuterà l'influenza di diversi scenari di cambiamento climatico relativamente agli estremi di caldo e siccità, (iv) modellerà le interazioni tra le aziende svizzere, quindi quantificherà il modo in cui le perturbazioni del sistema energetico si propagano all'economia svizzera, (v) identificherà le possibili reazioni della popolazione alle perturbazioni energetiche, e (v) condurrà una revisione esaustiva degli strumenti politici e delle decisioni politiche rilevanti. Infine, RECIPE proporrà modi per garantire la resilienza dell'infrastruttura energetica svizzera e concluderà con lo sviluppo di raccomandazioni attuabili per i responsabili politici, le autorità, i proprietari di infrastrutture, e gli attori economici, lavorando con loro a stretto contatto su casi di studio reali.



1 Work programme overview

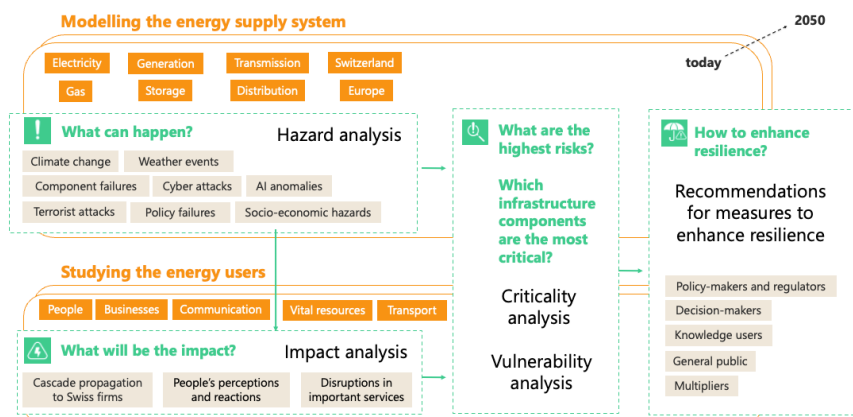
In the coming decades, Switzerland will be undergoing two major changes. On the one hand, its energy system will be progressively transformed to a system with net-zero CO₂ emissions, according to the Energy Strategy 2050. On the other hand, the ongoing climate change is expected to manifest itself with increasing intensity. Due to the crucial importance of uninterrupted energy supply for the Swiss economy, population well-being and vital resources, it is imperative to timely identify the risks and the appropriate mitigation measures. In this direction, the RECIPE consortium objectives are to:

- OBJ1. identify a set of (technical, societal, economic, environmental) hazards, to which the Swiss energy system is vulnerable during the energy transition, posing the highest risks;
- OBJ2. assess and quantify the criticality of each infrastructure type relevant to the Swiss energy system throughout the energy transition, at national, cantonal and municipality levels for various energy system evolution and climate change scenarios;
- OBJ3. propose a set of resilience enhancement measures that are techno-economically and socially suitable for reducing the identified risks;
- OBJ4. propose a roadmap of actions to the Swiss stakeholders, such as federal, cantonal and municipality authorities, infrastructure owners and operators, interest groups and economic actors, so that they can timely and efficiently address the identified risks.

The project consists of 6 subprojects (WPs), each having a clearly distinct focus and objectives. The combination of these subprojects will allow to satisfy the consortium's objectives.

The outcome of WP1 will consist of a selection of hazards to be further considered for detailed quantitative analysis in the context of the energy system. WP2 is the cornerstone of the quantitative analysis in RECIPE, developing a "modelling suite" of the combined energy and ICT systems, allowing to

quantify "energy system disruptions", such as loss of power at specific nodes for a specific duration or increased or very volatile energy prices, resulting from hazards. WP3 develops and utilizes a set of methodologies to quantify the "criticality metrics", i.e., the impacts on the Swiss economy, population, and resources. WP4 will perform the criticality and vulnerability analysis, i.e., it will holistically address two of the call's three research questions. The criticality metrics will be quantified for the hazards selected in WP1 using the methods developed in WP2 and WP3. WP5 will address the call's third research question; how can risks be mitigated and resilience be enhanced. Finally, WP6 will synthesize the results of the project and co-produce actionable proposals for resilience enhancement measures etc. with and for stakeholders and citizens.





2 Progress of activities

RECIPE is at its early stage. The emphasis during the first months has been on establishing appropriate coordination among the consortium members as well as with the cooperation partners and on moving forward with tasks (in WP 1-3) which will serve as a basis later in the execution of the project. Following, we summarize the most noteworthy progress.

Scenario identification and selection

The scenario space has been expressed by three dimensions: “climate”, “socio-economic” and “technology”. Scenario sources, linking the scenarios dimensions with the energy sector have been identified (such as [CROSS], [TYNDP2024], [EP2050+], [NEP2040]), with objective to utilize scenarios which are commonly used by Swiss authorities and stakeholders. Already, the consortium has decided that climate evolution scenarios will be expressed by means of global warming levels, while the [CROSS] inputs assumptions (typically stemming from the Swiss federal offices) and the associated energy infrastructure scenarios will be the basis of RECIPE’s scenario selection.

Hazard selection and consolidation

The RECIPE team has assembled a preliminary list of hazards; 46 hazards stemming from climate and weather, policy, the energy system, ICT/cyber, the economy, and society. Hazard storylines are being developed, following the “hazard files” template of FOCP.

Climate variables and identification of relevant climate data

In support of assessing climate risks, key climate variables and associated hazards with relevance to the energy system were identified, alongside with an assessment of the feasibility of data provisions. While commonly used variables like air temperature and precipitation are readily available, others—such as lightning and hailstorms—pose challenges due to limited data availability. To address this, the IAC engages with modelling teams to understand specific requirements and explore viable data sources. Synergies with other ongoing initiatives are leveraged, including the forthcoming Swiss climate assessment ([CH2025], expected November 2025). In addition, regional climate model simulations from Euro-CORDEX that are specifically processed in the context of both RECIPE and the Speed2Zero project (<https://speed2zero.ethz.ch/de/>) will be considered.

Model coupling, in particular the pan-European electricity transmission grid model

A key step in WP2 is the coupling between the various models for economic dispatch (FlexECO), steady state security analysis (DeRisk, Cascades), and dynamic simulation (FlexDYN, FlexGAS). The main challenge is that, despite operating on inherently different temporal (seconds, hours, years) and spatial scales (European level, Swiss level), the models should represent consistent situations during the hazard analysis. For example, a situation with high transit flows through Switzerland (FlexECO) triggering cascading outages during a disturbance (Cascades) with subsequent critical dynamic transients (FlexDYN) should use the same system state. Currently, each model was developed with different data sets (ENTSO-E TYNDP model, ENTSO-E dynamic model, PyPSA, IEEE benchmark networks) and has advantages and disadvantages (availability of spatial coordinates, quality of the grid representation, integration with existing tools and related studies, and open-source data). A unified grid modelling suite based on the PyPSA model has been selected. This introduces new challenges, particularly the creation of a completely new dynamic grid model of Europe in FlexDYN. However, the benefit would be a consistent modelling suite, the open-source characteristic of the model, and the leveraging of previous experiences of RRE (Cascades) and FEN (FlexECO) with this model.



Modelling of the ICT system

A map of the interdependencies between ICT components and energy infrastructures has been created and is being updated / reviewed. The goal is a holistic review of the critical ICT components, that need to function for the energy system to properly operate.

Literature review relating to impact of power disturbances on households and authorities

A currently ongoing systematic review of existing literature, with a specific focus on contexts relevant to Switzerland examines how power outages impact households and individuals, focusing on factors that affect their resilience. The review aims to identify factors that have been shown to jeopardize or bolster individual, household, collective, and social energy resilience. A second review analyses the effects of short-term blackouts, long-term energy shortages, and sustained high prices on three key resources: water, food, and healthcare. All three are highly dependent on electricity, making them uniquely vulnerable. The review found that reliance on electricity makes these sectors fragile, though their resilience varies. For example, water supply can be fragile in areas that rely on electric pumps, while food security is better due to strategic stockpiles, except for fresh and chilled goods. Similarly, large hospitals have backup power for several days, but outpatient and home care services have limited backup. The review concludes that effective risk management requires strong coordination among federal, cantonal, and private organizations to protect these vital services, under frameworks like the National Economic Supply Act and the National Strategy for the Protection of Critical Infrastructure, is essential for managing risks.

Interactions with stakeholders

The project has significantly advanced its collaboration with the FOCP (Federal Office for Civil Protection), securing partnerships with key sectors: food, water, medical supply, and road transport. Future discussions will focus on aligning the project's analysis with existing sectoral resilience plans. A workshop has already been held with ASTRA (road transport) to define next steps.

Identification of data sources to quantify the impact of power disturbances on the Swiss economy

Projects has been made on acquiring and preparing the necessary data to analyse the propagation of energy disturbances on the Swiss economy. Access to the FACTSET Database has been secured, project members are in contact with the Hungarian Central Bank to obtain granular VAT data for validation of reconstruction methods. Our team is also actively engaged in web scraping to create a firm-level production network for Switzerland. Finally, to understand the direct impact of energy shocks, consortium members have reached out to the BFE/BFS for access to their microdata on firm-level energy use, which will be crucial for estimating the energy consumption of Swiss companies.



3 Highlights of outputs

Since the RECIPE project is at each early stage, no major planned outputs have yet been reached. Two highlights that the consortium has achieved during its first months are briefly described below.

Scientific publication / project finding: Reduction of hydro resources due to climate change

To assess the impact of past climate change and variability on run-of-river (RoR) hydropower generation in Switzerland, as well as its implications for electricity system planning, [Had25] developed a high-resolution modelling pipeline. This was used to estimate the generation of 601 RoR plants between 1991 and 2022. The results revealed strong interannual variability and a slight long-term decline in generation, even when controlling for infrastructure expansion. The study attributes this trend to reduced water availability linked to climate change. Simulations using the Nexus-e electricity systems model demonstrate that climate-driven variability in RoR output has a significant impact on electricity prices, particularly in scenarios without renewable energy targets. In contrast, systems with high renewable energy targets demonstrate greater resilience to hydrological fluctuations. The findings emphasise the importance of considering climate variability in energy planning and imply that infrastructure expansion has implicitly served as a climate adaptation strategy. The study emphasises the necessity of climate-resilient energy systems in the context of mounting hydro-climatic uncertainty.

Stakeholder engagement workshop: Building a resilient energy transition, how do we get there?

The RECIPE consortium brought together over 60 Swiss stakeholders at ETH Zürich for its first workshop (<https://sweet-recipe.ch/event/recipe-workshop-1/>). The workshop marked an important step toward building participatory research and will contribute to shape RECIPE's way forward. The workshop participants reflected on the risks and challenges of the energy transition, and explored relevant hazards, vulnerabilities, criticalities, as well as potential measures from multiple perspectives.

Key messages from the panel discussion were:

- Extreme events are increasing in frequency and intensity, creating more imbalances and higher costs.
- A successful energy transition must support prosperity — the two are interconnected.
- Building resilience comes at a cost, and it is essential to assess what constitutes a reasonable cost and how it should be shared within the Swiss economy and society.
- To build a resilient energy future for Switzerland, we must work together — across systems, markets, and society.

The outcomes of the discussions in smaller groups were documented in a short document, and made available online:

https://sweet-recipe.ch/wp-content/uploads/2025/06/2025-05-15_RECIFE-Stakeholder-workshop-1-Summary.pdf



4 References

- [CH2025] <https://www.meteoswiss.admin.ch/about-us/research-and-cooperation/projects/2023/climate-ch2025.html>
- [CROSS] <https://sweet-cross.ch/scenarios/>
- [EP2050+] <https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html/>
- [Had25] Yann Yasser Haddad, Lukas Gudmundsson, Jonas Savelsberg, Jared B Garrison, Elena Raycheva, Tobias Wechsler, Massimiliano Zappa, Gabriela Hug and Sonia I Seneviratne, "Recent climate impacts on run-of-river hydropower and electricity systems planning in Switzerland", Environmental Research Letters, vol. 20, no. 8, July 2025, <https://iopscience.iop.org/article/10.1088/1748-9326/ade4df>
- [NEP2040] <https://www.swissgrid.ch/en/home/projects/future-grid.html>
- [TYNDP2024] <https://www.entsoe.eu/outlooks/tyndp/2024/>