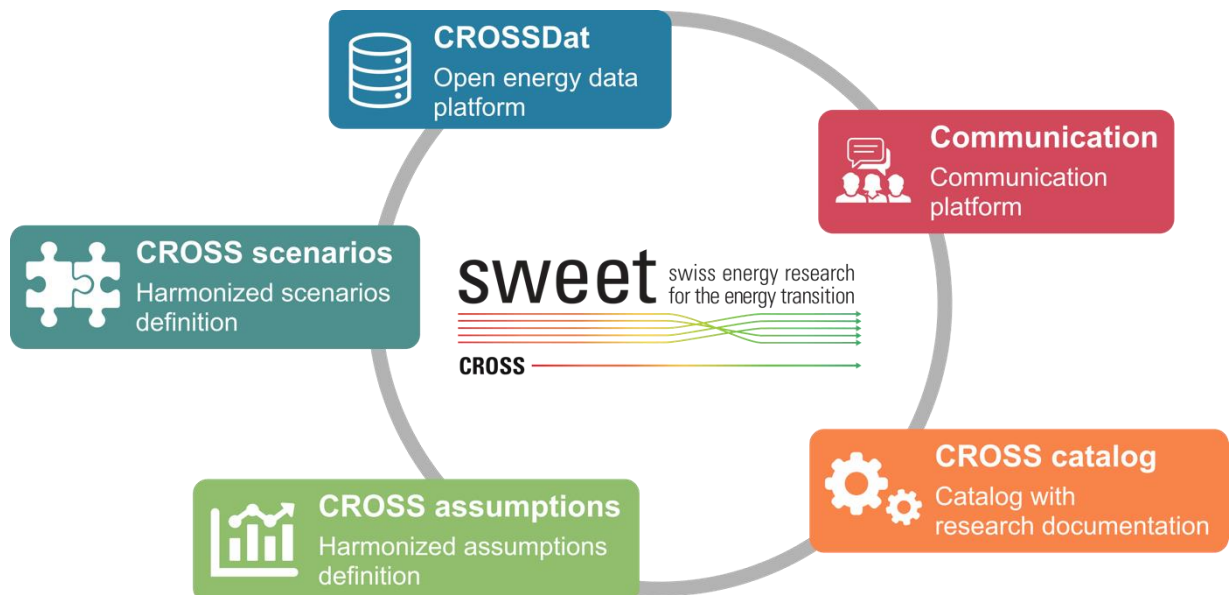




Final Report

Coordination of Scenarios for SWEET (CROSS)



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ETH zürich



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Summary

CROSS (CooRdination Of Scenarios for SWEET) is a joint activity of the four consortia DeCarbCH, EDGE, PATHFNDR and SURE, supported by the SWEET program and coordinated by ETH Zurich. CROSS established a platform that increases transparency in energy research, access to energy research data and reproducibility of modelling results. The following are the main outcomes of CROSS:

- **CROSSDat** is a platform designed and developed to offer unified and open access to energy-related research data. CROSSDat increases the accessibility of research findings and modelling assumptions.
- **CROSS scenarios** are a set of harmonized scenarios defined along two dimensions: climate policy and energy market integration. Having harmonized scenarios contributes to providing insights to the energy policy discussion from complementary perspectives.
- **CROSS assumptions** are reference values for various input parameters for energy system models. These harmonized assumptions improve the consistency and comparability of modelling results across the research projects in SWEET.
- The **CROSS catalog** is an online platform developed to give a comprehensive overview and description of tools and research groups in the SWEET consortia. The CROSS catalog fosters exchange and networking development.
- **Model result comparison** using the harmonized CROSS scenarios: We determined similarities and differences in the findings from different energy system models. This comparison is informative for both energy modelling researchers and policy makers.

Résumé

CROSS (CooRdination Of Scenarios for SWEET) est une activité commune aux quatre consortiums DeCarbCH, EDGE, PATHFNDR et SURE, soutenue par le programme SWEET et coordonnée par l'ETH Zurich. CROSS a permis de créer une plateforme qui améliore la transparence dans la recherche énergétique, l'accès aux données de recherche énergétique et la reproductibilité des résultats de modélisation. Les principaux résultats de CROSS sont présentés ci-dessous :

- **CROSSDat** est une plateforme conçue et développée pour offrir un accès unifié et ouvert aux données de recherche liés à l'énergie. CROSSDat améliore l'accessibilité des résultats de recherche et des hypothèses de modélisation.
- Les **scénarios CROSS** sont une série de scénarios harmonisés définis dans les dimensions de la politique climatique et de l'intégration au marché de l'énergie. Ces scénarios harmonisés contribuent à éclairer le débat sur la politique énergétique sous des angles complémentaires.
- Les **hypothèses CROSS** sont des valeurs de référence pour les différents paramètres d'entrée des modèles de systèmes énergétiques. Ces hypothèses harmonisées améliorent la cohérence et la comparabilité des résultats de modélisation entre les projets de recherche du programme SWEET.
- Le **catalogue CROSS** est une plateforme en ligne conçue et développée pour offrir une vue d'ensemble et une description des outils et groupes de recherches des consortiums du programme SWEET. Le catalogue CROSS favorise l'échange et le développement de réseaux.
- **Comparaison des résultats de modèles** sur la base des scénarios CROSS harmonisés : les points communs et les différences entre les résultats de différents modèles de systèmes énergétiques ont été identifiés. Cette comparaison est instructive tant pour les chercheurs dans le domaine de la modélisation des systèmes énergétiques que pour les responsables politiques.



Zusammenfassung

CROSS (CooRdination Of Scenarios for SWEET) ist eine gemeinsame Aktivität der vier Konsortien DeCarbCH, EDGE, PATHFNR und SURE, die vom SWEET-Programm unterstützt und von der ETH Zürich koordiniert wird. Mit CROSS wurde eine Plattform geschaffen, die die Energieforschung, den Zugang zu Energieforschungsdaten und die Reproduzierbarkeit von Modellierungsergebnissen transparenter gestaltet. Im folgenden Abschnitt sind die wichtigsten Ergebnisse von CROSS aufgeführt:

- **CROSSDat** ist eine Plattform, die entworfen und entwickelt wurde, um einen einheitlichen und offenen Zugang zu energiebezogenen Forschungsdaten zu bieten. CROSSDat verbessert den Zugriff auf Forschungsergebnisse und Modellierungsannahmen.
- **CROSS-Szenarien** sind eine Reihe von harmonisierten Szenarien, die entlang zweier Dimensionen definiert sind: Klimapolitik und Energiemarktintegration. Sollte harmonisierte Szenarien tragen dazu bei, die energiepolitische Diskussion aus komplementären Perspektiven zu beleuchten.
- **CROSS-Annahmen** sind Referenzwerte für verschiedene Eingabeparameter für Energiesystemmodelle. Diese harmonisierten Annahmen verbessern die Konsistenz und Vergleichbarkeit der Modellierungsergebnisse zwischen den Forschungsprojekten in SWEET.
- Der **CROSS-Katalog** ist eine Online-Plattform, die entwickelt wurde, um einen umfassenden Überblick und eine Beschreibung der Werkzeuge und Forschungsgruppen in den SWEET-Konsortien zu geben. Der CROSS-Katalog fördert den Austausch und die Entwicklung von Netzwerken.
- **Vergleich der Modellergebnisse** unter Verwendung der harmonisierten CROSS-Szenarien: Gemeinsamkeiten und Unterschiede in den Ergebnissen verschiedener Energiesystemmodelle wurden ermittelt. Dieser Vergleich ist sowohl für Forscher im Bereich Energiemodellierung als auch für politische Entscheidungsträger aufschlussreich.

Riassunto

CROSS (CooRdination Of Scenarios for SWEET) è un'attività congiunta di quattro consorzi: DeCarbCH, EDGE, PATHFNR e SURE. L'attività è sostenuta dal programma SWEET e coordinata dal Politecnico di Zurigo. Nell'ambito di CROSS, è stata creata una piattaforma che mira a migliorare la trasparenza della ricerca energetica, facilitando l'accesso ai dati e aumentando la riproducibilità dei risultati ottenuti attraverso la modellazione. Tra i risultati più significativi ottenuti grazie a CROSS, vi sono:

- **CROSSDat** è una piattaforma sviluppata per offrire accesso unificato e aperto ai dati della ricerca nel campo energetico. L'obiettivo di CROSSDat è quello di migliorare l'accessibilità ai risultati di ricerca e alle ipotesi alla base della modellazione.
- Gli **scenari CROSS** sono una serie di scenari armonizzati definiti in base a due dimensioni: politica climatica e integrazione del mercato energetico. Questi scenari armonizzati aiutano a far luce sul dibattito riguardante la politica energetica da punti di vista complementari.
- Le **ipotesi CROSS** rappresentano i valori di riferimento per vari parametri di input dei modelli del sistema energetico. Tali ipotesi armonizzate contribuiscono ad aumentare la coerenza e la comparabilità dei risultati della modellazione tra i progetti di ricerca di SWEET.
- Il **catalogo CROSS** è una piattaforma online creata per fornire una panoramica completa degli strumenti e dei gruppi di ricerca dei consorzi SWEET. Tale catalogo promuove lo scambio e lo sviluppo della rete di contatti.
- Il **confronto tra i risultati dei modelli** che utilizzano gli scenari armonizzati di CROSS permette di identificare le somiglianze e le differenze tra i risultati dei diversi modelli del sistema energetico.



Tale confronto rappresenta un'informazione utile sia per i ricercatori nell'ambito della modellazione dei sistemi energetici che per i decisori politici.



1 Objectives

CROSS (CooRdination Of Scenarios for SWEET) is a joint activity of the four SWEET consortia DeCarbCH, EDGE, PATHFNDR and SURE. The main goal of CROSS is to increase the comparability of the simulations from the four consortia by harmonizing and documenting assumptions and scenarios; by publishing model documentations; and by providing a platform with open energy research data.

The main goals can be broken down into specific goals, which are defined along five main topics:

1. Data: Establish a digital platform with unified and open access to data generated and used by SWEET consortia and further energy-related research.
2. Scenarios: Jointly define CROSS-scenarios to be analyzed by different models in the SWEET-consortia. By analyzing the same set of scenarios, the results from the different consortia can complement each other, which helps drawing conclusions that are as comparable as possible.
3. Harmonization of assumptions: Harmonize a basic set of input parameters across consortia to improve comparability of the results and, therefore, their relevance. This harmonization includes ranges (min, max and reference values) for uncertain parameters.
4. Models:
 - Build a model catalog with information about inputs, outputs, and capabilities.
 - Map inputs and outputs of the different models to identify possible synergies.
5. Communication platform: Establish a discussion platform for researchers in the SWEET consortia, to communicate with the scientific community (within and outside the SWEET consortia) and the public domain.

2 Activities and outputs

2.1 CROSSDat: CROSS Data platform

CROSSDat is a platform with unified and open access to data generated and used by SWEET consortia, and further energy-related research. CROSSDat provides a platform for aggregation of energy (research) data, irrespective of where it is stored and curated. CROSSDat increases the efficiency of data access and contributes to the exchange, outreach, and development of SWEET-related research.

The main distinguishing feature of CROSSDat is that it is both a database and a metabase (database of metadata) that presents data consumers with a platform containing aggregated energy data:

- The metabase automatically understands, harvests, and presents metadata from existing external data management systems and databases. This allows data producers, which already use existing databases, to use CROSSDat without duplicating efforts.
- The database allows researchers from SWEET consortia and beyond to host and directly publish energy-related data (with its accompanying metadata).

The principles of CROSSDat are: Unified data access; Distributed research data management; Findable; Accessible; Interoperable; and Reusable. The CROSSDat concept [1] describes each of these principles in detail.

We defined the structure of CROSSDat (Figure 1) following the structures of the data spaces from the UVEK and EDA report on data spaces [2]. The main actors and components in CROSSDat are: (1) Data suppliers that deliver data either using their preferred data management system or upload it to the CROSSDat database; (2) The infrastructure operator defines standards and operates the technical



infrastructure; (3) The technical infrastructure includes all the layers for the technical operation of CROSSDat; and (4) the governance, on top of these actors.

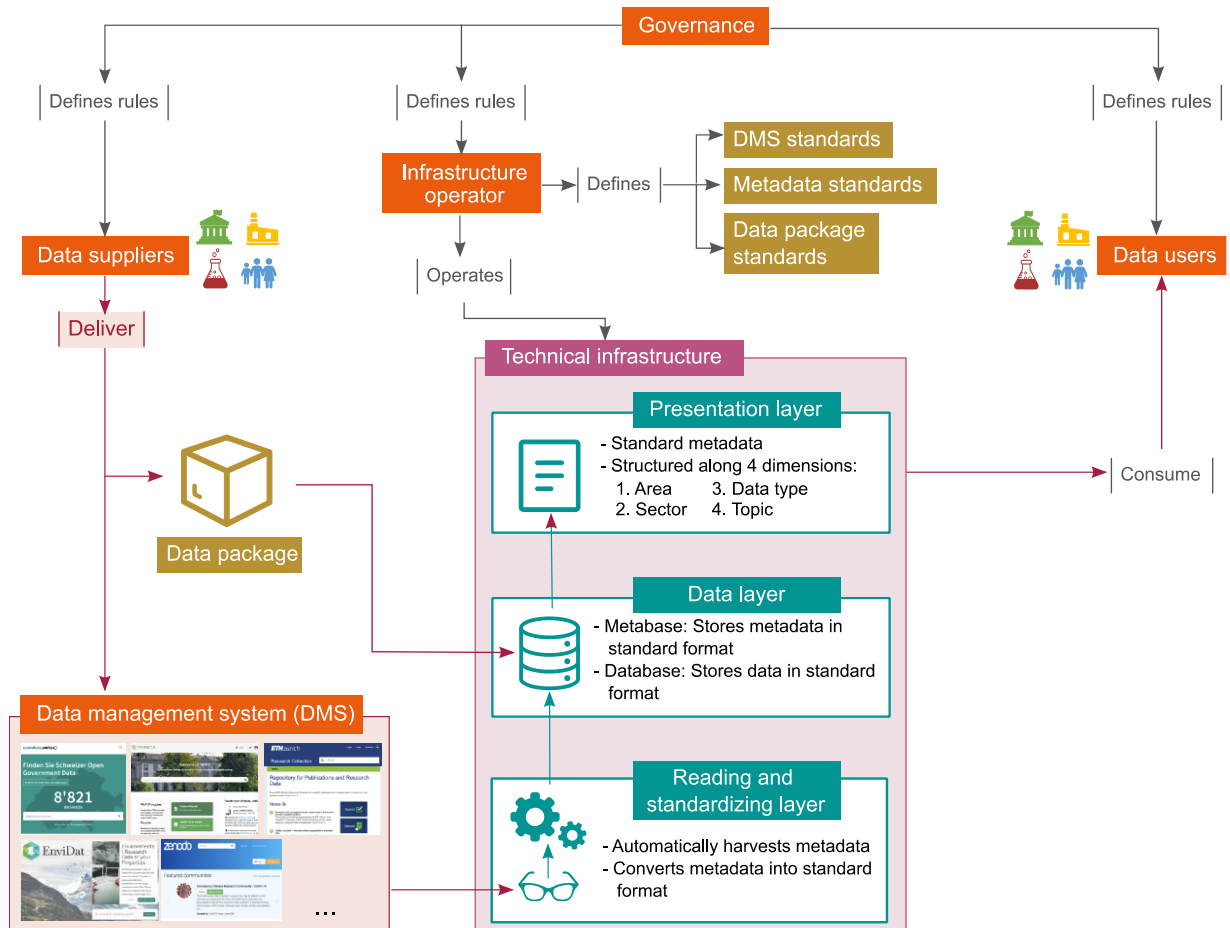


Figure 1: CROSSDat structure

Table 1 presents the activities and corresponding outputs that we undertook to develop the CROSSDat concept [1] and its current implementation.

Table 1: CROSSDat activities, contributors, and outputs

Activity	Contributors	Output
Discussions with SWEET-DeCarbCH WP1 on concept for a joint data platform	A. Marcucci M. Rittmann-Frank and J. Chambers (DeCarbCH)	
Presentation Energy Data Working Group of opendata.ch (6.10.2021)	M. Rittmann-Frank (DeCarbCH), A. Marcucci	
First draft CROSSDat concept using survey to researchers in the SWEET consortia (Section 2.4) and discussion with the Energy Data Working Group of opendata.ch	A. Marcucci	



Workshop with members of SWEET consortia Call 1-2020 to discuss CROSSDat concept (27.01.2022)	CROSS team (J. Dujardin, V. Heinrich, A. Marcucci, E. Panos, S. Yilmaz) DeCarbCH (J. Chambers, E. Linder, M. Neugebauer, G. Guidati) PATHFNDR (S. Pfenninger, C. Schaffner) SURE (B. Thelen, R. Krause)	
CROSSDat concept	A. Marcucci	CROSSDat concept [1] (Appendix 1)
CROSSDat code development using the code from the JASM data platform . This included several changes: <ul style="list-style-type: none"> - Development of the metabase - Front-end development adding filtering capabilities - CROSSDat structure and categories 	A. Marcucci	CROSSDat webpage: https://sweet-cross.ch/crossdat/
Migrating data packages from JASM to CROSSDat	A. Marcucci	JASM data packages in CROSSDat
Harmonization data packages with SFOE standards	A. Marcucci A. Foletti (SFOE)	
New data packages, new structure, and categories	A. Marcucci N. Neugebauer (DeCarbCH)	Data packages in CROSSDat

2.2 CROSS Scenarios

The CROSS scenarios are possible future developments of the Swiss Energy system. They are defined along different dimensions that have a direct or indirect effect on energy use or energy production. The process of defining the CROSS scenarios version 2022-09 was a collaborative effort of the SWEET consortia from Call 1-2020 with an initial workshop and meetings with and feedback from partners from the four consortia (EDGE, DeCarbCH, PATHFNDR and SURE) and the SFOE (Table 2 presents a detailed list of all activities and outcomes). This version of the scenarios was specifically designed to be implementable by the consortia of the SWEET Call 1-2020. However, the CROSS scenarios evolve with the findings from the SWEET consortia and the energy market and policy landscape. Hence, the scenario dimensions are not static in time and can be updated by the SWEET consortia whenever new insights are available. To keep track of the changes in the main assumptions over time, we have established a scenario versioning scheme for the CROSS scenarios. The versioning refers to the updates to the scenario descriptions, underlying data, or key assumptions.

Table 2: CROSS scenarios activities, contributors, and outputs

Activity	Contributors	Output
Workshop on scenarios with 20 researchers from the SWEET consortia call 1-2020 (8.12.2021)	4 participants per SWEET consortium and CROSS team	First ideas for CROSS scenarios
Writing first draft of scenarios based on ideas from the scenarios workshop	CROSS team	First draft scenarios (5.04.2022)



Feedback from SWEET consortia call 1-2020 (April-June 2022)	Directors EDGE, DeCarbCH, PATHFNDR, and SURE SFOE	
Changes from comments from SWEET Consortia Call 1-2020	A. Marcucci	Second draft scenarios (13.07.2022)
Discussions on dimensions of scenarios, storylines, and names (29.08.2022)	SFOE CROSS team	
Writing and refining the storylines for each scenario	E. Panos	Scenario storylines
Changes from comments from SFOE	A. Marcucci	CROSS scenarios v2022-09 (Appendix 2)

CROSS scenarios v2022-09 (Figure 2) comprise four scenarios along two dimensions: Climate policy and energy market integration. In the climate policy dimension, we consider the goal of the Swiss Federal Council to reduce the GHG emissions to net-zero by 2050 [3] with or without compensation abroad. In the energy market integration dimension, we assume high and low integration of Swiss and international energy markets regarding electricity, biofuels, hydrogen, and synthetic fuels. Appendix 2 includes the detailed description of the scenarios [4].

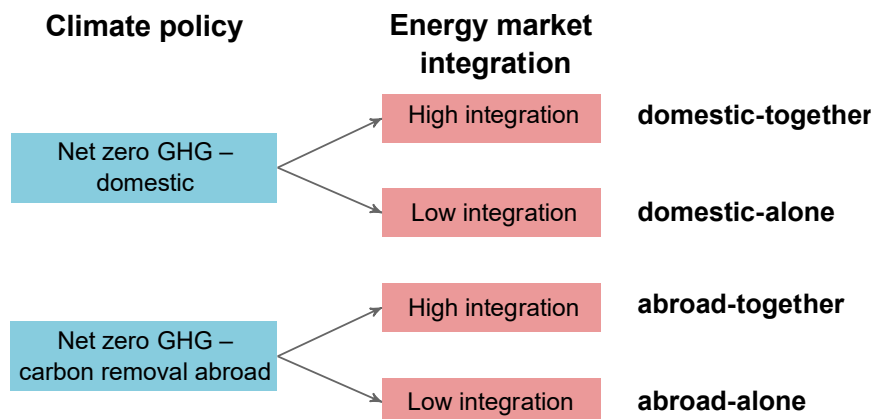


Figure 2: CROSS scenarios V2022-09

2.3 Harmonization of assumptions

We collected and calculated various input parameters for energy system models with the aim to improve the consistency across the research projects in the SWEET consortia. In CROSS, we focused on national energy system models, so the harmonizing assumptions are all at a national scale. These input parameters are intended to be a reference point from which all consortia can further develop their own scenario analyses.

We provide reference values and intervals for: population, number of households, working population, GDP, energy reference area (ERA) and building stock, energy service demands, potential of renewable resources (wind, solar, hydropower and biomass), fuel import prices (oil, gas, hydrogen). Table 3 presents a summary of the estimation, references and resulting data package for each variable. Details on the estimation of the different parameters can be found in Chapters 3-6 of the CROSS Scenarios



Document V2022-09 [4]. As in the case of CROSS scenarios, the harmonized assumptions can be updated with inputs from the SWEET consortia, research, and global and national developments. Therefore, we also implemented a versioning scheme for input parameters.

Besides providing these reference values, we also collected technology assumptions of nine different models to compare their investment costs and efficiencies. This data is now in a [Data package on CROSSDat](#).

Table 3: CROSS harmonized assumptions

Activity	Contributors	Output
Estimation of national macro-economic drivers: Update from JASM assumptions [5] using recent projections for population [6], number of households [7], working population [8] and GDP [9]	A. Marcucci	Population, number of households, working population and GDP (reference, minimum and maximum values for 2020-2050): <ul style="list-style-type: none"> Chapter 3 CROSS Scenarios Document V2022-09 [4] Data package on CROSSDat
Estimation of total ERA and building stock by construction period for residential (single- and multi-family houses) and commercial sectors	A. Marcucci	Total ERA and building stock: <ul style="list-style-type: none"> Section 5.1 CROSS Scenarios Document V2022-09 [4] Data package on CROSSDat
Estimation of energy service demands of space heating (residential, industrial, and commercial); process heat (industrial and commercial); warm water (residential, industrial, and commercial) using an econometric model using population, GDP, or ERA as explanatory variable. Update of transport demand using the 2021 Swiss Transport Perspectives [10]	A. Marcucci	Energy services demands (reference, minimum and maximum values for 2020-2050) <ul style="list-style-type: none"> Chapter 5 CROSS Scenarios Document V2022-09 [4] Data package on CROSSDat
Renewable potential using different studies for Switzerland: <ul style="list-style-type: none"> Hydropower [11] Wind [12]–[19] Solar [13], [20]–[27] Biomass: Update of JASM-Biosweet potentials [28] using CROSS population and GDP projections. This includes wood, manure, green waste, sewage sludge and fossil waste 	A. Marcucci	Renewable potentials <ul style="list-style-type: none"> Chapter 6 CROSS Scenarios Document V2022-09 [4] Biomass: Data package on CROSSDat
Import prices: Update from JASM assumptions [5] using recent projections [29]	E. Panos	Data package on CROSSDat
Comparison of technology assumptions	S. Yilmaz V. Heinrich	Data package on CROSSDat

2.4 CROSS catalog

The [CROSS catalog](#) contains information about existing models and research approaches involved in the different SWEET consortia. The information includes description; developers and contact; facts



(class, spatial, and temporal and sectoral resolution, and coverage); inputs and outputs; and references. Currently the catalog has 53 entries, and it includes a form so that new models can be included. The main source of the information is the data and models survey that we carried out in 2021 with all researchers from the SWEET consortia from Call 1-2020. The survey included questions regarding groups and models, inputs and outputs, and additional information concerning the use of data platforms. We published the **results of the questionnaire** on the CROSS webpage.

We also developed the **visualization** of the input and output connections between the groups. This allows the research community to easily collaborate and find synergies (Figure 3).

- Category selected
- Socioeconomic aspects
 - Energy demand
 - Direct demand of resources
 - Models
 - Infrastructure
 - Energy supply
 - Trade
 - Environment
 - Resource potential
 - Technologies
 - Prices

Model mapping

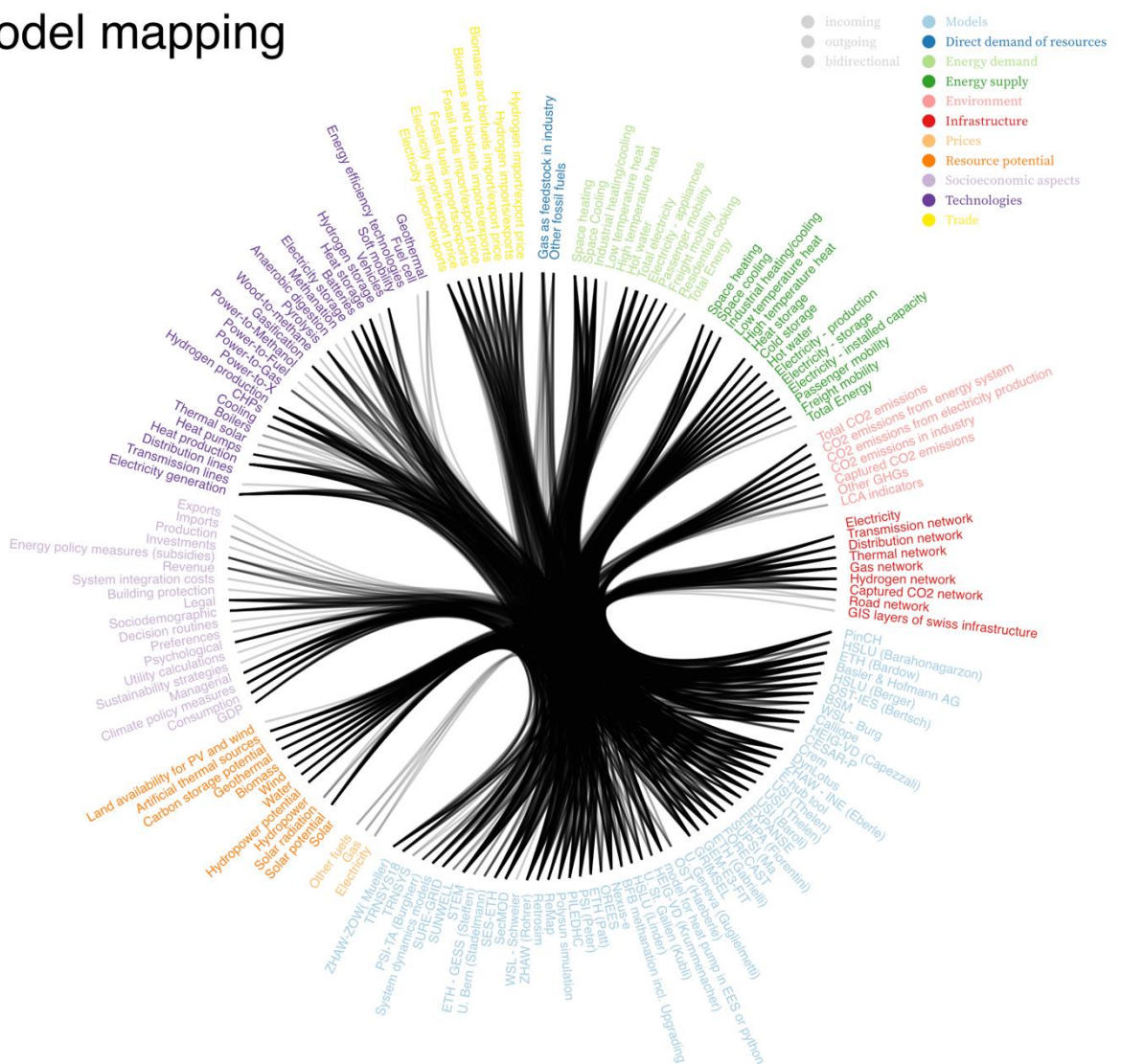


Figure 3: CROSS catalog visualization



Table 4 presents the activities and corresponding outputs that we carried out to develop the CROSS catalog and its visualization.

Table 4: CROSS catalog activities, contributors, and outputs

Activity	Contributors	Output
Survey definition and analysis	A. Marcucci, S. Yilmaz DeCarbCH: M. Rittmann- Frank, J. Chambers	Design of the survey: content, form, and questions
Development of online questionnaire	A. Marcucci	
Survey to all researchers in the SWEET consortia Call-1 2020	Researchers from DeCarbCH, EDGE, PATHFNDR	
Analysis of survey results	A. Marcucci	The results of the questionnaire are published on the CROSS webpage
Data processing from survey, creation of MySQL database	A. Marcucci	Database
CROSS catalog code development	A. Marcucci	CROSS catalog https://sweet-cross.ch/catalog/
CROSS catalog validation	CROSS team	Validation of inputs in catalog with all the teams
SURE models description in catalog	E. Panos	SURE model reference cards in CROSS catalog
Visualization inputs – outputs	Z. Wang A. Marcucci	https://sweet- cross.ch/catalog/about

2.5 First CROSS model result comparison

We compared model results of the CROSS scenarios V2022-09. The comparison involved five models: SES-ETH [30], Calliope [31], Nexus-e [32], STEM [33] and the Empa model [34]. We also included the results from the Zero Basis scenario of the EP2050+ [15]. We compared electricity production (Figure 4) and consumption; hydrogen supply and use; and space heating production. We found important similarities and differences in the results. The main agreements among models are: An increase in electricity demand to around 80 TWh; the need for solar photovoltaics, heat pumps and electric vehicles; and the need for carbon capture and storage. The main differences are in the production and use of hydrogen, and the production of electricity from wind and hydrogen.

Besides the results concerning the energy system, this exercise had other key learnings for the community and future similar activities: The value of well-defined variables for the comparison of results; large contribution of model variety and modelling differences; importance of harmonizing a set of model assumptions to increase the comparability of the results; and the value of comparing modelling results for the further development of the models.

Table 5 presents the activities and corresponding outputs that we undertook to develop the CROSS model result comparison.

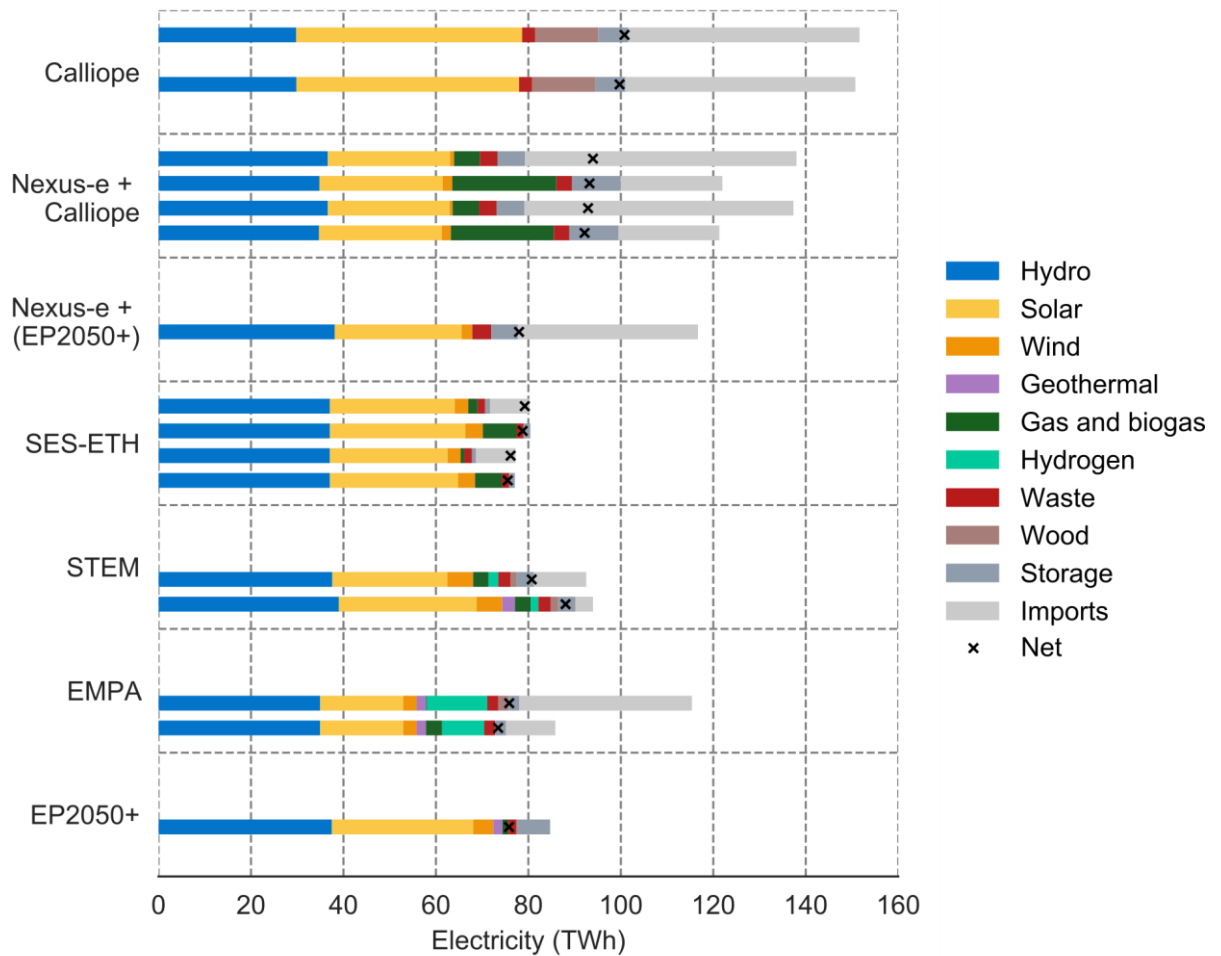


Figure 4: Electricity production in CROSS scenarios. From top to bottom: domestic-together, domestic-alone, abroad-together, abroad-alone

Table 5: CROSS model result comparison activities and outputs

Activity	Contributors	Output
Result template definition	G. Guidati	Result template
Scenario runs	G. Guidati, F. Sanvito, J. Garrison, E. Panos, M. Rüdüsüli	Results from different models
Iterations with modelers after first result comparison, meetings, workshops	Modelling teams, A. Marcucci	
Comparison of results	A. Marcucci	Overview of results comparison

3 Significance

CROSS established a platform that facilitates collaboration among SWEET consortia and communication with different stakeholders. Such platform increases research transparency and



reproducibility of modelling results in the energy domain. Each of the activities in CROSS has a meaningful contribution to the community and to the achievement of the net-zero goal and Switzerland:

- **CROSSDat:** CROSSDat is the first stop point to find and publish research data in the energy field. Having a central platform with open data helps the community move towards open science and increases transparency and accessibility of research findings and modelling assumptions to stakeholders and researchers. Moreover, CROSSDat includes data consolidated by the different modelling teams in the various SWEET consortia, which leads to a high-quality database.
- **CROSS scenarios:** Having harmonized scenarios helps us providing relevant and useful insights to the energy policy discussion from complementary perspectives. For instance, by having a clear definition of the net-zero emissions target (including agriculture and industry), we make sure that our research insights answer the same fundamental question and provide complementary insights.
- **Harmonization of assumptions:** Having reference values for different assumptions increases the comparability of modelling results, which allows interested stakeholders to easier distil relevant policy insights. Moreover, comparable assumptions also contribute to model development since it allows models to benchmark their assumptions and results.
- **CROSS catalog:** The CROSS catalog gives a comprehensive overview of tools and groups in the SWEET consortia, which fosters exchange and networking development. It allows researchers and stakeholders to get a better understanding of the different tools, which tool is suitable for which task, possible synergies and how to connect to each other.
- **First model result comparison:** By comparing the findings from different models using the CROSS scenarios, we could determine similarities and differences in the modelling results. These are informative for both modelers and policy makers. Common results can be interpreted as energy policy priorities since they represent those technologies that all models, despite their different nature, consider part of the energy system to reach net-zero emissions. Of equal or higher value, the process of understanding major discrepancies contributes to both model development and to exploring alternative future developments of the energy system.

4 Outlook

The activities of CROSS will continue as part of the new SWEET-CoSi consortium. Some of the envisioned follow-up activities are:

- **CROSSDat:** We will continue using and developing CROSSDat to enable the integration of relevant data from the researchers in CoSi, other SWEET consortia and other interested stakeholders. We will extend the CROSSDat platform by: (1) Establishing a governance strategy and metadata standards; (2) Defining a data architecture making use of semantic technologies; (3) Extending the CROSSDat front-end, allowing for user registration as well as filtering and improved categorization of data; (4) Making the data in CROSSDat accessible using a queryable endpoint via an application programming interface (API).
- **CROSS catalog:** We will further develop the CROSS catalog by improving its current front-end to allow for an easier update and upload of catalog entries; and enhancing its back-end, in particular, the structure of the input and output data.
- **CoSi Scenarios:** We will develop new scenarios for the co-evolution of Swiss society, economy, and the energy sector following a co-creation process with energy modeling teams and social science and



humanities community in CoSi and outside, as well as with the key stakeholders. These new scenarios aim to serve as general framework for forward-looking analyses in Switzerland, capturing diverse aspects of major overarching developments in society, economy, environment, as well in the technical and political spheres for the period until 2050. As with CROSS the scenarios, the documentation of CoSi scenarios will feature a versioning scheme to track updates to the narratives, the underlying data, and the input assumptions.

- CoSi assumptions: We will continue providing reference ranges for different input assumptions including a technology outlook; macro-economic variables, such as economic growth, population, energy prices; demand behavior, including hourly profiles of industrial, residential heat or different charging profiles of electric vehicles; and other relevant variables. Assumptions will be regularly updated by monitoring the developments in the SWEET consortia, federal offices, and any other relevant stakeholder. As with CROSS scenarios, CoSi-assumptions will have a versioning scheme to facilitate referencing.
- Model results comparison: Within CoSi, we will develop a platform for communicating and comparing modeling results. This platform shall allow stakeholders to find answers from different models and perspectives to relevant matters on the energy transition.

5 References

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Appendix

Appendix 1: CROSSDat concept [version 12.2022]

Appendix 2: CROSS Scenarios and Drivers Definition [Version: CROSS-v2022-09]