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Authors The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.	Francesca Celina, *francesca.cellina@supsi.ch* Jalomi Maayan Tardif, *jalomi.maayantardif@supsi.ch* Matteo Palucci, *matteo.palucci@supsi.ch* Roman Rudel, *roman.rudel@supsi.ch*
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1 Introduction

The ambitious Swiss target to achieve net-zero greenhouse gas (GHG) emissions by 2050 has received substantial attention, and, for instance, recommendations and actions needed for Switzerland were presented by Kirchner et al. (2022) and Boulouchos et al. (2022). Cantonal public authorities are tasked with translating the Federal objectives into regional decarbonisation pathways with actionable policy measures that respect local capacity and resource boundaries, while maintaining support and acceptance from their local voters.

To carry out this task, the cantonal policymakers seek energy system transition models which can be scaled to their region, converging with Federal models while reflecting the specific regional context and narrative. Recognising the heightened need for energy transition models to support cantonal policymaking, WP13 of SURE focuses on bringing the general SURE framework to the cantonal level and complementing it with a tool aimed at regional policymaker end-users. This case study for canton Ticino fits within the general SURE framework in terms of the main objective of i) using models to describe energy system transition pathways and ii) assessing the sustainability and resilience of the resulting energy system through a Multi-Criteria Decision Analysis (MCDA). As in the SURE framework, the cantonal case study emphasises on an early and continuous engagement of stakeholders that will help frame the challenges and opportunities of the energy system transition scenarios. The general framework of the Ticino case study is depicted in Figure 1.

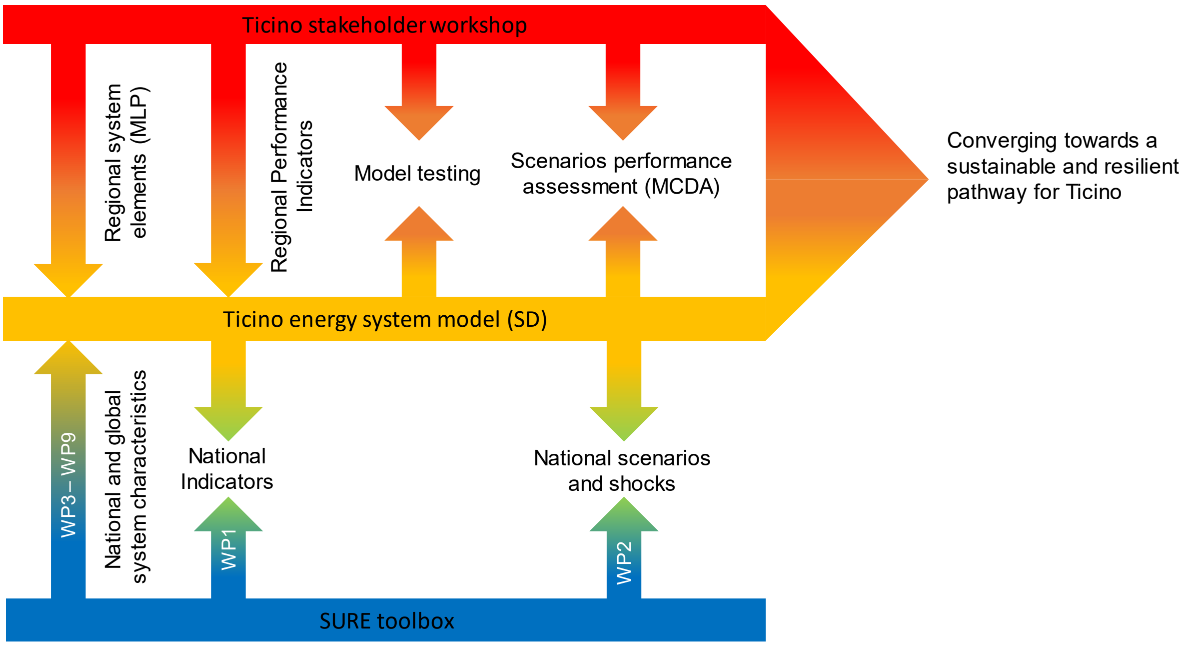

Figure 1: General framework for supporting the formulation of a sustainable and resilient Ticino energy transition.

In this report, we briefly introduce our approach and the principal methodologies adopted for the design and execution of the cantonal case study (Section 2). Section 3 details the activities performed to identify and engage Ticino stakeholders and the outcomes of two stakeholder workshops aimed at gathering their perspectives on the main components of the Ticino energy system. The same section presents conceptual maps of the Ticino energy system, which are based on the components evoked by the stakeholders and supported by the large body of knowledge in the energy system transition field. We conclude by presenting the activities that will be performed in the following years, with the objective of providing a tool with which the cantonal policymakers can explore possible future scenarios and assess them in terms of sustainability and resiliency (Section 4).

2 Approach

Forecasting the long-term future can be a Sisyphean and unrealistic task, as the world constantly changes and evolves (Huntington et al., 1982). Nevertheless, the development of scenarios and their analysis provides means of characterising the future and its uncertainties through methodologically thorough and creative processes. Currently, scenario analysis serves a variety of users and disciplines, such as policymaking, business planning, resource management, and global environmental understanding (Fortes et al., 2015). With the recent rise in the number and heterogeneity of users that seek to draw insights and directives for reining in, keeping in pace with, or pushing for an energy transition, so has grown the panoply of energy transition scenarios that have been modelled over the past decade (Berntsen & Trutnevyte, 2017; Densing et al., 2016; Guivarch et al., 2017; Landis et al., 2019; Prina et al., 2022). However, despite the increased interest in energy transition scenarios, the potential of these scenarios to inform alignment and risk assessment has yet to be fully unleashed (Auer et al., 2021). Some of the hurdles identified have been; a lack of transparency and clarity in the underlying model assumptions, a wide range of methods using non-harmonised datasets on varying spatial and temporal scales, as well as hindered access to outputs that advanced users could use for further work (Yalew et al., 2020: Pfenninger et al., 2018; Chang et al., 2021).

Thus far, the primary methods to model energy systems are Integrated Assessment Models (IAM) and Energy System Optimisation Models (ESOM) (Hirt et al., 2020). While it has been repeatedly asserted that social and political activity plays a vital role in transition processes, according to Li et al. (2015) and Fortes et al. (2015), there have been only a few attempts to bridge socio-technical perspectives and such models. These scholars are among a growing community of researchers and practitioners that argue that energy modelling should go beyond a technology and economics focus and incorporate broader behavioural and social insights (Trutnevyte et al., 2019). It has been suggested that combining insights from IAM and ESOM models with Socio-Technical Energy Transition (STET) models could enhance the capability of capturing features of system complexity, non-equilibrium, uncertainty, tipping points, path dependency, and feedback loops (Hof et al., 2020; van Sluisveld et al., 2020; Bolwig et al., 2020). Amongst the STET modelling frameworks, System Dynamics (SD), Agent-Based Modelling (ABM), and Stock-Flow Consistent (SFC) approaches have been identified to provide these features, which are particularly relevant in the case of a low-carbon energy transition (Hafner et al., 2020). Additionally, some recent work suggests that higher pathway robustness can be achieved by taking advantage of a large ensemble of scenarios representing a diverse assumptions, worldviews, and model frameworks and by applying methods that guide decision-making under uncertainty (Guivarch et al., 2022; Pruyt, 2010).

In addition, since the seminal paper by Voinov and Bousquet (2010) on modelling with stakeholders, a vast and growing body of research has acknowledged that early engagement of local stakeholders and their active contribution to setting model inputs and structure can lay the ground for trust in the model outcomes (Laniak et al., 2013; Becu et al., 2015; Gray et al., 2016; Voinov et al., 2016; Videira et al., 2017; Voinov et al., 2018; van Bruggen et al., 2019). Building the confidence of the end-user is fundamental for prompt, less conflictual and effective decision-making and deliberation aimed at steering the system towards the desired direction and the later implementation of the decisions made. By activating a collective learning process, helping to get a shared understanding of the complexity of the regional energy system, and allowing conflicts to arise (and be effectively managed), the participatory decision-making process can favour social acceptance of novel transition pathways.

Acknowledging these movements in the field of energy transition and scenario modelling, we adopted an exploratory approach for supporting decision-making in the energy transition process of Canton Ticino. The case study will be developed in the following stages:

1. Stakeholder engagement and system mapping – involves recognising and mobilising local stakeholders that will identify the principal elements of the current energy system and those that could play a role in its transition. These stakeholders are also called upon to determine

policies and actions that regional policymakers can implement to impact the system. This stage also includes a participatory reflection on the indicators that can be used to evaluate simulation outcomes according to a multi-criteria perspective.

2. Modelling and validation – a model of the Ticino energy system will be developed such as to encompass the components evoked by the local stakeholders in the previous stage. As the cantonal future energy system is deeply interconnected with the federal pathways, the cantonal model will rely on the SURE toolbox[1] to set global and national technological, economic, and political characteristics and their evolution until 2050 (e.g., fixed and variable costs of technologies and energy carriers, commercial and industrial activities, GDP, national immigration law, etc.).

3. Exploration, evaluation, and convergence – the possibility space (possible futures and actions that can lead to them) will be explored by building scenarios with the stakeholders. The model aims to allow the policymakers to interrogate the model and iteratively generate scenarios to extend their own cognitive abilities while refining their preferred scenario. Finally, using an MCDA approach, a selection of preferable scenarios will be performed.

Progress between these stages is iterative, particularly as the generation of scenarios matching the involved stakeholders' preferences (Stage 3) might show critical system vulnerabilities, requiring some adaptations to the conceptual energy system map drafted in Stage 1.

These planned activities are intertwined with the broader SURE framework, as they are designed for identifying sustainable and resilient pathways to be generated by participatory processes. For example, the Ticino case study plans to incorporate elements and data derived from the national scenarios (WP2) as fundamental boundary conditions. This approach is predicated on the presumption that the Ticino energy system is unlikely to independently establish or exert significant influence over the availability and pricing of technologies. Rather, it is expected to align with trends observed in the Swiss and global markets. Consequently, these factors are regarded as exogenous, and will be mirrored onto the Ticino landscape when simulating the national scenarios within the regional context. Moreover, the outcomes of these scenarios are to be evaluated by means of MCDA. The process of defining the indicators to be used in the MCDA is still ongoing in WP1. In Y2 of the project is planned a workshop with the Ticino "core stakeholders in which an initial set of indicators developed in WP1 will be discussed and rated in terms of their relevance at the CH and TI level. During this exercise will be revealed which indicators are significant to the "core stakeholders", while also observing if the stakeholders would rate the indicators differently for the national and regional scale. Moreover, the stakeholders will be invited to offer suggestions about indicators that might be missing in the original set and that would be relevant at the Swiss level, or in their decision-making process when assessing scenarios at the Cantonal level. The feedback from this session will be transmitted to WP1 for consideration. It might be mentioned that if the Ticino stakeholder identify an indicator that is critical to them, but might not be as relevant at the national level or for most other Cantons (ex: an indicator related to the geographical location of Ticino and its commercial interactions with Italy), then it might be included singularly in the Ticino model being developed.

In addition, in the cantonal case study will be applied principles of socio-technical transition theory, using the Multi-Level Perspective (MLP) as an underlying theoretical framework, which will be embedded in a model that strives to provide insights in quantitative terms using the System Dynamics (SD) approach. More information on these two approaches is provided hereafter.

[1] a) the GEM-E3 general equilibrium macro-economic model from E3Modelling (Capros et al., 2017); b) the Swiss TIMES energy systems model (STEM) of PSI (Kannan & Turton, 2014); c) the spatial building stock model sBSM (Jakob et al., 2013) and the ALADIN mobility model from TEP/Fraunhofer ISI (Plötzet al., 2014); d) the spatial analyses toolbox (SEAT) from TEP; e) electricity and gas grid network models from ETHZ-FEN (Fuchs et al., 2017); and f) the EXPANSE spatial renewable generation model from University of Geneva (Sasse & Trutnevyte, 2019).

2.1 Socio-technical transitions and the Multi-Level Perspective (MLP)

Conceptualising sectors of the economy as socio-technical systems entails adopting a “system view” that encompasses the natural and built components, such as energy resources or infrastructures, as well as societal and institutional elements (Hirt et al., 2020, 2021; Li et al., 2015). The MLP (Geels, 2002; Geels & Schot, 2007) is one of the conceptual approaches of socio-technical transition theory which provide valuable insights into the complex and multi-dimensional nature of energy transitions (Li et al., 2015; Sovacool et al., 2020) and can be elemental in the process of supporting strategic decision-making (Auvinen et al., 2015).

The MLP is particularly suitable to activate a discussion and favour the achievement of a shared understanding of the dynamics underlying a system's components and their role within a transition process, as it conceptualises the system itself, and specifically system transitions, as the result of continuous interactions between i) innovation processes occurring in protected *niches*, ii) socio-technical *regime* elements that keep perpetuating themselves under reinforcing conditions, and iii) *landscape* factors that bring exogenous pressure onto both regimes and niches. Specifically, according to the MLP, socio-technical system transformations can occur when three mutually reinforcing processes take place: the emergence of innovations in protected niche spaces, the weakening of existing dominant configurations in regime conditions, and the emergence of exogenous pressures among the landscape factors. When all niches, regimes and landscapes align towards novel directions, they can create windows of opportunities for socio-technical transitions to emerge and settle, thus replacing previous system configurations. This process of learning, co-evolution and adaptation at multiple levels results in multiple innovations, such as “investment in new infrastructures, the establishment of new markets, development of social preferences, and adjustment of user practices” (Geels et al., 2017).

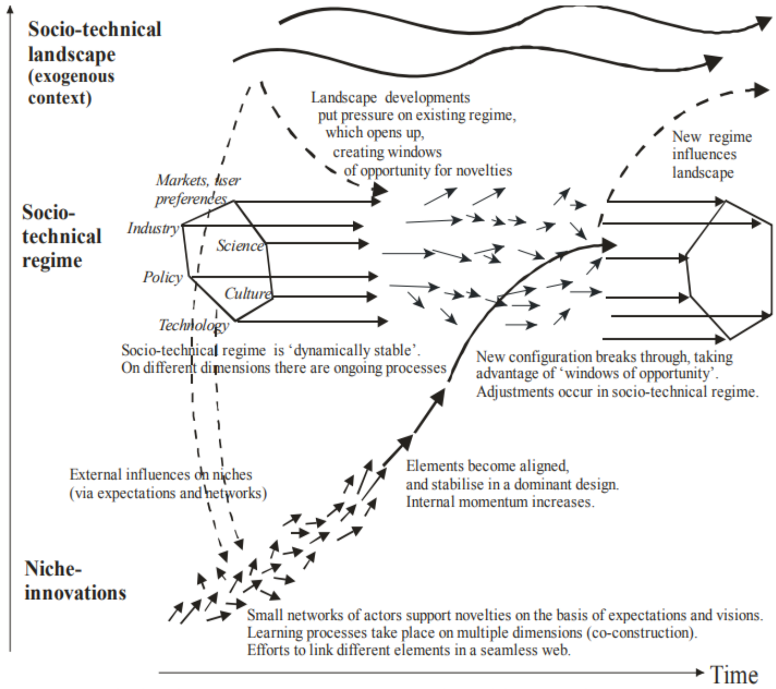

Figure 2: Schematic representation of a socio-technical transition according to the Multi-Level Perspective (Geels & Schot, 2007).

As presented by Hirt et al. (2021), the MLP framework has predominantly been applied at national scales, but contextual factors may result in variations in the regime within a country, potentially affecting niche-innovation adoption and overall transition dynamics. Thus, a more conducive approach could be to view a socio-technical regime not as homogenous but rather as heterogenous within a country. In this context, we deemed its application in a cantonal case study as an interesting and promising opportunity to uncover some of the regional contextual factors. The operationalisation of a conceptual approach such as MLP in quantitative terms and in modelling to inform long-term decision-making, as opposed to understanding structural changes that occurred in the past, has been acknowledged to be difficult (Li et al., 2015). Thus, for the Ticino case study, the MLP approach is complemented by the development of a model based on the System Dynamics approach, which has been used to provide quantitative results for socio-technical energy transition processes (Laimon et al., 2020; Li et al., 2019; Ochoa & van Ackere, 2009; Pruyt, 2014; Zapata Riveros et al., 2019).

2.2 System Dynamics (SD)

Uncovering real-world system dynamics through live experimentation can be a long process and, in some cases, might even risk exposing the population or ecosystems to dangerous or ethically unacceptable situations. Simulations might allow to mitigate such risks and support the exploration of paradigm shifts in complex systems. System Dynamics (SD) modelling, which builds on theories of non-linear dynamics and feedback loops developed in mathematics, physics, and engineering (Forrester, 1961; Ford & Forrester, 1997), has been suggested for the study of the impacts of energy policies, as it allows to investigate effects of specific policies in the underlying system before these are implemented (Martínez-Jaramillo et al., 2022). SD modelling has been found to stimulate a learning process: users receive information and feedback about the dynamics of a system and revise the decisions they make and possibly the mental models that motivate those decisions (de Gooyert et al., 2020). SD has emerged for its potential to enrich quantitative energy models with socio-technical facets related to learning processes, policy, and behavioural changes (Bolwig et al., 2019). With this approach, the model turns into a tool for scenario exploration.

The SD modelling process uses the following tools:

- Mind mapping and Causal Loop Diagrams (CLD) – Mind mapping is a method to visualise concepts and thoughts that help frame them and communicate them to others. Mind maps are well-known for their ability to enable the exploration of ideas and problems in an unconstrained and structured way (Chen et al., 2021). CLDs are conceptual models, that allow mapping of hypotheses of system structures by linking causal relationships between variables. CLDs take the mind maps a step further by conceptually identifying causality and feedback loops. As a visual tool, both mind maps and CLDs help to engage stakeholders during the process of setting a dynamic hypothesis about the system under investigation. CLDs are not the final simulation and are not a mandatory part of the system dynamics modelling process. However, they allow a smoother transition to quantitative stock-and-flow diagrams used for simulations (Dhirasasna & Sahin, 2019). CLDs have been suggested for bringing stakeholders on the same page and favouring the development of a collective understanding of the challenges and opportunities to be pondered upon (Pluchinotta et al., 2022)

- Stock and Flow Diagrams (SFD) – stock and flow diagrams are used in system dynamics to translate conceptual models, such as CLDs, to mathematical ones. Stocks can mathematically be expressed as integrals and are generally considered the state variables of the system. Flows set the rate at which the stocks change. In addition to the stocks and flows, the models use auxiliary variables, which are variables that influence the flows but do not change the mathematical structure of the system. The fourth main component of these diagrams is the delay variables which exist when a casual action occurs later in time. For example, delay variables exist when there is a time lag between policy interventions and a change in a pattern of human behaviour (Lin et al., 2020).

As described by Sterman (2000) and summarised in Dhirasasna & Sahin (2019) and Laimon et al. (2022), the application of SD in policy support research usually involves the following process:

1. <u>Problem definition</u> –identifying research problems and key variables or concepts. Common practices to articulate problems are interviews, stakeholder engagement and quantitative data collection and analysis.

2. Formulation of dynamic hypotheses – explaining the problem dynamics by identifying endogenous variables and mapping system structures. Mind maps and CLDs are commonly used for this step.
3. Formulation of simulation model – translating the conceptual maps into stocks, flows, auxiliary variables, and delays using mathematical models.
4. Model testing – validating the behaviour of the model through i) behaviour reproduction tests, ii) extreme condition tests, iii) structure and parameter verification. Some of these tests can be performed using a participatory approach where field experts from different relevant sectors are called to verify the model outputs and validate its behaviour based on given inputs. If the model behaviour does not match their expectations, then its components are explored in depth, to evaluate if this is due to personal pre-conceptions or a fault in the model.
5. Policy design and evaluation – testing the system's reaction to the application of policies that vary in strength, timing, and combination and comparing their outcomes.

The following section describes Stage 1 of WP13 - Stakeholder engagement and system mapping" - in which the MLP framework was applied to engage local stakeholders in identifying key aspects of their current and future energy system, which constitute the basis for steps 1 and 2 of the SD process.

3 Stakeholder Engagement and System Mapping

Acknowledging the benefits of participatory modelling processes, such approaches have increasingly been adopted within the framework of the energy and climate transition (Kowalski et al., 2009; Eker et al., 2018; Ernst et al., 2918; Moallemi & Malekpour, 2018; Bakken, 2019; McGookin at al., 2021). Such an approach is also adopted in SURE's regional case study for Canton Ticino, which aims at supporting its energy transition and the revision of the cantonal energy plan.

The preliminary activity in a participatory process consists of a stakeholder mapping process, through which we identify the group of stakeholders to engage in project activities. For this purpose, we build on our long-standing engagement in cantonal energy planning processes in Ticino and follow the methodology proposed by Reed et al. (2009). The authors define stakeholder mapping as a process aimed at i) identifying which aspects of given social or natural phenomena are affected by a given decision or action, ii) identifying individuals, groups, and organisations who are affected by or can affect the phenomenon, and then iii) prioritising these individuals and groups for their involvement in a decision-making process. The phenomena we consider in this case are related to a broad conceptualisation of the Canton Ticino energy system, which thus encompasses the evolution of society, the economic system, as well as of environmental conditions. According to such a conceptualisation, the list of the key groups and organisations that we identified as those that can either affect or be affected by system evolution is reported in Table 1. We then classify them depending on their roles, interest, and influence on regional decision-making processes, with the aim of involving them with different rhythms and roles during the case study. Specifically, we adopt a descriptive approach to stakeholder mapping (Reed & Curzon, 2015), exploiting an "Interest/Influence grid" to classify them into four categories (High interest and influence, Low interest and influence, High interest but low influence, and Low interest but high influence) as represented in Figure 3. Finally, we further aggregate the four categories in the two broader categories of the "core" and "support" stakeholders. Core stakeholders are those characterised by high interest in the evolution of the cantonal energy system, as well as high influence in driving its evolution. This stakeholder category is fully involved in all case study activities, including participatory modelling. Active engagement in participatory modelling activities is an intellectual and practical effort, which requires in-depth knowledge of the system being modelled, personal and institutional engagement, as well as time to conceptualise it as a system of interlinked systems. The "support" group of stakeholders is instead composed of the remaining stakeholders, who either have low interest or influence, or both. They will be involved at a later stage, supporting the validation of the model in terms of the main components and behaviour. They will also be invited to explore pathways collectively and assess their implications for a set of relevant indicators previously identified in a participatory workshop.

Table 1 Stakeholders identified through stakeholder mapping activities.

Category	Stakeholder institution	Type of institution	Involved person(s)
Core stakeholders	Cantonal Office for Energy	Public – cantonal office	Head
	Cantonal Office for Climate, air, and renewable energies		Head
	TicinoEnergia	Association supporting the implementation of cantonal energy policy	Director
	Azienda Elettrica Ticinese	Cantonal utility company	Director, grid asset manager
	EnerTI	Association of regional utility companies	President
	Parliamentary commission on Energy – Canton Ticino	Politicians	President
Support stakeholders	Cantonal Office for Economic Development	Public – cantonal offices	Not involved yet
	Cantonal Office for Mobility		
	Cantonal Office for Social support		
	SwissEnergy	Public – federal office	
	Associazione Città dell'energia	Association of municipalities	
	Cc-Ti – Camera di commercio, dell'industria, dell'artigianato e dei servizi del Cantone Ticino	Associations of private companies	
	Associazione Industrie Ticinesi (AITI)		
	Camera Ticinese dell'Economia fondiaria (CATEF)	Associations of building owners	
	APF – HEV Ticino		
	Società svizzera impresari costruttori (SSIC – TI)	Associations of building developers	
	Swiss Association of Real Estate Investment Fiduciaries (SVIT Ticino)		
	Pro Natura Ticino	Environmental NGOs	
	WWF Ticino		
	ATA (Associazione Traffico e Ambiente - VCS)		

INFLUENCE		
	Low interest, High influence **(*Support* stakeholder group)** Cantonal offices (Economic Development, Mobility, Social Support)	**High interest, High influence** **(*Core* stakeholder group)** Cantonal offices (Energy, Climate, air and renewable energies) Association supporting the implementation of cantonal energy policy Cantonal utility company Association of regional utility companies Politicians
	Low interest, Low influence **(*Support* stakeholder group)** Associations of municipalities Associations of private companies Associations of buildings owners Associations of building developers	**High interest, Low influence** **(*Support* stakeholder group)** Environmental NGOs

INTEREST

Figure 3: Classification of the identified stakeholders according to the "Interest-Influence" grid.

Core stakeholders will help identify challenges and key elements that play a role in the energy transition and validate the model's general structure and assumptions. Then, together with "support stakeholders", they will be involved in scenario exploration and evaluation with a multi-criteria assessment approach. The participatory process will allow reviewing assumptions of the developed model and validating resulting system behaviour, increasing the chances that the model helps identify trade-offs in social, technical, economic, and environmental realms relevant to model users. While scenarios are used extensively for communication about climate change mitigation, little is usually known about the interpretation of these scenarios by end-users (Xexakis & Trutnevyte, 2021). The participatory approach, instead, allows us to iteratively solicit the core stakeholders throughout the process, thus reducing the gap between what modelling provides and what the end-user needs, which is especially crucial when it comes to specific policy questions and modelling of political or societal paradigm changes (Süsser et al., 2022).

Five topics of interest will be investigated with the stakeholders, each of which aims at collecting information, perspectives, and needs of the group. The topics can be summarised as follows:

1. ***Key system components***: using the MLP approach to perform an overall representation of the regional energy system's components and identify elements that could play a role in the system transition processes with a long-term perspective.
2. ***Actionable policy tools***: identify variables or policies, either internal to the regional energy system or external to it, that are relevant to the core stakeholder group and which they would be interested in dynamically manipulating to explore their impact on the system.
3. ***Scenario performance indicators***: identify the indicators that, from the stakeholders' perspective, are needed to assess the performance of a scenario.
4. ***Energy system feedback loops***: a causal loop diagram which represents prominent feedback loops among the identified components (technologies, practices, policies) of the cantonal energy system will be proposed to the core stakeholders. The exploration of the system, as well as its performances on the selected indicators, will serve both to develop a common understanding of the dynamics of the system, as well as to validate the feedback loops and adapt them if need be.
5. ***Scenario creation and selection***: core and support stakeholders will be invited to create their own scenarios by adjusting the policy tools available at the cantonal level, as well as a selection of external variables, controlling their intensity, timeframe, and combinations. The outcomes of these scenarios will be assessed and compared, entering a phase of consensus building aiming to converge towards a sustainable and resilient roadmap for the Ticino energy system.

At the time of drafting the present report, two workshops with the core stakeholder group have been carried out, investigating topics 1 and 2, and their outcomes are briefly reported in this section. At this point, the main objective of these workshops was to collect raw information from experts of the Ticino energy system while avoiding, as much as possible, influencing the outcomes with pre-conceptions and personal biases of the SUPSI researchers.

3.1 Topic 1 – Key system components

The session focusing on Topic 1 was inspired by the work of Ulli-Beer et al. (2017), who adopted the Multi-Level Perspective (MLP) on socio-technical transitions by Geels (2007) as an overarching theoretical framework. The entire core stakeholder group gathered on January 19, 2022, for a two-hour online meeting. The discussion started with a general presentation of the SURE framework and the objectives of the Canton Ticino case study. Before entering the subject of the MLP perspective, the floor was opened to the participants' main questions and expectations in the context of the Swiss Energy Transition and methods to model it and extract meaningful indicators for decision-makers. A selection of comments brought by the attendant of the workshop, translated from Italian, is reported in Table 2.

Table 2 A selection of comments by core group stakeholders about their expectations on WP13 modelling activities.

Topic	Comment by core stakeholders
Energy transition modelling	There are many different models and multiple scenarios: what is the added value of this model? The difficulty is in representing the complexity of the system. Perhaps it is better to focus on the relationships between the components of the system.
	Can you include factors outside the model? For example, social aspects, political aspects, mentality, etc.?
Pathway scenarios	It is important to understand what the starting conditions are. What are the assumptions under each scenario? What is the reference scenario? When you apply a shock, against what base case do its effects compare?
Shock scenarios	I want to understand better what these shocks are. How are they delimited? Is it in terms of lack of raw materials, power supply, or something else? We should be careful to avoid redundancy of efforts: some problems are already addressed by OSTRAL, the Organisation for Power Supply in Extraordinary Situations.
Indicators	Is the analysis based on energy or economic aspects? I am interested in understanding the effects of incentives and measures.

Expectations and comments regarding energy transition modelling and key elements of the SURE approach (pathways, shocks, indicators) highlighted the interest of the core stakeholders in the capacity of a model to capture socio-political factors such as actor agency, social acceptance, political feasibility, shifts in social behaviour, and the impact of policymakers on the system. Such interest of model end-users, such as policymakers, is consistent with the findings of a study by Süsser et al. (2022), during which the priorities of model users were assessed. It is also in line with the study by Geels et al. (2020), which presented current limitations to model-based low-carbon scenarios. The feedback also emphasised the importance of the growing trend in the energy system and scenario modelling field, which shifts from “black box” models to open and transparent models (Pfenninger et al., 2018) in which assumptions and data are clear and easily accessible to the individuals, such as policymakers, who will use the results to support their decisions. The stakeholders also asserted the value of including scenario performance indicators outside the economics realm. Finally, some comments could be interpreted as supporting the development of a tool in which the policymakers can test themselves the implementation of incentives and measures, playing with their intensity, timing, and combinations.

Following the discussion about the expectations and needs of the core stakeholder group, the MLP conceptual framework and its terminology and concepts were introduced as the basis for the workshop activities. This stage aimed at identifying key elements characterising energy system transitions (Figure 4) in terms of:

- regime elements characterising the cantonal energy system.
- the most relevant and promising innovation processes that have already emerged in niches or they expect to emerge at the cantonal level.
- the landscape conditions affecting the regime and the developed niches within it.

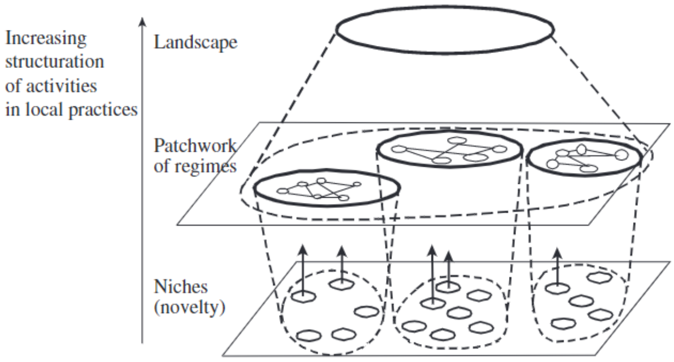

Figure 4: Multiple levels as a nested hierarchy (Verbong & Geels, 2007).

Core stakeholders were invited to reflect on phenomena that could occur in the mid-to-long-term future, namely by the years 2035 and 2050. Specifically, workshop participants were invited to answer the following three questions:

1. Which sub-systems to consider as components of the cantonal energy regime?
2. Which are the most relevant innovation processes (niches) that will influence the cantonal energy system in the mid-to-long term (2035, 2050)?
3. Which are the most relevant external factors (landscape) that will influence the identified sub-systems and innovation processes in the mid-to-long term (2035, 2050)?

Feedback from the stakeholders was collected through sticky notes on Google Jamboard, which were elaborated on individually and then commented on at the group level. An example of the raw information gathered during the workshop is reported in Figure 5.

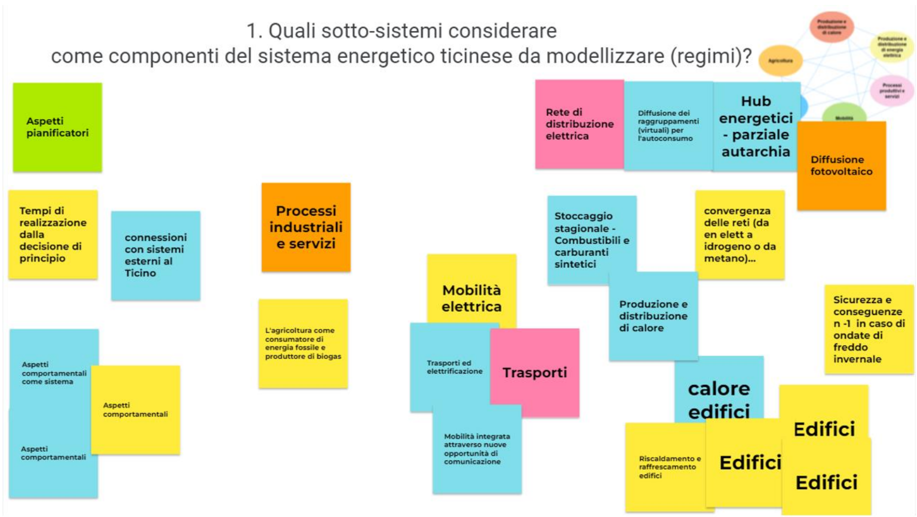

Figure 5: Sample of the Google Jamboard used to interact with the core stakeholders during the workshop (in Italian).

The following table reports the resulting niche, regime, and landscape factors, as summarised in our analysis (complete lists of the obtained materials are reported in Appendix A). Most of the innovation processes (niches) identified by the core stakeholders refer to technological innovation in the production and distribution of energy; a few niche elements also hint at underlying processes of diffusion within society, such as those about the electrification of mobility, ICTs and novel mobility-as-a-service schemes, and the diffusion of self-consumption communities exploiting photovoltaics and local storage capacities. Only two niche elements identified by the core stakeholders are strictly related to the evolution of individual and collective practices, namely the diffusion of teleworking and home-office practices and the changes in food and shopping behaviour.

Table 3 Key elements that characterise the Canton Ticino energy system from the MLP perspective emerged from Topic 1 activities with the core stakeholders.

	Key components of the Canton Ticino energy system
Innovation processes in niches	Convergence of energy vectors (hydrogen, gas, electricity) Syngas Hydrogen Co-(Tri-)generation Nuclear fusion Electrification of mobility PV, storage, and self-consumption communities Fuel cells for heating Seasonal heat storage Biogas production ICT Home-office practices Changes in individual behaviour and practices (food, shopping, etc.) Changes in industrial and commercial practices (ESG) Transition to a service economy mobility-as-a-service
Regime sub-systems into dynamic equilibrium conditions	Heat production and distribution Electricity production and distribution Industry and services Mobility Buildings Agriculture
Landscape factors	Climate change Winter cold waves CO_2 and climate protection policies Health crises Migration (and related cultural change) Re-population of valleys and secluded regions Ageing of the population Land planning choices Digitalisation, artificial intelligence, blockchain Geopolitical tensions Decisions by other countries Authorisation times Market regulations

Although most of the above elements are not surprising, this first stage did serve to confirm which sectors should be the focus of the model, which innovation processes should be considered to simulate system transitions, and which external factors to consider. This information, which is depicted in Figure 6 , lays the ground for the next steps, in which these elements and the link between them will be explored in depth.

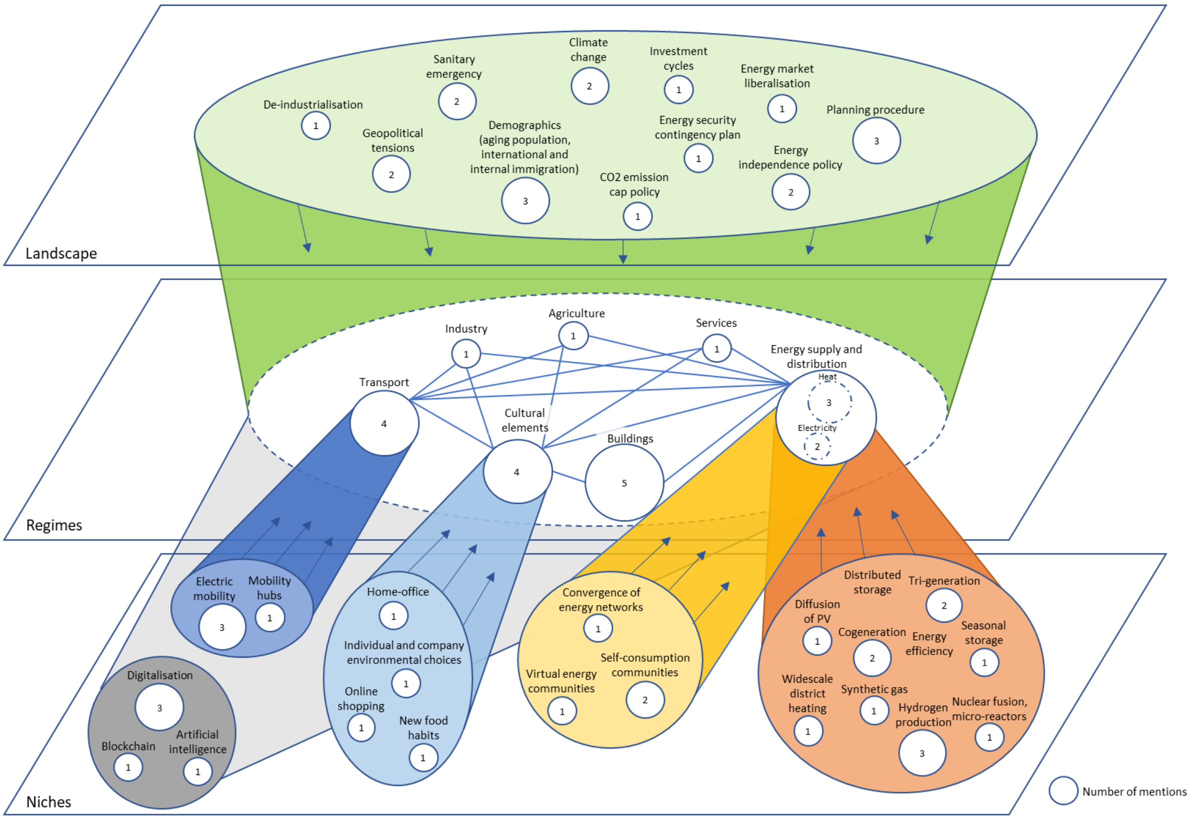

Figure 6: Key elements mentioned by the core stakeholders

3.2 Topic 2 – Actionable policy tools and variables

This exercise was inspired by the En-ROADS climate simulator[2] (Sterman et al., 2013; Siegel, 2018; Rooney-Varga et al., 2020), which is an SD model that allows to explore the impact of policies — such as electrifying transport, pricing carbon, and improving agricultural practices — on factors like energy prices, temperature, air quality, and sea level rise. En-ROADS is equipped with an interactive dashboard that represents all the key system elements users can manipulate by simply moving dynamic sliders. Setting a slider value for each element of interest means setting the model assumptions for a simulation: as the user changes the assumptions on the different elements, the effects are shown via charts and selected indicators. While the users "act on the sliders" and explore the outcome of different inputs, they learn how the system responds and get an understanding of the complex, non-linear, and occasional unexpected effects of such variations.

[2] https://www.climateinteractive.org/en-roads

Figure 7: The interactive dashboard of the online En-ROADS climate simulator developed by Climate Interactive/MIT Management Sustainability Initiative. The system elements that users can act upon to set simulation assumptions are represented through sliders.

To guarantee that the tool is informative to the user, it is important that it provides its users with the right variables to act on – namely, the elements that they believe are relevant to the future energy system and upon which they think someone, internal or external to the regional energy system, could exert an influence by taking specific actions. For this reason, we believe that the selection of the system elements to act upon (the “sliders”) must be performed together with the potential users of the model and loyally mirror the ensemble of events and actions that they might consider while making decisions under uncertainty.

The workshop was performed in person on May 17, 2022, with all the core stakeholders previously involved. A discussion was stimulated by means of a graphical representation of a dashboard with “slider” elements that reproduced the En-ROADS example, which was introduced at the start of the workshop to clarify the goals of the meeting and the expected outcomes. The identified elements in Workshop 1 were used to populate a preliminary proposal regarding “macro-level sliders", which the decision-makers could potentially manipulate to perceive the impact of general macro-level trends via the modelling tool interface. The "macro-level" sliders, as illustrated in Figure 8, were designed to represent broad technological advancements (such as electrification and efficiency improvements) and societal and economic developments (including behavioural shifts, urbanization, market liberalization, and de-industrialization). These macro-level sliders were strategically employed to initiate discussions, as they pertained to the system elements previously identified by our same stakeholders during Workshop#1, conducted four months earlier. This step not only served as a recap of the prior workshop but also offered the opportunity to reconsider if any elements had been overlooked. Furthermore, it demonstrated the continuity of our engagement with stakeholders, emphasizing that each workshop and the eventual Ticino energy system model are built upon the insights they contribute.

In the second phase of Workshop#2, the discussion centred on the "micro-level" sliders, as depicted in Figure 9. The objective here was to delve deeper into each potential development and identify specific technologies and societal behaviours whose diffusion the core stakeholders think that they could facilitate or hinder through the application of policies. Furthermore, participants were encouraged to propose policies and measures that could be implemented at the Swiss and cantonal levels (CH/TI) to stimulate or discourage the diffusion process. Initial ideas for incentives and restrictions were provided in the booklets to guide stakeholders and stimulate their responses. Thus, stakeholders were invited to add their own ideas, as well as modify or cancel the initial suggestions if they found them inapplicable, with explanations.

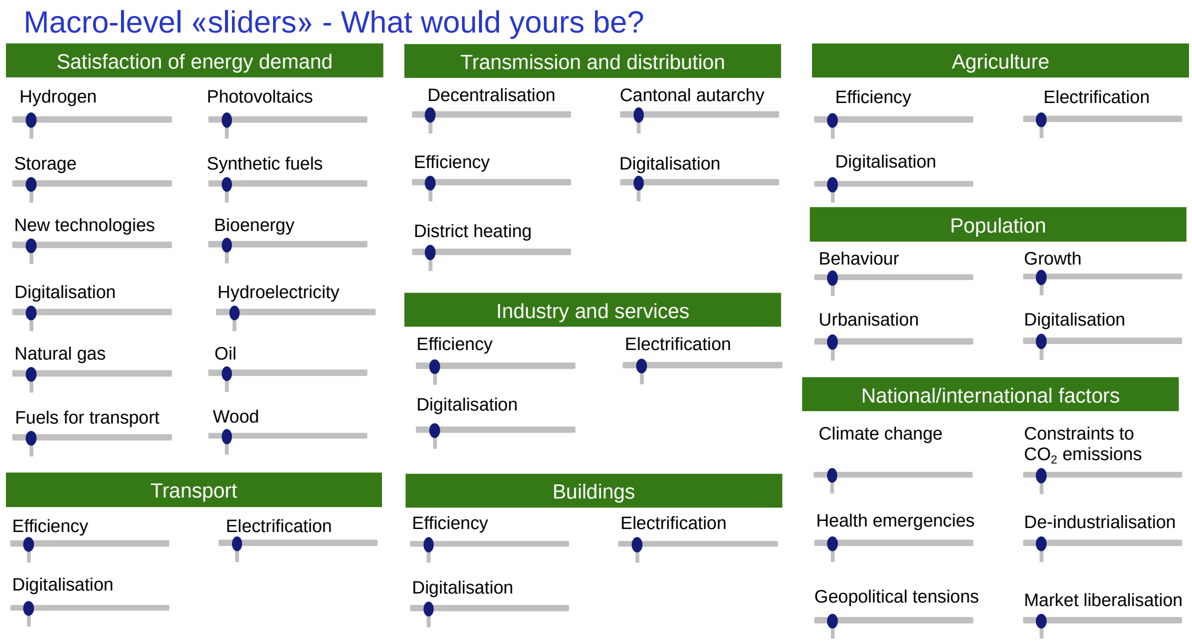

Figure 8: Example of macro-level "slider" elements derived from Workshop 1 (translated from Italian). Core stakeholders were invited to revise, integrate, and refine elements as they deemed relevant.

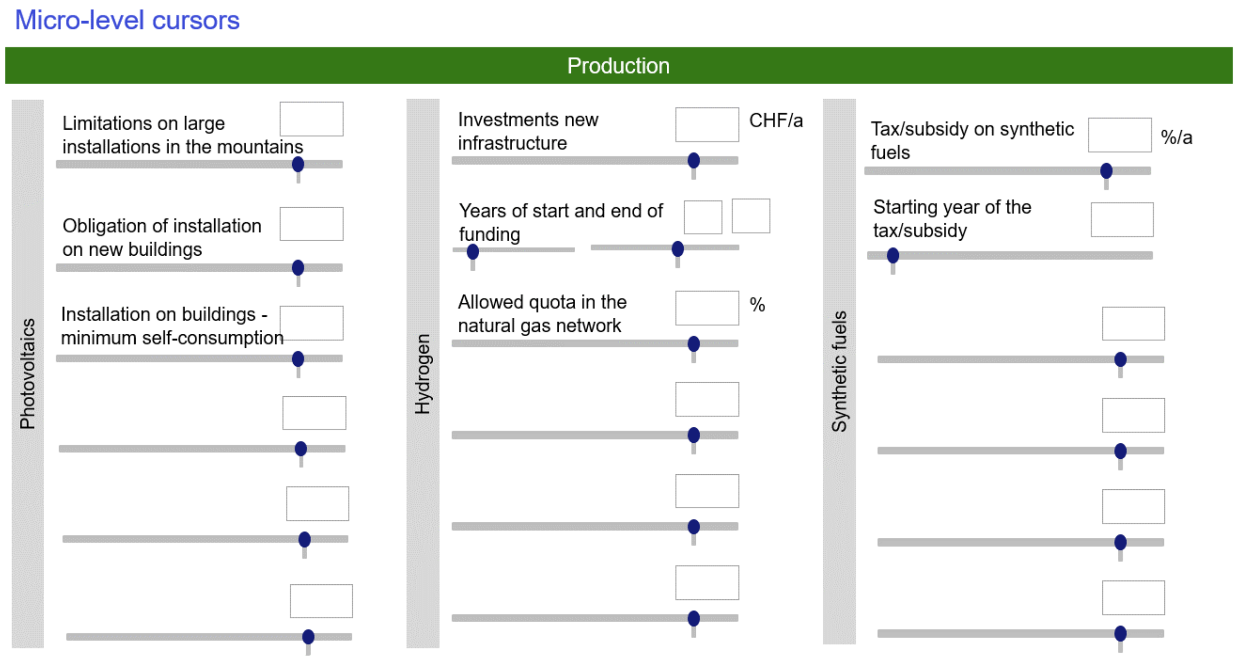

Figure 9: Example of micro-level "slider" elements derived from Workshop 1 (translated from Italian). Core stakeholders were invited to revise, integrate, and refine elements as they deemed relevant.

This process allowed us to filter the system components identified in the first workshop and scrutinise them, such as to recognise which the stakeholders could act upon, as opposed to the components that would be included in the model of the system but will not be available for direct manipulation by the user. The full set of elements that emerged through the workshop is reported in Appendix B.

3.3 System Mapping

Informed by the insights garnered from our two core stakeholder workshops, we embarked on the creation of a mind map that outlines the conceptual structure of the Ticino energy system. These maps incorporate elements derived from workshops 1 and 2, enriched with selected components and connections informed by the expertise of our research team and relevant literature on System Dynamics and System Dynamics models in the context of energy transition (Ahmad et al., 2016; Bolwig et al., 2019; Felix Teufel et al., 2013; Selvakkumaran & Ahlgren, 2020; Li et al., 2015). It is crucial to emphasize that the maps presented in this report should not be viewed as finalized models complete with identified quantifiable variables and parameters; instead, they represent tentative visual interpretations that encompass niche, regime, and landscape elements as discussed by the stakeholders. These interpretations are integrated with key elements sourced from pertinent literature. The process of linking these elements and making preliminary assumptions about correlation and causality is an iterative one. Some additional initial mental maps, developed for the purposes of visualization and discussion between researchers and stakeholders, are available in Appendix C.

To enhance visual clarity, the following system maps depicted in the following figures consolidate or simplify certain key components of the Canton Ticino energy system as mentioned by stakeholders. For instance, specific carriers, generation technologies, and demand sectors are described generically, denoted by subscripts "j" for carriers and subscripts "i" for generation technologies. Following standard System Dynamics graphical conventions, the mind map diagrams in these figures employ symbols and rules to facilitate interpretation:

- an arrow with a "+" indicates that if the cause variable increases, the affected variable increases as well.
- an arrow with a "-" sign indicates that if the cause variable increases, the affected variable decreases.
- two parallel lines on an arrow indicate a lag/delay.

An important assumption in the current system map of the Ticino energy system is that the occurrence A significant assumption within the current system map of the Ticino energy system is that gaps in the supply and demand of any energy carrier can trigger a sequence of actions on both the energy demand and supply sides, albeit with some delays. As storage occupies a transitional role between demand and supply, as it consumes a carrier to provide it later when needed, it is positioned as a pivotal element within the energy supply and demand system. This assumption is visually represented in Figure 10, referred to herein as the Carrier Balance Deltoid (CBD), inspired by a typical generation capacity expansion model as discussed in a review by Ahmad et al. (2016).

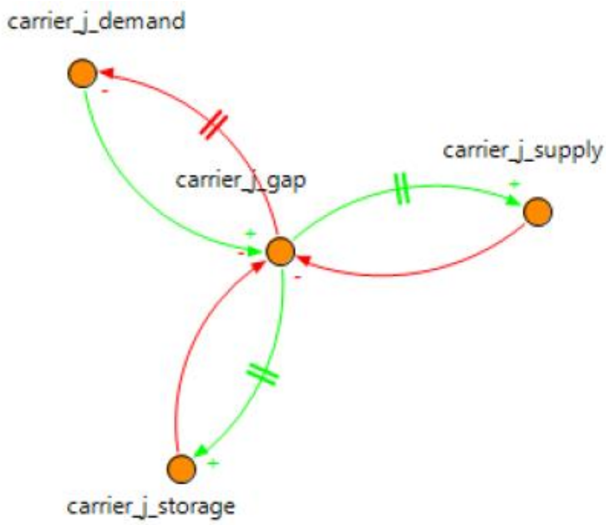

Figure 10: Simplified interplay between demand, supply, and storage of an energy carrier (Carrier Balance Deltoid).

The identification of key elements influencing energy demand, supply, and storage is exemplified in Figure 11, focusing on the electricity energy carrier. The elements of the CBD are highlighted within a red circle.

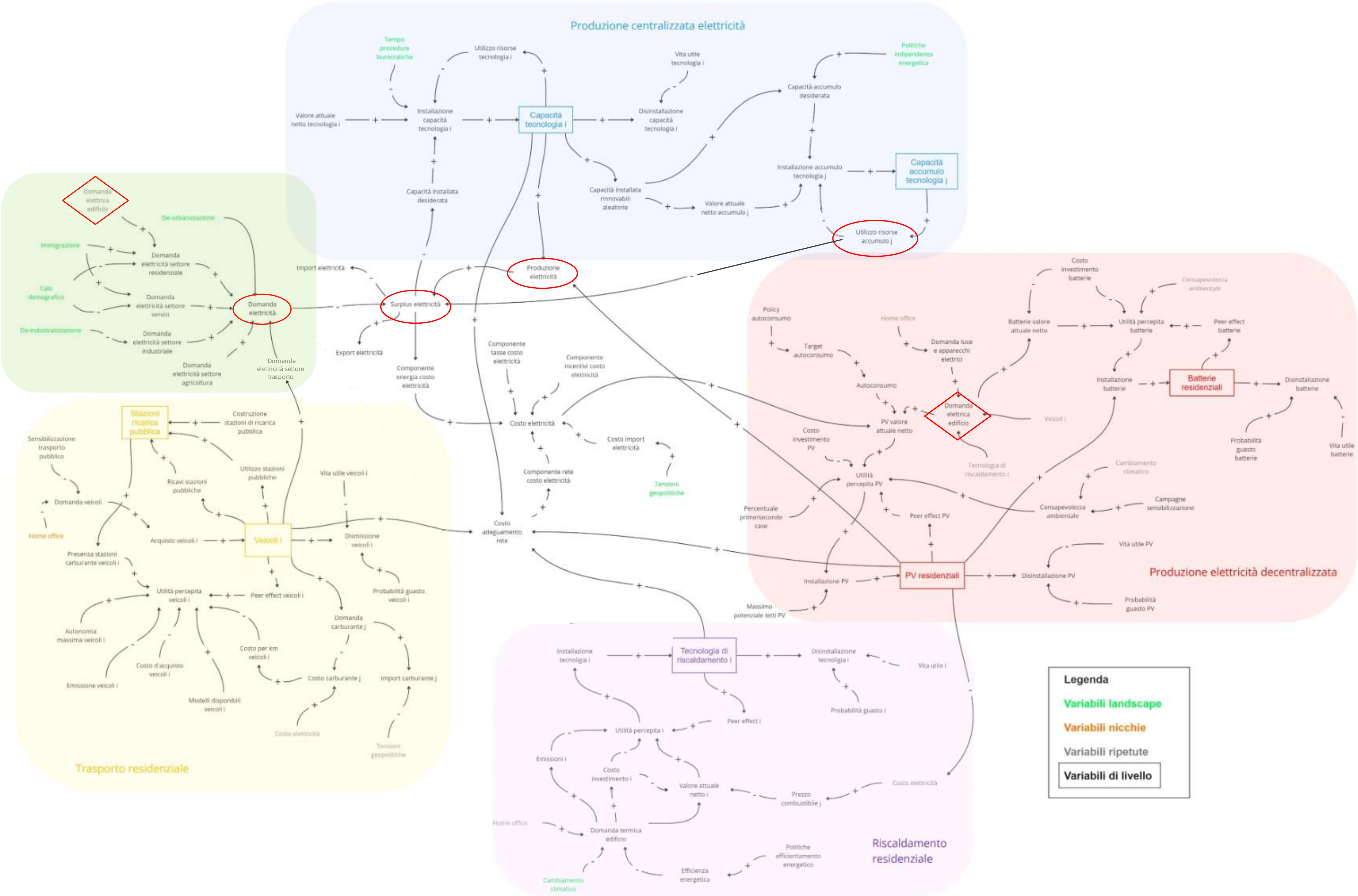

Figure 11: System mapping of the Ticino energy system

Figure 12 provides a closer examination of a segment of the previous figure, where electric demand aggregates from five distinct sectors: i) residential, ii) commercial services, iii) industrial, iv) agriculture, v) transport. These sectors, recognized as regimes during workshop #1, also align with the level of disaggregation presented in the annual energy balance monitor for the canton[3]. This sectorial disaggregation into these categories establishes a recognizable starting point for interactions with the core stakeholders.

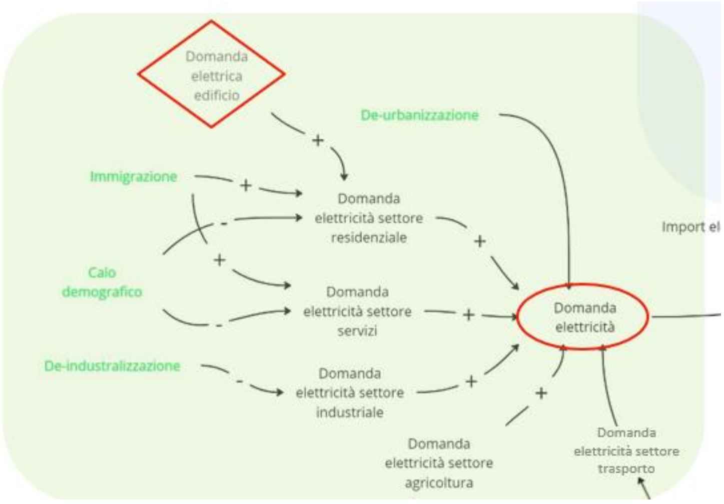

Figure 12: snapshot of the sectorial disaggregation forming the electricity demand

The elements that form the electric demand and supply of the residential sector, highlighted in a red rectangle n Figure 12, are further depicted in detail in Figure 13. It is assumed that the primary elements of electric demand in this sector encompass: i) appliances and lighting, ii) electricity-based heating technologies, iii) electricity-based private transport. A notable element in Figure 13 is the introduction of the perceived utility of a technology (highlighted with a blue diamond shape), along with the depiction of various economic, technological, environmental, and social aspects believed to influence the decision to adopt a technology, in this case PV. This concept allows for the mapping of assumptions regarding the expected influence different policies exert on technology diffusion. For instance, a policy requiring a minimal level of self-consumption ("policy autoconsumo") would influence the design of PV systems and, consequently, the perceived utility of residential PV systems ("utilità percepita PV"). This mapping also enables the visualization of correlations between different technologies. For example, an assumption linking the evolution of electric-based heating ("Technologia di riscaldamento") and vehicles ("Veicoli") to household electricity demand, and subsequently, the appeal of installing a photovoltaic system.

[3] https://www.oasi.ti.ch/web/energia/consumo-per-settore.html

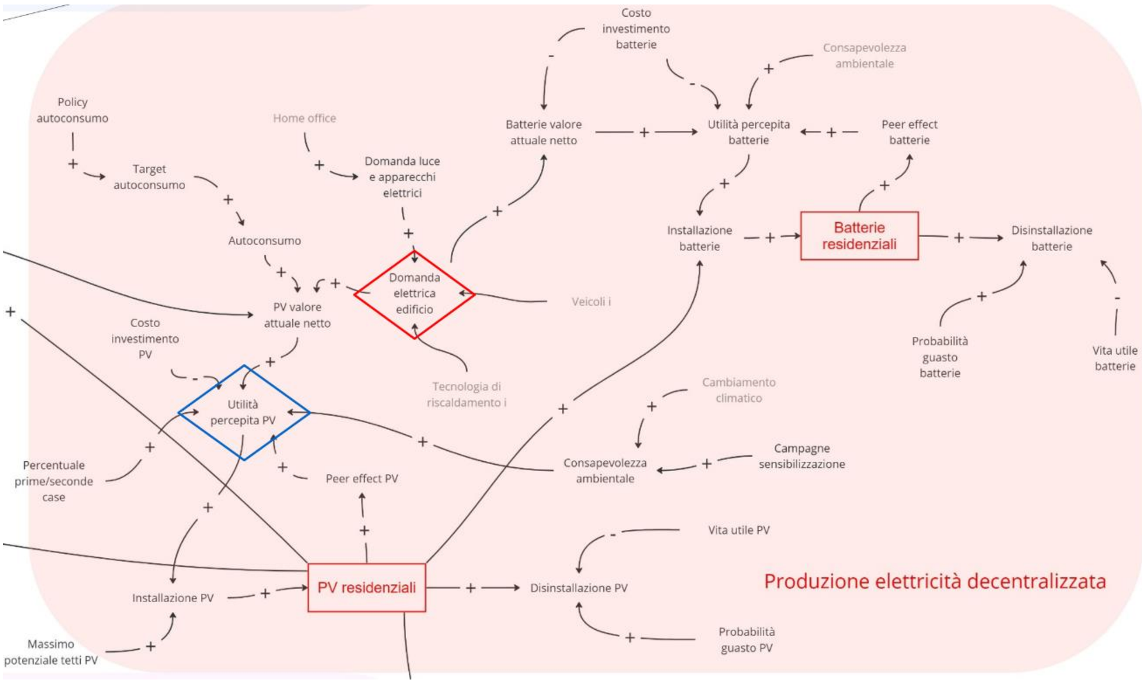

Figure 13: mapping of the electric demand and supply of the residential sector

As previously noted, these system maps serve as qualitative visual representations of the system and act as tools for effective communication with various stakeholders. They also form the foundation for identifying key elements that core decision-makers in the Ticino energy sector believe should be integrated into a model capable of providing quantitative results on the short-term and long-term effectiveness of various policies on the system.

4 Conclusions and next steps

In this deliverable, we presented the general approach of WP13 and the reasoning behind it. This is followed by the description of five topics that will be explored with a stakeholder group consisting of key cantonal policymakers in the energy sector. The specific activities that have been undertaken so far to engage a core subset of this stakeholder group and elicit their perspectives regarding the regional energy system are extensively detailed, using the MLP approach as a basis for structuring the discussions. The process of linking the components collected during the workshop by drafting a conceptual map is exemplified by sample diagrams representing i) the general energy supply and demand interplay, ii) the boundaries to local resources and the interdependencies between local generation technologies, iii) the economic, environmental, social, and technical factors that can influence the adoption or abandonment of a generation technology, iv-v) the economic, environmental, social, and technical factors that can influence the adoption or abandonment of residential heating and mobility technologies.

To maintain continuity and fluidity in the exchanges with the local stakeholders, while avoiding creating a heavy burden on the core stakeholders, workshops are planned to occur within 4-6 months intervals. So far, the first two topics about “key system components” and “actionable policy tools and variables” have been explored. In the next years, the remaining three topics will be investigated. Topic 3 about “scenario performance indicators” will be addressed in the next workshop, which should take place in early 2023, once the SURE scenarios, shocks, and indicators have been finalised. Core stakeholders will be presented with the scenarios and shocks elaborated in SURE's WP2 and with the indicators elaborated in WP1 and will be asked to provide their perspective from the cantonal policymaker point of view. We will investigate how the scenarios and indicators are interpreted by regional policymakers, and if there are any additional indicators that could be better suited for the formulation of a cantonal energy plan. The outcomes of this session will be shared with the SURE framework, which might provide insights that will enchain some adaptations to the national scenarios, shocks, and indicators. Topic 4 on “energy system feedback loops” will be brought to a wider stakeholder group once a “beta version” of the Ticino energy system model has been developed. At this point, the model will serve as a basis for discussions and will be explored such as to build a shared understanding of the way the different system components interact and react under the effect of the actionable policy tools evoked by the core stakeholders (Topic 2). An in-depth discussion at this stage might also call for a revision and re-iteration of the previous participatory sessions. Finally, the simulation tool created from the culmination of the previous sessions and modelling efforts should facilitate undertaking a process of building consensus around the most acceptable sustainable and resilient energy transition pathway for Ticino (Topic 5 “scenario creation and selection”).

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Appendix A – Stakeholder workshop 1

The following tables report the full set of elements that emerged during workshop 1 with the core stakeholders. Elements were identified individually and then individually reported on Google Jamboard sticky notes, followed by a brief explanation. A plenary discussion then aimed at identifying commonalities or -if any- differences between them. The outcome of workshop activities, based on the analysis and summary by the research teams, is reported in Table 3 of the deliverable.

Table 4 The list of elements that emerged during workshop 1 with the core stakeholders.

Question	Proposals by core stakeholders reported on sticky-notes	Number of occurrences
Which sub-systems should we consider as components of the cantonal energy regime?	Land planning issues	1
	Power plant realisation times (from ideation to entering activity)	1
	Connections with systems outside the canton	1
	Behavioural aspects	3
	Industrial processes and services	1
	Agriculture (consumer of fossil fuels and biogas producer)	1
	Electric mobility and transport	2
	Transport	1
	Electric grid	1
	Photovoltaics	1
	Seasonal storage	1
	Synthetic fuels	1
	Heat production and distribution	1
	Convergence of different grids (electricity, natural gas, hydrogen, etc.)	1
	"N-1" security level for the electric grid, in case of cold Winter waves	1
	Buildings	3
	Heating demand for buildings	1
	Heating and cooling demand for buildings	1
Which are the most relevant innovation processes (niches) that will influence the cantonal energy system in the mid-to-long-term (2035, 2050)?	Reduction in typical investment cycles' duration	1
	Wide diffusion of district heating	1
	Production of hydrogen	1
	Production and distribution of synthetic gases	1
	Co- and tri-generation	1
	De-centralised (domestic) storage plants	1
	Reversible fuel cell heat engines	1
	Artificial intelligence	1
	ICT and digitalisation	2
	Blockchain	1
	Diffusion of home-office practices	1
	Virtual groups for electricity self-consumption	1
	Energy hubs for partial autarchy	1
	Energy efficiency in buildings and appliances	1
	ICT-supported multi-modal mobility	2
	New food behaviours	1

Question	Proposals by core stakeholders reported on sticky-notes	Number of occurrences
Which are the most relevant external factors (landscape) that, in the mid-to long-term (2035, 2050), will influence the identified sub-systems and innovation processes?	New actors in the energy field	1
	Re-population of secluded valleys	1
	Digitalisation	1
	Social networks and online shopping	1
	New technologies for energy production (e.g., nuclear fusion)	1
	Climate change (need for adaptation)	2
	Demography	1
	Ageing of the population	1
	Migrations (and related cultural change)	2
	Health emergencies	1
	Regulations limiting CO_2 emissions	1
	Diffusion of voluntary corporate ESG standards, change in business culture	1
	Liberalisation of the electricity market	1
	De-industrialisation	1
	Geopolitical tensions	2
	Energy autonomy and self-sufficiency, interaction with bordering countries	2

Figure 14 reports the way workshop outcomes were visually summarised to favour immediate understanding by the core stakeholders. Large bubbles represent regime components of the current energy system, which are in dynamic equilibrium with each other. Small, dotted bubbles instead represent innovation processes emerging in niches, while the landscape factors affecting both regime components and niches are represented through black arrows. Such a visualisation of the outcome of workshop 1 activities was offered to the core stakeholders at the start of workshop 2 activities.

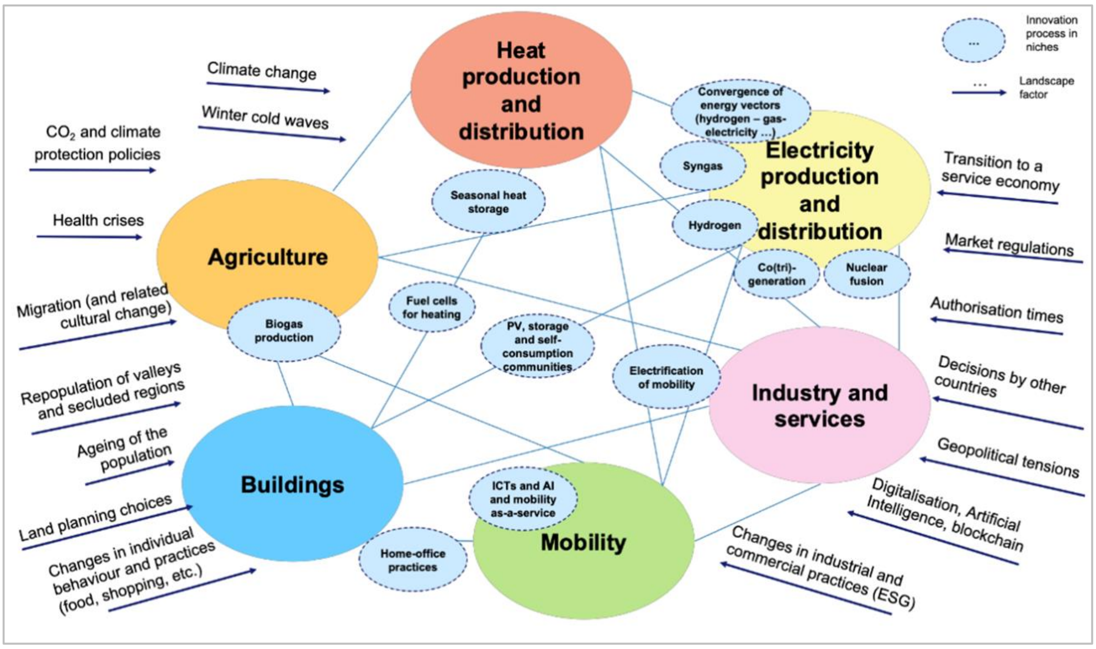
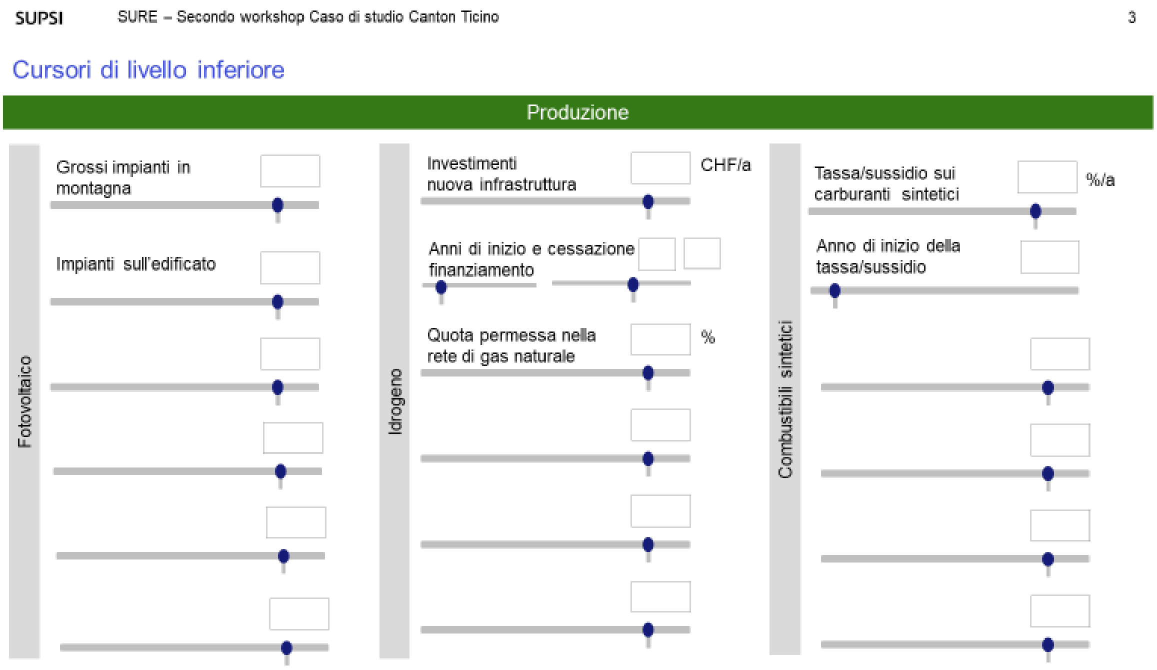
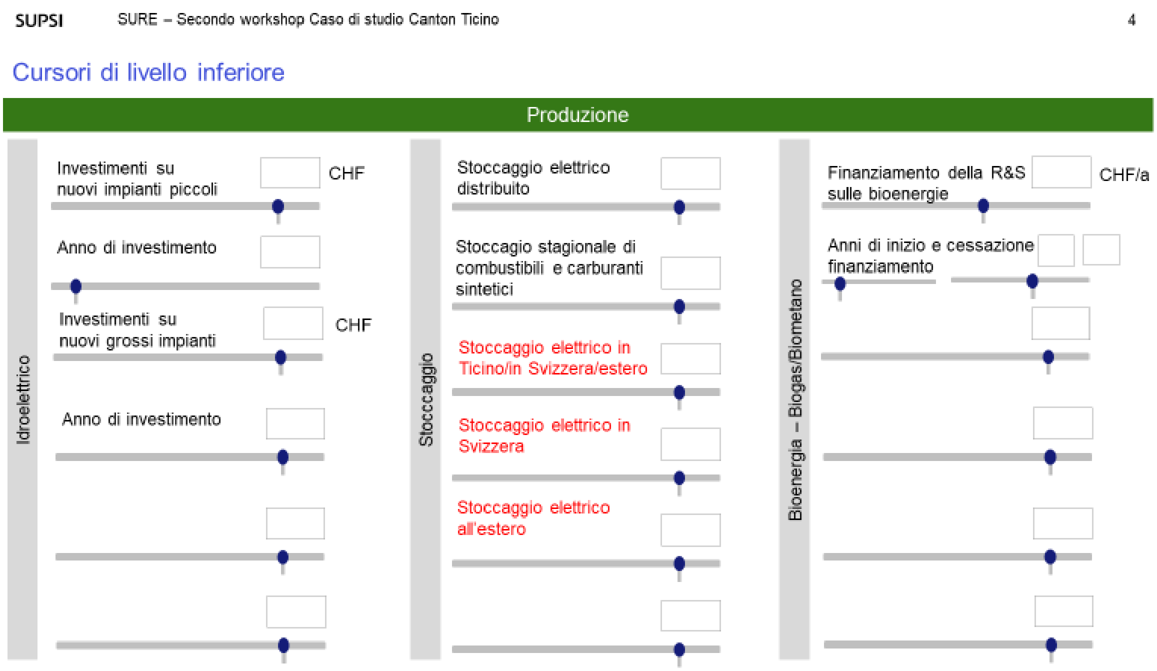


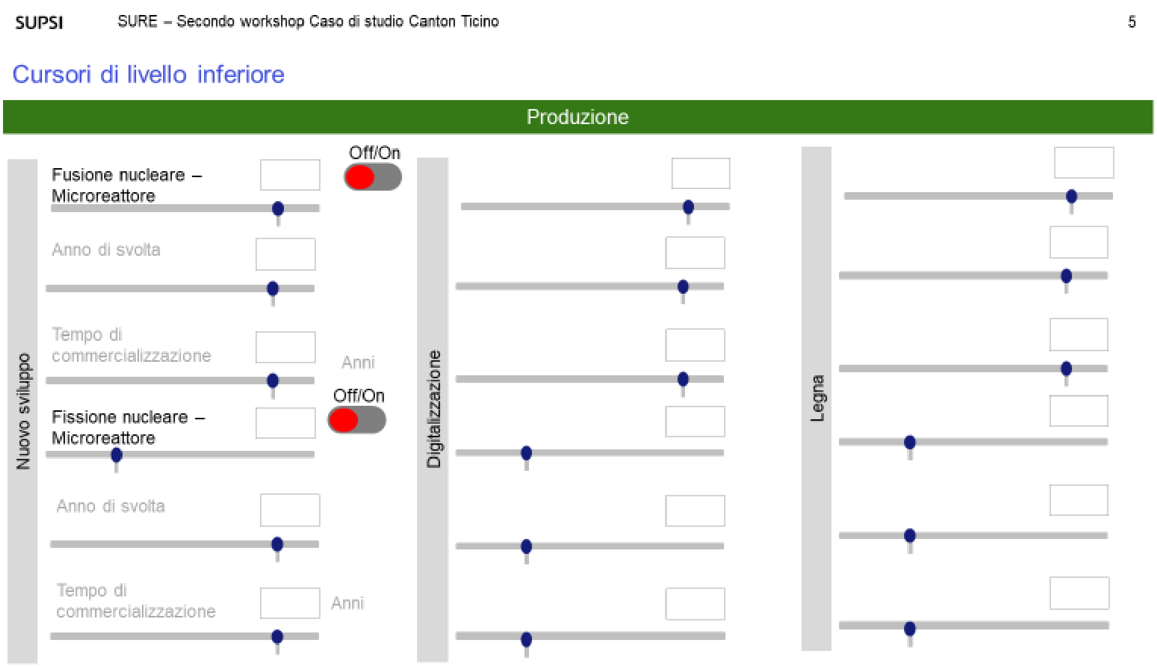
Figure 14: Summary visualisation of the outcome of *Stage one* activities.

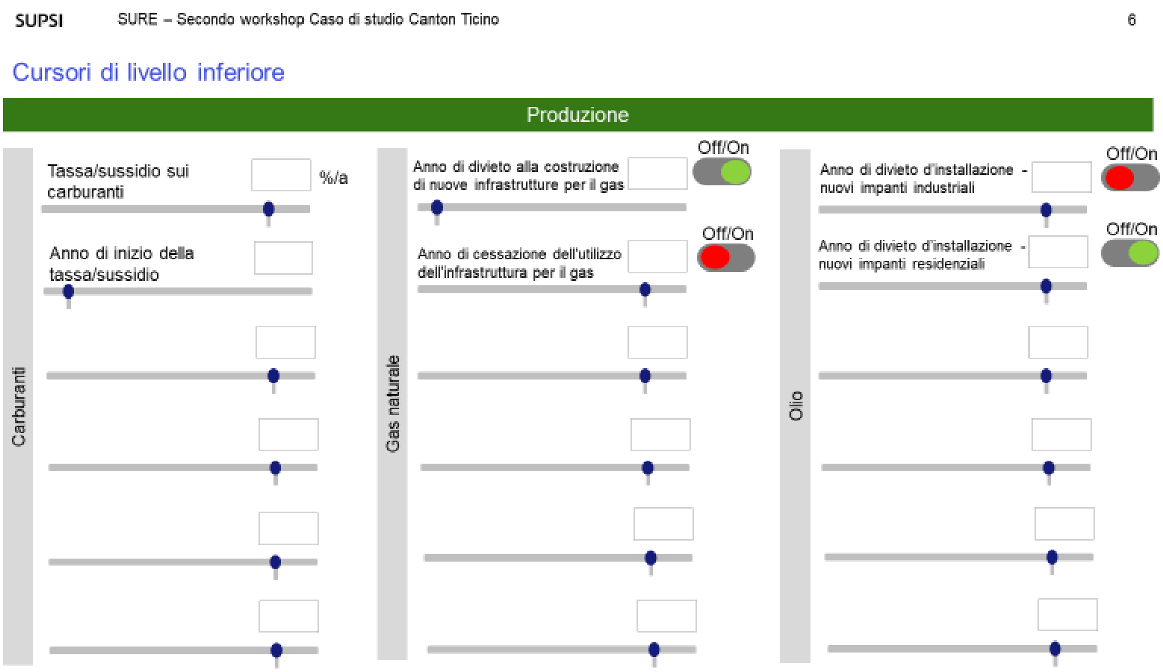
Appendix B – Stakeholder workshop 2

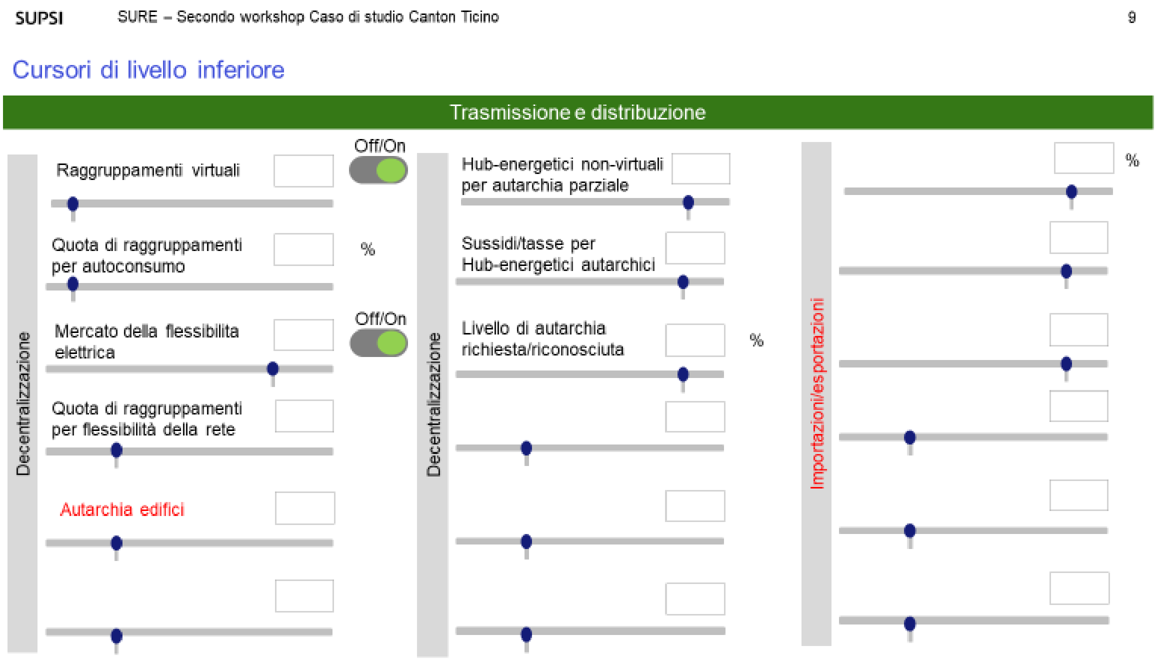
In the following figures can be found some of the raw material developed along with the “core stakeholder”.

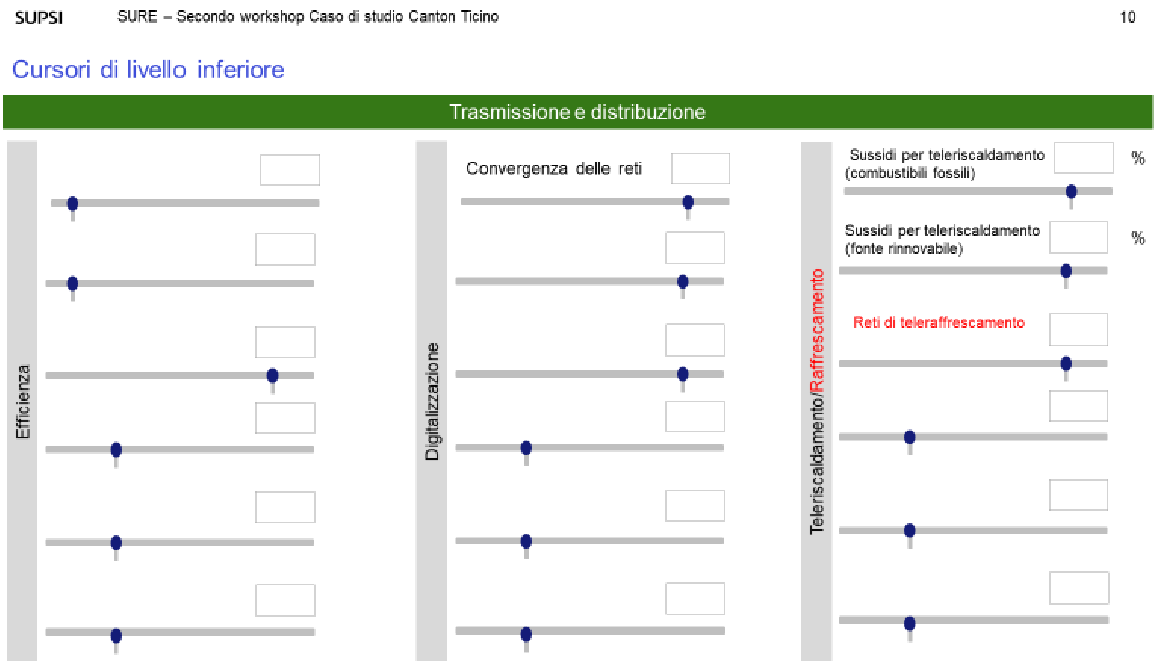

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
3
Cursori di livello inferiore
Produzione
Fotovoltaico
Grossi impianti in montagna
Impianti sull'edificato
Idrogeno
Investimenti nuova infrastruttura
CHF/a
Anni di inizio e cessazione finanziamento
Quota permessa nella rete di gas naturale
%
Combustibili sintetici
Tassa/sussidio sui carburanti sintetici
%/a
Anno di inizio della tassa/sussidio


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
4
Cursori di livello inferiore
Produzione
Idroelettrico
Investimenti su nuovi impianti piccoli
CHF
Anno di investimento
Investimenti su nuovi grossi impianti
CHF
Anno di investimento
Stoccaggio
Stoccaggio elettrico distribuito
Stoccagio stagionale di combustibili e carburanti sintetici
Stoccaggio elettrico in Ticino/in Svizzera/estero
Stoccaggio elettrico in Svizzera
Stoccaggio elettrico all'estero
Bioenergia – Biogas/Biometano
Finanziamento della R&S sulle bioenergie
CHF/a
Anni di inizio e cessazione finanziamento

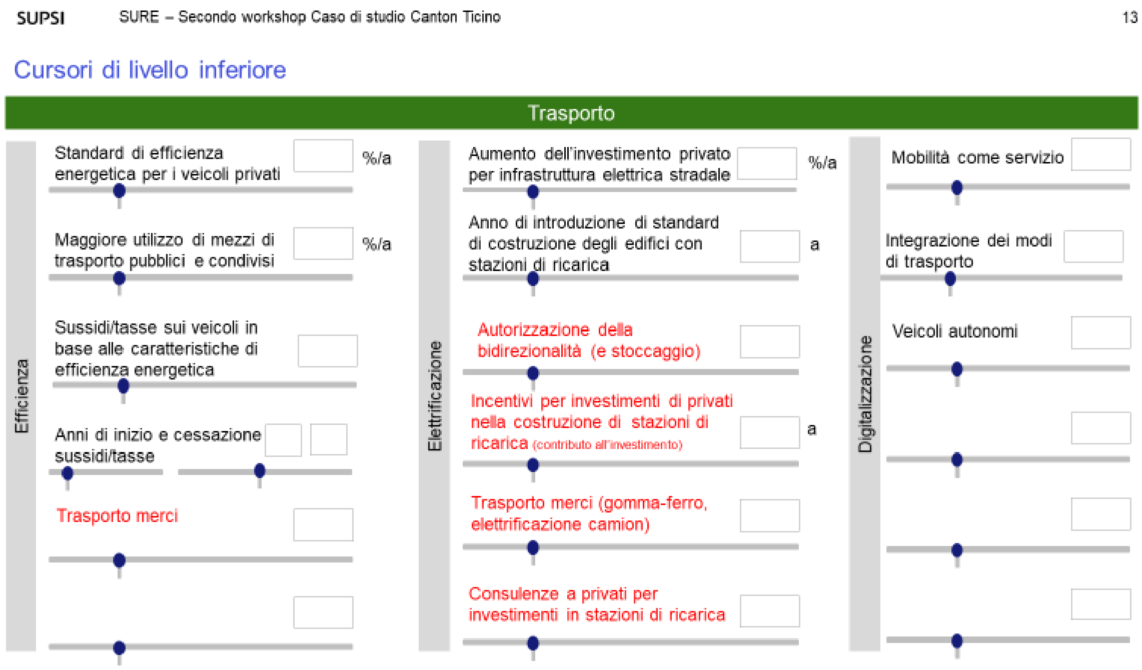

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
5
Cursori di livello inferiore
Produzione
Nuovo sviluppo
Fusione nucleare – Microreattore
Off/On
Anno di svolta
Tempo di commercializzazione
Anni
Fissione nucleare – Microreattore
Off/On
Anno di svolta
Tempo di commercializzazione
Anni
Digitalizzazione
Legna

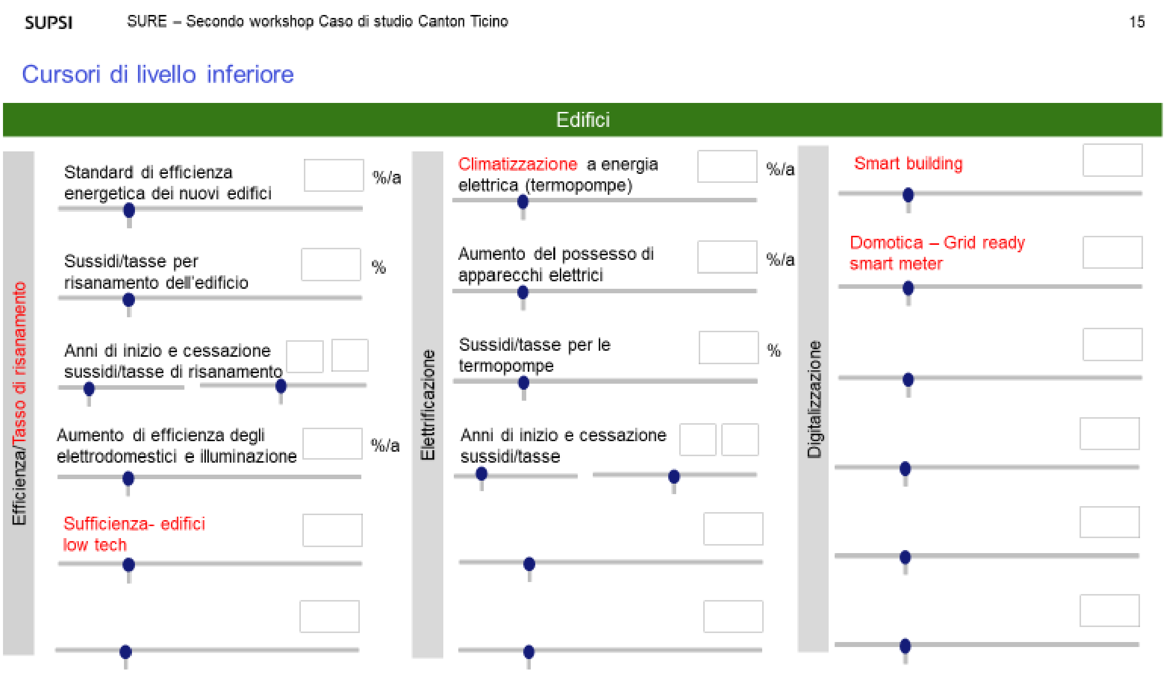

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
6
Cursori di livello inferiore
Produzione
Carburanti
Tassa/sussidio sui carburanti
%/a
Anno di inizio della tassa/sussidio
Gas naturale
Anno di divieto alla costruzione di nuove infrastrutture per il gas
Off/On
Anno di cessazione dell'utilizzo dell'infrastruttura per il gas
Off/On
Olio
Anno di divieto d'installazione - nuovi impianti industriali
Off/On
Anno di divieto d'installazione - nuovi impianti residenziali
Off/On

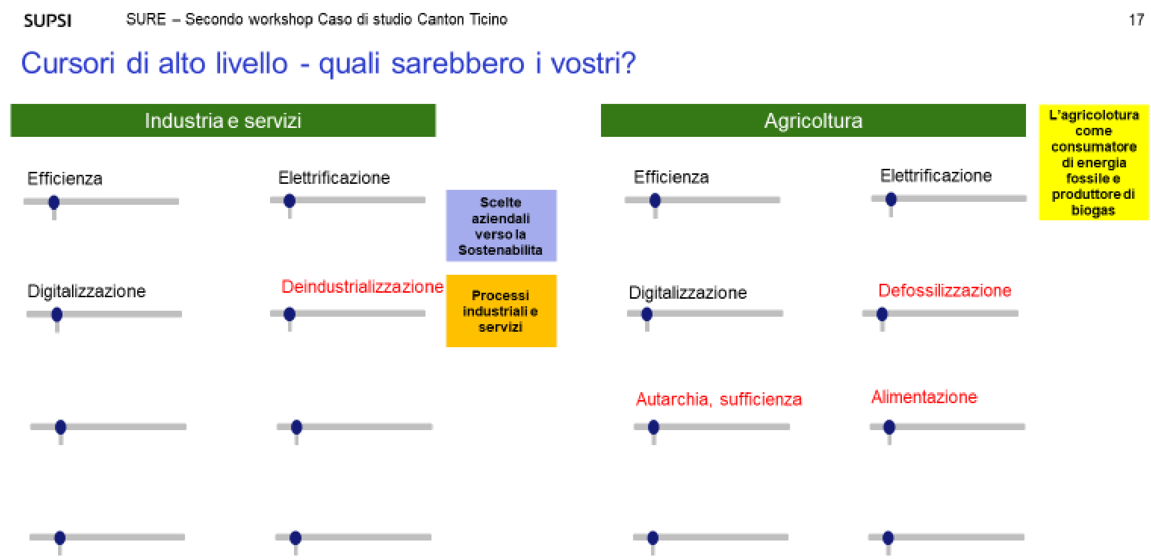

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
9
Cursori di livello inferiore
Trasmissione e distribuzione
Decentralizzazione
Raggruppamenti virtuali
Off/On
Quota di raggruppamenti per autoconsumo
%
Mercato della flessibilita elettrica
Off/On
Quota di raggruppamenti per flessibilità della rete
Autarchia edifici
Decentralizzazione
Hub-energetici non-virtuali per autarchia parziale
Sussidi/tasse per Hub-energetici autarchici
Livello di autarchia richiesta/riconosciuta
%
Importazioni/esportazioni
%

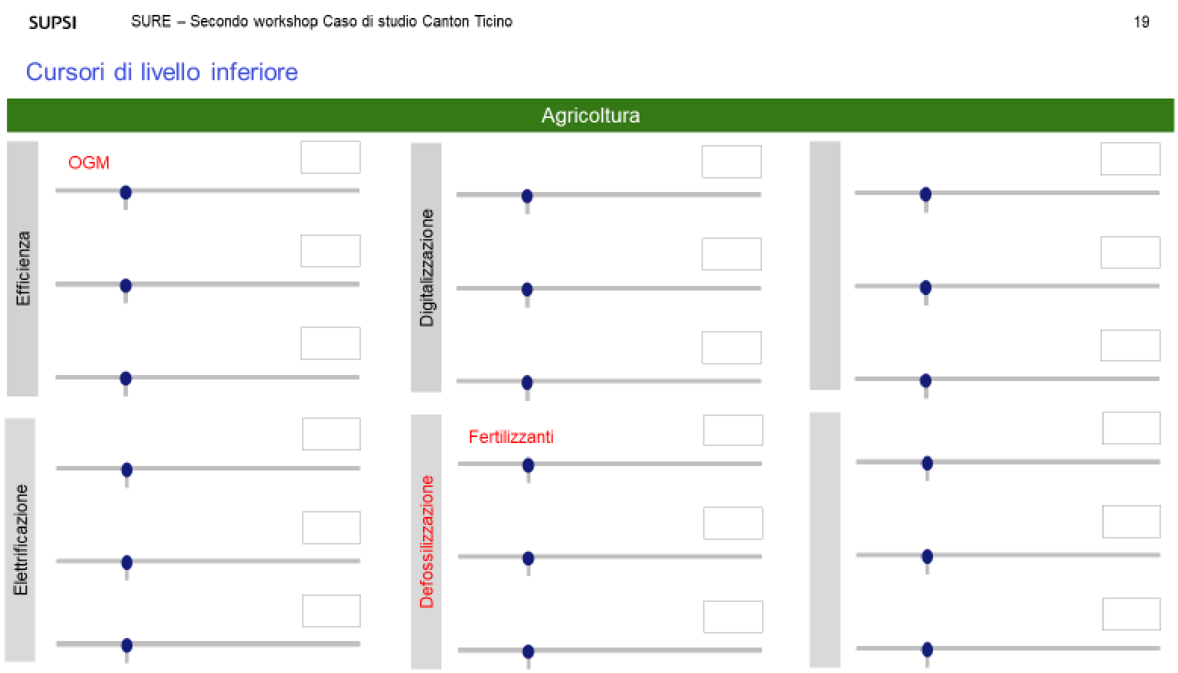

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
10
Cursori di livello inferiore
Trasmissione e distribuzione
Efficienza
Digitalizzazione
Convergenza delle reti
Teleriscaldamento/Raffrescamento
Sussidi per teleriscaldamento (combustibili fossili)
%
Sussidi per teleriscaldamento (fonte rinnovabile)
%
Reti di teleraffrescamento


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
12
Cursori di alto livello - quali sarebbero i vostri?
Trasporto
Efficienza
Elettrificazione
Digitalizzazione
Mobilità attiva
Trasporti
Trasporti ed elettrificaione
Mobilità elettrica
Mobilità integrate attraverso nuove opportunità di comunicazione
Edifici
Efficienza
Elettrificazione
Digitalizzazione
Densificazione
Autarchia/Edifici attivi
Tasso di risanamento
Edifici
Calore edifici
Produzione e distribuzione di calore
Riscaldamento e raffrescamento edifici
Riscaldamenti a celle combustibili reversibili

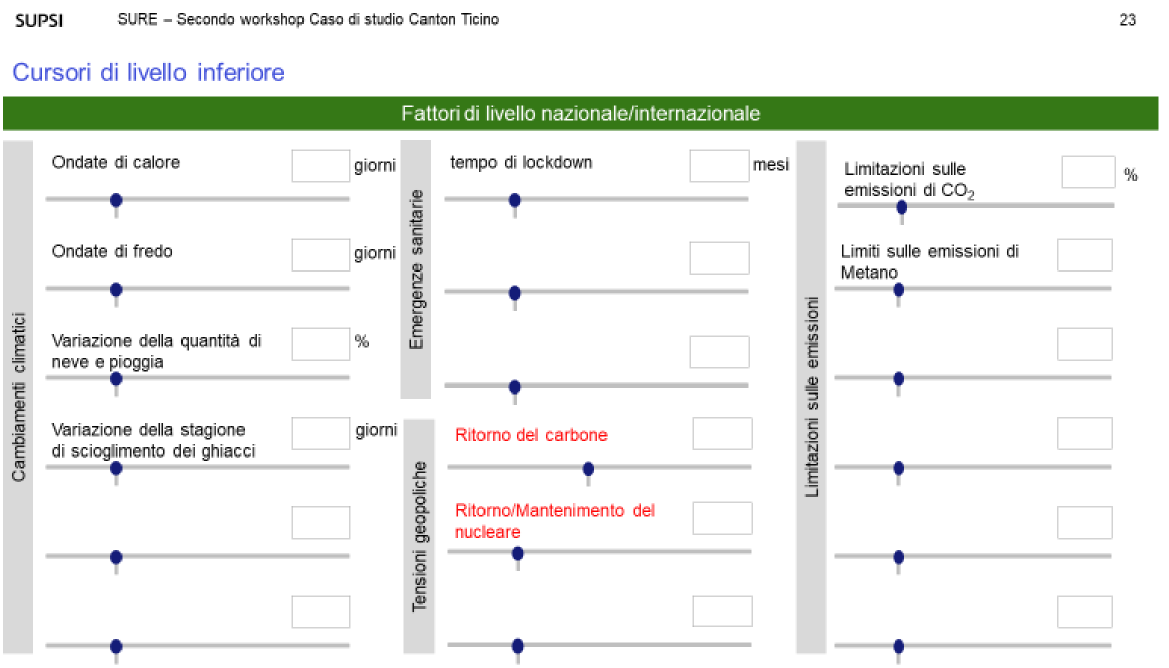

SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
13
Cursori di livello inferiore
Trasporto
Efficienza
Standard di efficienza energetica per i veicoli privati
%/a
Maggiore utilizzo di mezzi di trasporto pubblici e condivisi
%/a
Sussidi/tasse sui veicoli in base alle caratteristiche di efficienza energetica
Anni di inizio e cessazione sussidi/tasse
Trasporto merci
Elettrificazione
Aumento dell'investimento privato per infrastruttura elettrica stradale
%/a
Anno di introduzione di standard di costruzione degli edifici con stazioni di ricarica
a
Autorizzazione della bidirezionalità (e stoccaggio)
Incentivi per investimenti di privati nella costruzione di stazioni di ricarica (contributo all'investimento)
a
Trasporto merci (gomma-ferro, elettrificazione camion)
Consulenze a privati per investimenti in stazioni di ricarica
Digitalizzazione
Mobilità come servizio
Integrazione dei modi di trasporto
Veicoli autonomi


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
15
Cursori di livello inferiore
Edifici
Efficienza/Tasso di risanamento
Standard di efficienza energetica dei nuovi edifici
%/a
Sussidi/tasse per risanamento dell'edificio
%
Anni di inizio e cessazione sussidi/tasse di risanamento
Aumento di efficienza degli elettrodomestici e illuminazione
%/a
Sufficienza- edifici low tech
Elettrificazione
Climatizzazione a energia elettrica (termopompe)
%/a
Aumento del possesso di apparecchi elettrici
%/a
Sussidi/tasse per le termopompe
%
Anni di inizio e cessazione sussidi/tasse
Digitalizzazione
Smart building
Domotica – Grid ready smart meter


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
17
Cursori di alto livello - quali sarebbero i vostri?
Industria e servizi
Efficienza
Elettrificazione
Scelte aziendali verso la Sostenabilita
Digitalizzazione
Deindustrializzazione
Processi industriali e servizi
Agricoltura
L'agricolotura come consumatore di energia fossile e produttore di biogas
Efficienza
Elettrificazione
Digitalizzazione
Defossilizzazione
Autarchia, sufficienza
Alimentazione


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
19
Cursori di livello inferiore
Agricoltura
Efficienza
OGM
Digitalizzazione
Elettrificazione
Defossilizzazione
Fertilizzanti


SUPSI
SURE – Secondo workshop Caso di studio Canton Ticino
20
Cursori di alto livello - quali sarebbero i vostri?
Popolazione
Aspetti comportamentali
Crescita
Urbanizzazione
Digitalizzazione
"Sufficienza"
Manodopera formata disponibile
Alimentazione
Aspetti comportamentali
Invecchiamento della popolazione
Evoluzione demografica
Migrazione e relative cambi culturali
Eventi di livello nazionale/internazionale
Cambiamenti climatici
Tensioni geopoliche
Emergenze sanitarie
Deindustrializzazione
Limitazione sulle emissioni
Liberalizzazione del mercato
Mutamenti climatici
Cambiamenti climatici (migrazioni, comfort abitativo, ecc.)
Tensioni geopolitiche
Liberalizzazione del mercato
Limitazione sulle emission di CO2
Deindustrializzazione della Svizera
Social Network e shop Online
Ritorno di popolazione nelle valli – ripopolare le valli con smart office.
Problemi di dimensionamento delle infrastructure, bassato sulle esigenze di oggi (cfr. Alberton)



The following tables report the complete set of macro and micro-level "sliders" that the core stakeholders would appreciate manipulating during the exploration of transition pathways of the energy system of Canton Ticino. Elements reported in italics were integrated following suggestions by the core stakeholders during workshop 2. The other elements are either directly identified based on suggestions by the core stakeholders during workshop 1 or are proposed by the research team based on their previous experience.

Table 5 Elements to be manipulated – topic “Satisfaction of energy demand”.

Topic	“Macro-level slider”	“Micro-level slider”
Supply sources	Hydroelectricity	Investment on new small plants [CHF] and year of investment Investment on new large plants [CHF] and year of investment
	Oil	Year of ban of installation of new residential plants Year of ban of installation of new industrial plants
	Natural gas	Year of ban of the use of natural gas
	Liquified natural gas (LNG)	-
	Fossil fuels for transport	Taxation/subsidy Year of the start of taxation/subsidy
	Photovoltaics	In the built environment In secluded mountain areas
	Solar thermal	-
	Wind	-
	Geothermal	-
	Wood	-
	Biomass	Funding of R&D [CHF/year]
	Biofuels	Start/end year of funding
	Hydrogen	Investment in new infrastructure [CHF/year] Start/end year of investments Maximum share into natural gas grid [%]
	Synfuels	Taxation/Subsidies Start/end year of taxation/subsidy
	Syngas	-
	Waste	-
	Innovative technologies (not known or implemented yet)	Nuclear fusion, start year of availability Nuclear fission – microreactors, start year of availability
	Storage	*Spatially distributed electric storage* *Seasonal storage of synthetic fuels* *Electric storage in Ticino/abroad* *Electric storage in Switzerland/abroad*

Table 6 Elements to be manipulated – topic “Transmission and distribution”.

Topic	“Macro-level slider”	“Micro-level slider”
Transmission and distribution	Efficiency	-
	Decentralisation	Share of virtual energy communities for electricity grid flexibility [%] Non-virtual energy hubs for partial autarchy Energy autarchy of buildings
	Cantonal autarchy	Taxation/subsidies for energy autarchy Level of required autarchy
	Import	*Share of import/export*
	Digitalisation	Convergence of networks
	Electric grid	-
	Gas grid	Ban on new gas infrastructures Year of a ban on new gas infrastructures
	District heating *and cooling*	Subsidies for district heating fed by fossil fuels Subsidies for district heating fed by renewables Subsidies for district cooling

Table 7 Elements to be manipulated – topic “Mobility and transport”.

Topic	“Macro-level slider”	“Micro-level slider”
Mobility and transport	Efficiency	Energy efficiency standard for vehicles Share of public transport [%] Share of shared mobility [%] Taxation/subsidies for vehicles, based on energy efficiency class
	Electrification	Start/end year of taxation/subsidies Investment by privates for vehicle charging infrastructure *Incentives to investment by privates for vehicle charging infrastructure* *Consultancy and support to privates for vehicle charging infrastructure* Year of the introduction of building standard requirements for charging stations
	Digitalisation	*Year of authorisation to storage and bi-directional charging* Diffusion of mobility-as-a-service Level of integration of transport modes Diffusion of autonomous vehicles
	Active mobility	-
	Freight transport	Multi-modality (road-railway) *Electrification of trucks*

Table 8 Elements to be manipulated – topic “Buildings”.

Topic	“Macro-level slider”	“Micro-level slider”
Buildings	Efficiency	Energy efficiency standard for new buildings Taxation/subsidies for building energy retrofit Start/end year for taxation/subsidies *Low-tech buildings*
	Electrification	Heat pumps for heating and cooling Taxation/subsidies for heat pumps Year of start/end of taxation/subsidies Number of electric appliances owned
	Densification	-
	Energy retrofit rate	-
	Energy autarchy/ active buildings	-
	Digitalisation	*Smart building and home automation* *Grid-ready smart metering*

Table 9 Elements to be manipulated – topic “Industry and services”.

Topic	“Macro-level slider”	“Micro-level slider”
Industry and services	Efficiency	-
	Electrification	-
	Digitalisation	-
	De-industrialisation	-

Table 10 Elements to be manipulated – topic “Agriculture”.

Topic	“Macro-level slider”	“Micro-level slider”
Agriculture	Efficiency	-
	Electrification	-
	Digitalisation	-
	Energy autarchy, sufficiency	-
	Energy consumption for food	-
	Genetically Modified Organisms (GMO)	-
	De-carbonisation	*Fertilisers*

Table 11 Elements to be manipulated – topic “Population”.

Topic	“Macro-level slider”	“Micro-level slider”
Population	Growth	Migration towards other cantons/abroad Ageing of the population
	Availability of qualified workforce	-
	Urbanisation	Migration within the Canton
	Digitalisation	Increase in online shopping
	Behavioural aspects	*Energy Sufficiency* *Teleworking* *Food* *“Green” purchase*

Table 12 Elements to be manipulated – topic “National/international factors”.

Topic	“Macro-level slider”	“Micro-level slider”
National/ international factors	Climate change	Heat waves Cold waves Amount of rain and snow Duration of the ice melting season
	Constraints to CO_2 emissions	Regulations on methane emissions
	Health emergencies	Lock-down periods
	De-industrialisation	-
	Geopolitical tensions	*Coal* *Nuclear*
	Market liberalisation	-

Appendix C – Ticino energy system mind maps

The process of developing a Causal Loop Diagram for the Ticino energy system involves constructing mind maps in which are identified key elements, from a group perspective, and then methodologically making assumptions regarding causality. The following describes some of the mental maps that were iterated upon when undergoing this process.

The specific nomenclature used in the maps for the landscape, regime, and niche elements elicited during the two workshops is described in Table 13. While new technologies and practices are found under "Innovation processes in niches", current technologies and practices used to provide electricity, heat, and mobility are in the "Regime sub-systems". For example, in terms of technologies, hydropower, which is a well-established technology in Switzerland and in Ticino and was not explicitly mentioned by the core stakeholders as they took it for granted, could be defined within the current electricity production regime. On the other hand, PV which currently amount to only 3.2% of the Ticino electricity supply[4], is categorised under "Innovation processes in niches". Similarly, a current practice such as the common Swiss "42-hour work week" could be considered as part of the "Regime sub-systems" category, while practices such as "home-office" or "4-day work week" which are not (yet) widely embraced could enter in the "Innovation processes in niches" category. Although the traditional and incumbent technologies and practices enter different categories in the MLP, they will all be modelled according to an archetype which includes social, technical, economic, and environmental aspects that influence the rate at which they are adopted, maintained, or abandoned, such as policies, social-acceptance, unused local resource potential, etc. It is interesting to note that in a review of socio-technical agendas by Sovacool et al. (2020) some of the landscape elements evoked by the core stakeholder group, namely external shocks (ex: geopolitical tensions) and gradual trends (ex: increasing purchasing power) have been identified as key drivers of accelerated transitions.

Table 13: Key components of the Canton Ticino energy system according to stakeholders.

Type	Components from workshops (italic in text)	Components in the map (in blue and italic in text)
Innovation processes in niches	Syngas	*carrier_j_production_capacity*
	Hydrogen	*carrier_j_production_capacity*
	Co-(Tri-)generation	*installed_carrier_j_prod_capacity_by_tech_i*
	Nuclear fusion	*installed_carrier_j_prod_capacity_by_tech_i*
	PV	*installed_carrier_j_prod_capacity_by_tech_i*
	Storage	*carrier_j_storage*
	Fuel cells	*installed_carrier_j_prod_capacity_by_tech_i*
	Seasonal heat storage	*carrier_j_storage*
	Biogas production	*carrier_j_production_capacity*
	Changes in individual behaviour and practices	*online_purchase* *work_life_balance* *energy_sufficiency*
	Home-office practices	*Home_office*
Regime sub-systems	Heat production and distribution	*installed_carrier_j_prod_capacity_by_tech_i* *carrier_j_production_capacity*

[4] https://www.oasi.ti.ch/web/energia/produzione-per-vettore.html

		carrier_j_distribution_network
	Electricity production and distribution	installed_carrier_j_prod_capacity_by_tech_i carrier_j_production_capacity carrier_j_distribution_network
	Industry and services	GS_Goods_and_Services_end_use
	Mobility	H_households_end_use GS_Goods_and_Services_end_use
	Buildings	H_households_end_use GS_Goods_and_Services_end_use
	Agriculture	GS_Goods_and_Services_end_use
Landscape factors	Climate change	climate_change
	CO_2 and climate protection policies	CO2_emission_policy
	Migration	international_imigration_emigration internal_imigration_emigration
	Re-population of valleys and secluded regions	rural_repopulation_policy_support
	Ageing of the population	aging_population
	Land planning choices	land_use
	Geopolitical tensions	geopolitical_tensions
	Decisions by other countries	international_agreements
	Authorisation times	authorisation_time
	Market regulations	carrier_j_market_price_regulation labour_regulation energy_efficiency_policy_regulation

The elements in Figure 16 concern the local resources that might be used in the Ticino energy system, including their boundaries and interdependencies. For example, it is possible that electrolysis would only be envisaged if there is a high availability of local renewable electricity. In turn, the hydrogen produced by electrolysis would be essential as an ingredient to produce local synthetic fuels. Carbon Capture and Storage (CCS) is also included as it can be necessary as well in the production process of synthetic fuels. The figure also generally depicts the local electricity production technologies that were mentioned by the stakeholders during the two workshops – PV, hydro, wind turbines, combined cycle gas turbine, co-(tri)-generation, and (micro) nuclear. The development of this mind map is loosely inspired by the classification of the basic elements of socio-technical systems in terms of either "Production" or "Application domain, technology in use" presented in Sovacool et al. (2020). To the left of the CBD appear key components related to energy demand, and to the right appear key components related to energy supply. On the right side of the CBD are depicted some economic, social, environmental, and technical elements that are believed to influence the mix of local technologies and imports exploited for the supply of any energy carrier (*carrier_j _supply*). The regimes elements *Heat distribution* and *Electricity distribution* are described by the loop that increases and decreases the *carrier_j_distribution_network,* connected to a feedback loop linking the carrier distribution network with its associated supply capacity. These carrier supply and distribution elements and links are inspired by Gravelsins et al. (2018); Laimon et al. (2020, 2022); Ochoa & van Ackere (2009); Zapata Riveros et al. (2019) and Kwakkel & Pruyt, (2015); Blumberga et al. (2022). The regimes *Heat production* and *Electricity production* are represented by the element connected to *installed_carrier_j_prod_capacity_by_tech_i,* which stands for all technologies that can locally generate energy. Figure 15 shows the interplay between the use of local resources (*local_resource_extraction*) used in local generation technologies (*carrier_j_production_capacity*) and imports (*carrier_j_import*).

While both local supply and imports are confronted with market boundaries (ex: market price, price elasticity, market regulation), some specific limitations unique to either local supply or imports are identified. In the case of local production, technical and physical limits are set by natural energy resource availability (*local_resource_potential*) and land use (*land_use*). Imports, on the other hand, can be limited by international agreements (*international_agreements*) and geopolitical tensions (*geopolitical_tensions*). The geopolitical tensions might directly cause these international agreements to fail or might indirectly cause disruptions in the supply chain. In addition, both imported energy carriers and locally produced energy carriers are subject to social and political limitations. In this diagram, these are all conveyed by the element *social_political_acceptance,* which accounts, for example, for the limitation of imports following a desire for partial/full energy independence or the opposition to a local production technology due to issues of trust and aesthetics. The local resources required for different technologies, and some interdependencies between them, are described in more detail in Figure 16. More details about the factors influencing the choice of technology are provided in an additional diagram in Figure 17.

The left side of the CBD in Figure 10 shows many of the landscape factors (*Climate change*, *Migration*, *Re-population of valleys and secluded regions*, *Ageing of the population*, *Geopolitical tensions*) that are believed to influence the population and workforce in the region, and subsequently act as key drivers of any energy carrier demand (*carrier_ j _demand*) in the residential, commercial, agricultural, and industrial sectors. Certain landscape factors, such as *CO_2 and climate protection policies*, *market regulation*, *migration*, *and re-population of valleys and secluded regions,* are considered to be tied to policy actions. That is to say that these could potentially be “sliders”, which could be further explored in detail with and by the stakeholder, in view of a tool which could be used to test national and cantonal policy measures - varying in their intensity, timeframe, and combinations. In this diagram, the regimes *Buildings* and *Mobility* are represented in terms of energy end-user types and therefore belong to both the residential sector (*H_household_end_use)* as well as the good and services sectors (*GS_Goods_and_Services_end_use)*. Some more detailed examples of the components of this demand are provided for the residential sector in the following Figure 18 and Figure 19.

Figure 17 depicts numerous factors that could be considered to influence the perceived utility and adoption of a generic “energy_technology_i” (*installed_energy_tech_i*) that produces an energy carrier (*carrier_j_supply*). This diagram, which is inspired by a number of works (Freeman, 2021; González et al., 2016, Laimon et al., 2020; Li et al., 2019; Ochoa & van Ackere, 2009; Pruyt, 2014; Zapata Riveros et al., 2019, Blumberga et al. 2022), expands from the landscape, regime, and niche components mentioned by the core stakeholders, while still inspired by the exchanges during the two first workshops. This diagram focuses on the factors that can bring about the adoption or abandonment of technologies that can contribute to the locally produced energy carrier in Ticino. Each technology is judged according to its relative perceived utility with respect to the other technologies that can provide the same carrier required to meet the demand. As can be understood from the diagram, the perceived utility is based on its social, environmental, economic, and technical value. The social value (*energy_tech_i_social_acceptance*) is part of an important feedback loop, where the more a technology is present on the territory, the more people get familiar with it, thereby increasing the chances that they consider the installation of additional capacity. Social value is also a factor of the general image of a technology, as some technologies become more popular while others fall from grace on a global scale. The environmental value (*energy_tech_i_environmental_value*) is currently defined in terms of the Global Warming Potential (GWP) of the carrier it consumes (*carrier_j_consumed_GWP)* and of the construction of the technology itself (*energy_tech_i_GWP*). Additional environmental factors might be added in later stages of the modelling process, depending on the stakeholder interest and the SURE indicators. The economic value (*energy_tech_i_economic_value*) depends on the Net Present Value (*NPV*) of the technology, which includes the fixed cost (*energy_tech_i_fixed_cost*) and variable cost (*energy_tech_i_variable_cost*) of the technology over its lifetime (*energy_tech_i_lifetime*). The variable cost depends on the carrier consumed by the technology and its price (*carrier_j_consumed_price*) and operation and maintenance costs (*energy_tech_i_OM_cost*). The fixed cost can be reduced if it is supported by governmental incentives (*energy_tech_i_public_policy_support*) and the learning rate of the technology (*energy_tech_i_learning_rate*). The technology's perceived value also depends on the perceived value of the carrier it will produce (*carrier_j_perceived_value*), which depends in part on the gap between the supply and demand of the carrier (*carrier_j_gap*) that would provide an incentive to install additional capacity, and the perceived uncertainty and risk related to the carrier consumed or produced by the technology (*carrier_j_perceived_market_uncertainty_and_risk*). The perceived value is limited by technical limitations (*energy_tech_i_tech_limit*), which, depending on the technology, can be many things, such as local energy resource availability, land use, or permit restrictions. This diagram also describes a feedback loop between the installation of a technology and the workforce capable of installing it. It is conceived that the more present is a technology, the more the local skills will be developed to commission and maintain this technology. An increase in skills and abundance of a specialised workforce can, in turn, make the commissioning process faster and more reliable, as well as create a political motivation to maintain/increase the installation of that technology (creating/preserving local jobs). As mentioned previously, the higher the relative perceived relative value of a technology, the more the technology might be commissioned (*comissioning_energy_tech_i*). The lower the relative perceived value of the technology, the higher the chances that it might be decommissioned (*decomissioning_energy_tech_i*) at the end of its lifetime or abandoned even before reaching that stage.

The diagram in Figure 17 depicts an archetype for mapping the factors influencing the choice of a technology. An example of the application of this archetype for the regime *Mobility* in the residential sector is depicted in Figure 18. In this case, an individual or household can choose from a wide variety of vehicles: car, bicycle, bus, and train. All these competing or complementary options are represented by "vehicle_z”. In this case, the social value of the vehicle also depends on perceived social-status (*vehicle_z_social_status*). Another critical aspect is the supporting infrastructure (*vehicle_z_supporting_infrastructure*), which impacts social acceptance in terms of confidence in the vehicle as well as the technical value determined by physical barriers to adoption (Gómez Vilchez & Jochem, 2019). The technical value is also dependent on the characteristics of the vehicle itself (speed, size, range, etc.). The implications of the workforce, in this case, are not necessarily related to the manufacturing of the vehicles but rather to their maintenance and readily available replacement parts. Figure 19 provides another specific example relating to the regimes *Heat production* and *Buildings,* depicting the choice of a heating technology in the residential sector. Again, the relative perceived value of a heating technology is a combination of social, environmental, economic, and technical factors. In this case, the final energy carrier demand depends on both the technology providing the heat and the building characteristic. Therefore, the choice to demolish, renovate, and build a house is also included in this diagram. The main elements considered to affect the perceived value of a household relate to its characteristics, which are either Single Family House (SFH) or Multi-Family House (MFH) (*SFH_MFH*), located in an urban or rural environment (*rural_urban*), and differ in thermal envelope class (*residential_building_performance_certificate*). Aside from the section of this diagram depicting the evolution over time of the building stock's thermal performance, the selection of a heating technology follows the same principles as the archetype previously presented. The same concepts depicted in Figure 18 and Figure 19 will be reproduced for the Ticino commercial, industrial, and agricultural sector technologies and practices. However, for these sectors, the archetype for technology adoption and the related energy carrier supply and demand will be directly modelled in the SFD in the next steps of the project.

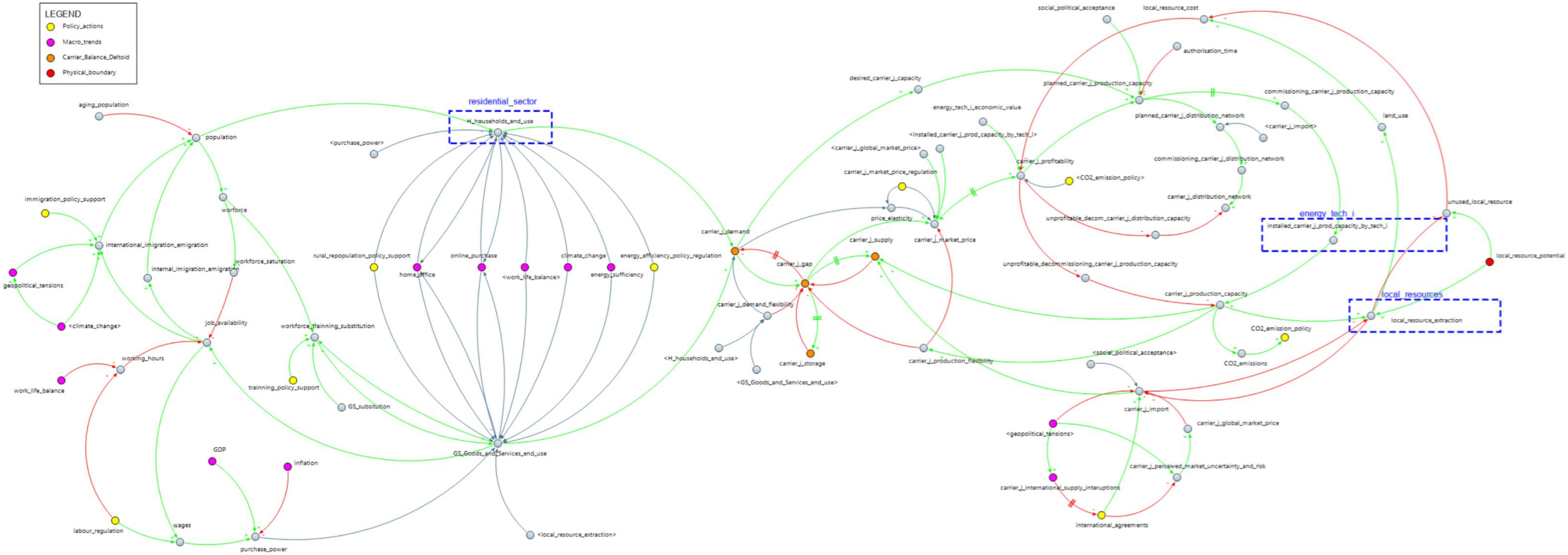


Figure 15: Mind map of the Ticino energy system.

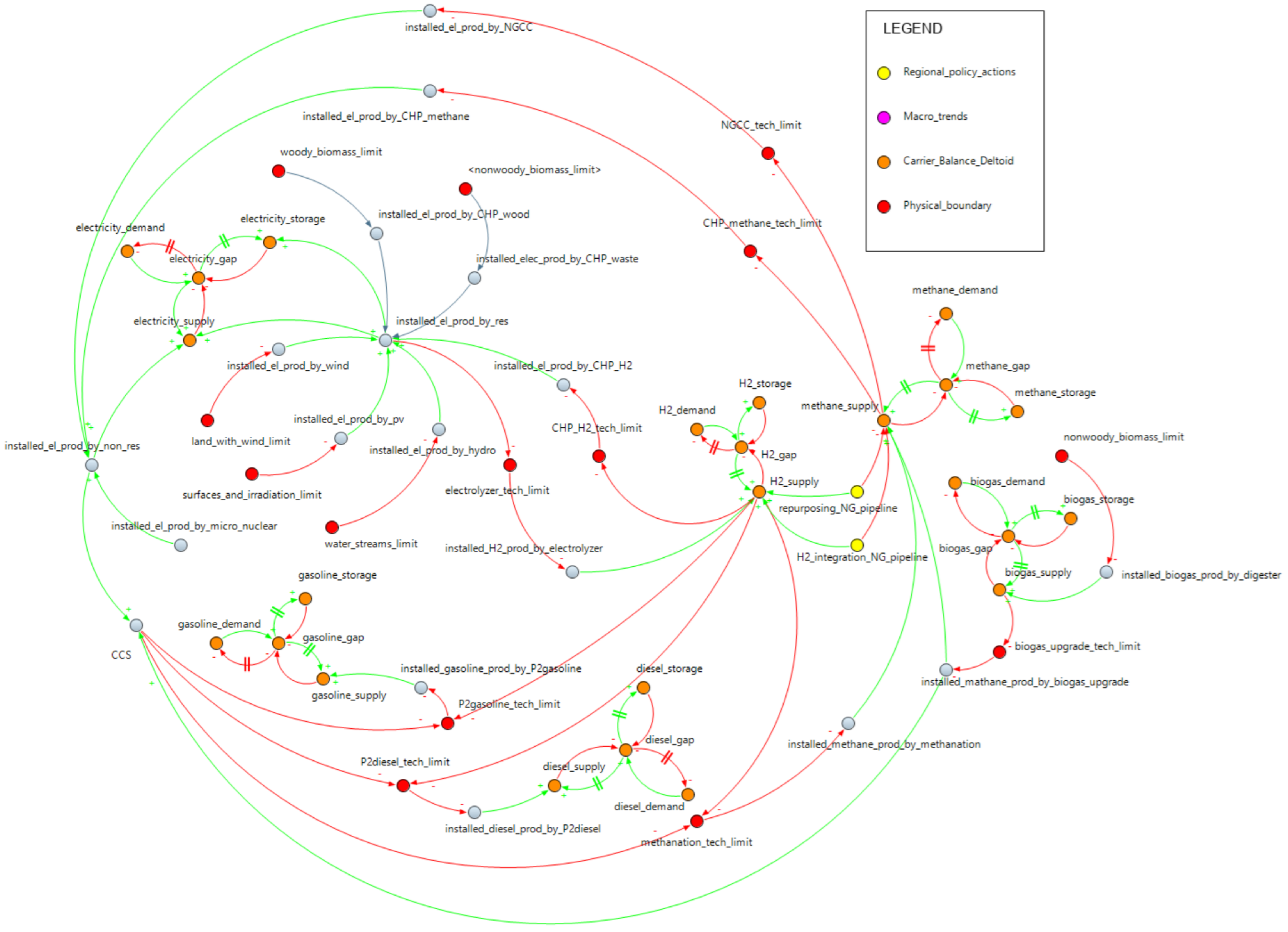


Figure 16: Simplified diagram of the interplay between local resources.

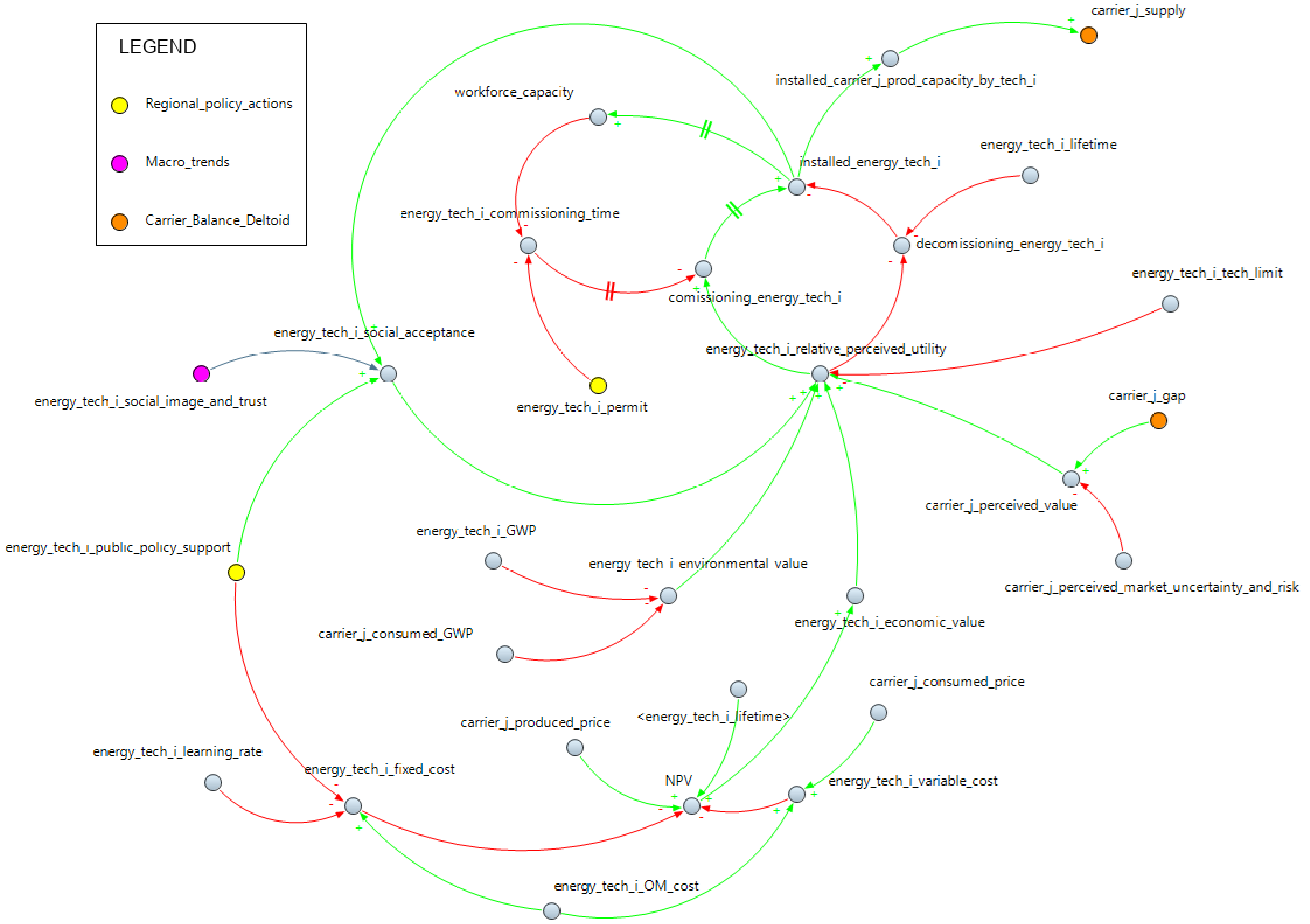


Figure 17: Simplified archetype of factors influencing the choice of an energy carrier supply technology.

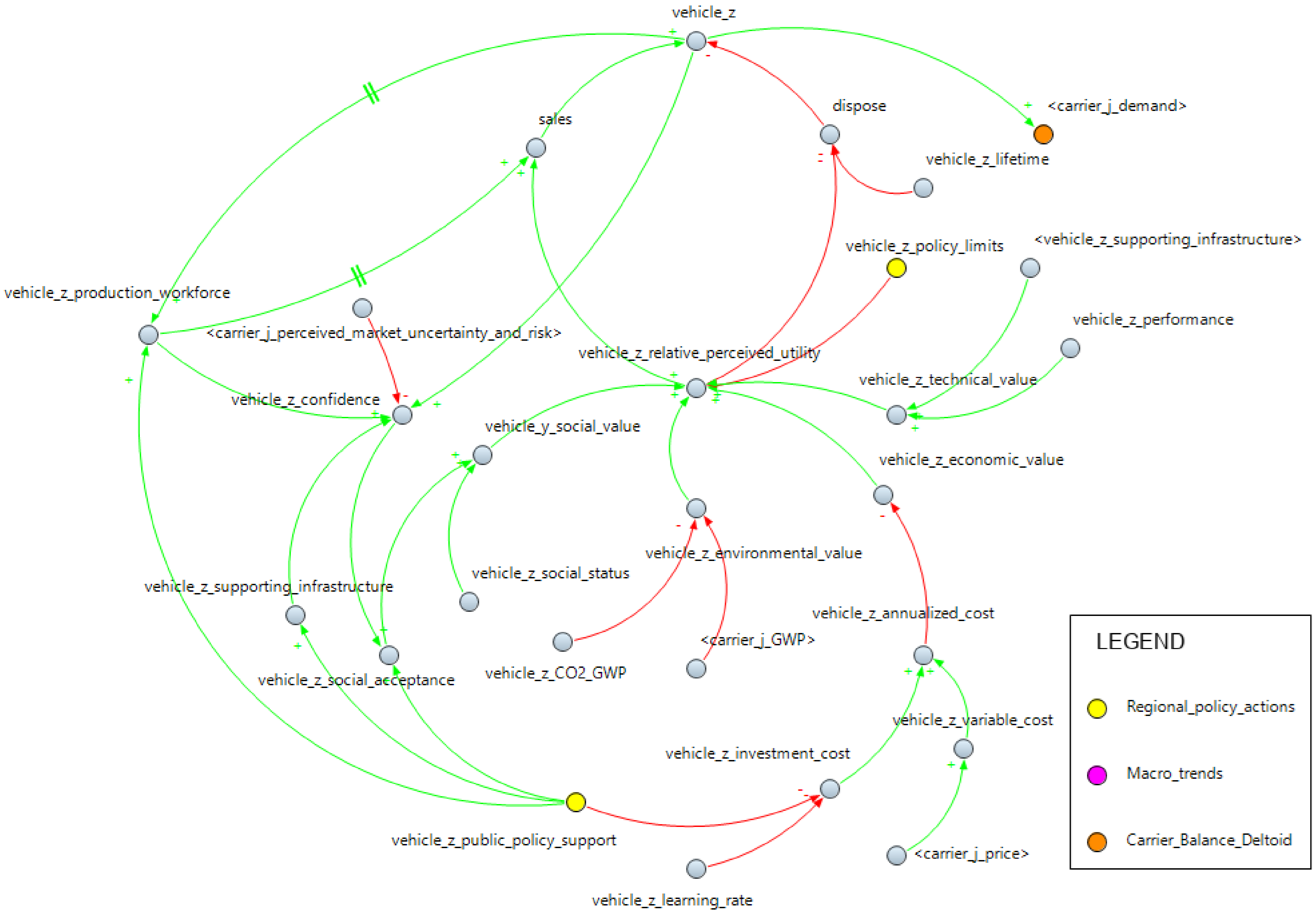


Figure 18: Residential sector – mobility.

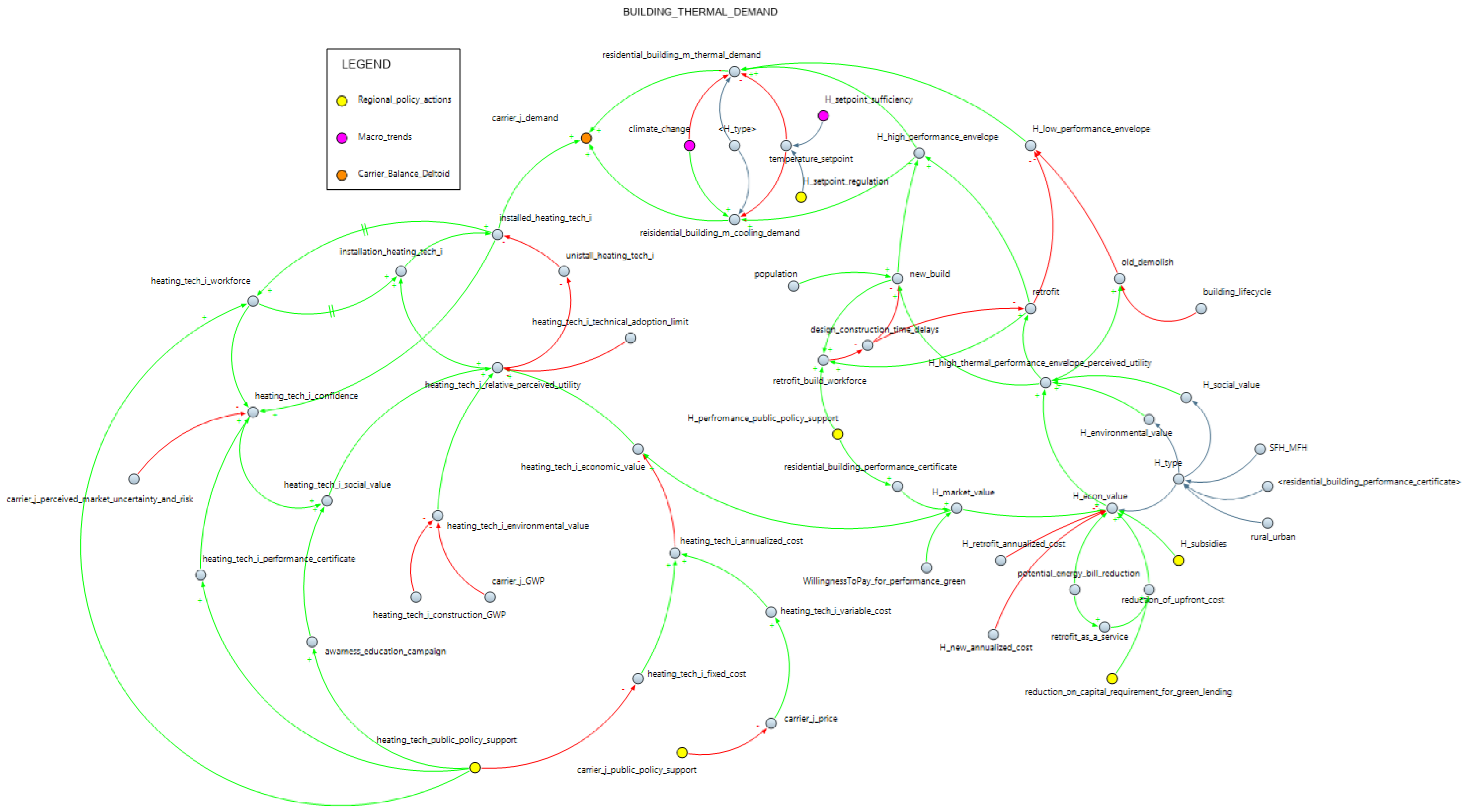


Figure 19: Residential sector – buildings.

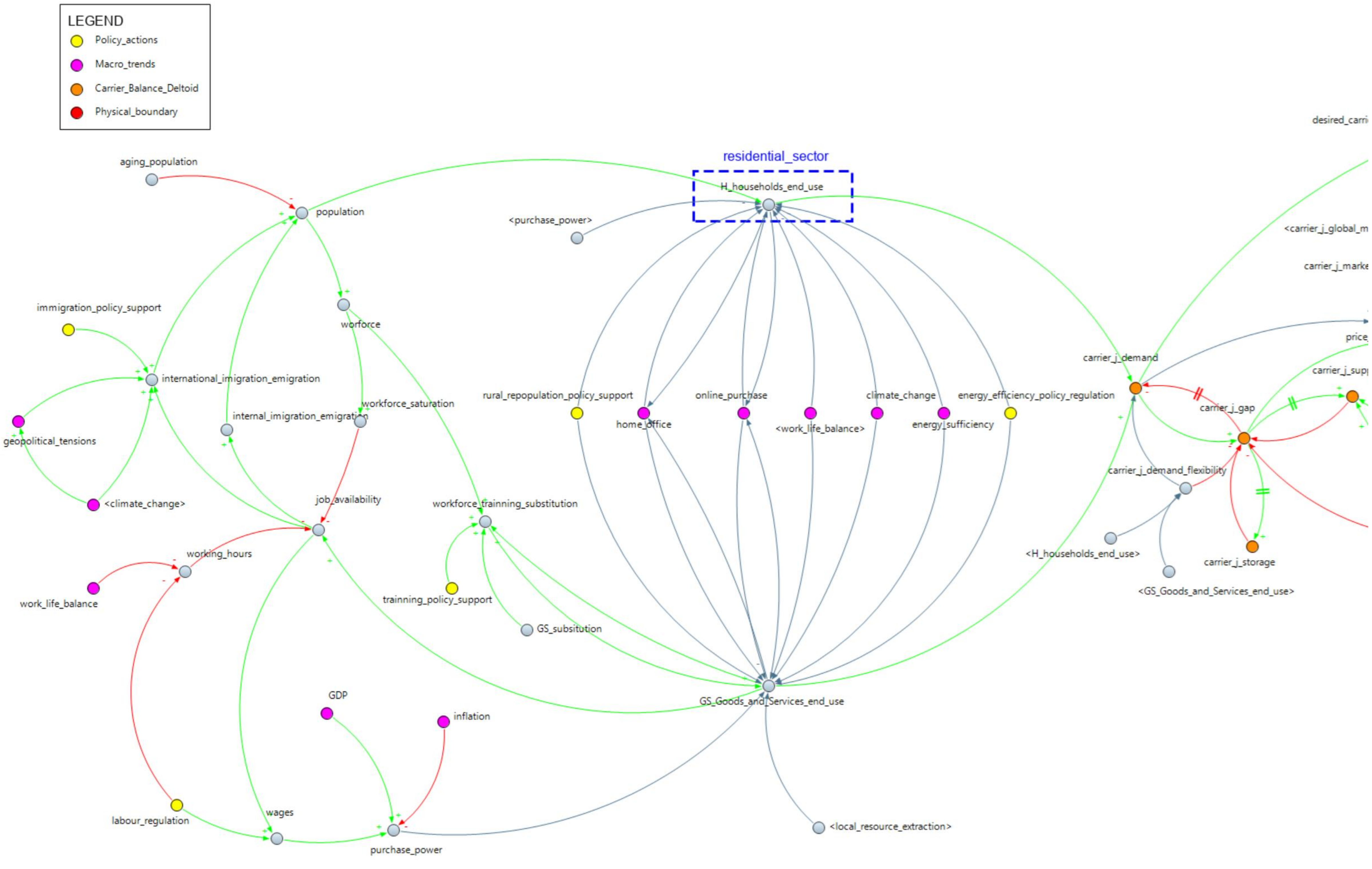


Figure 20: energy demand-side of the Ticino energy system mind map

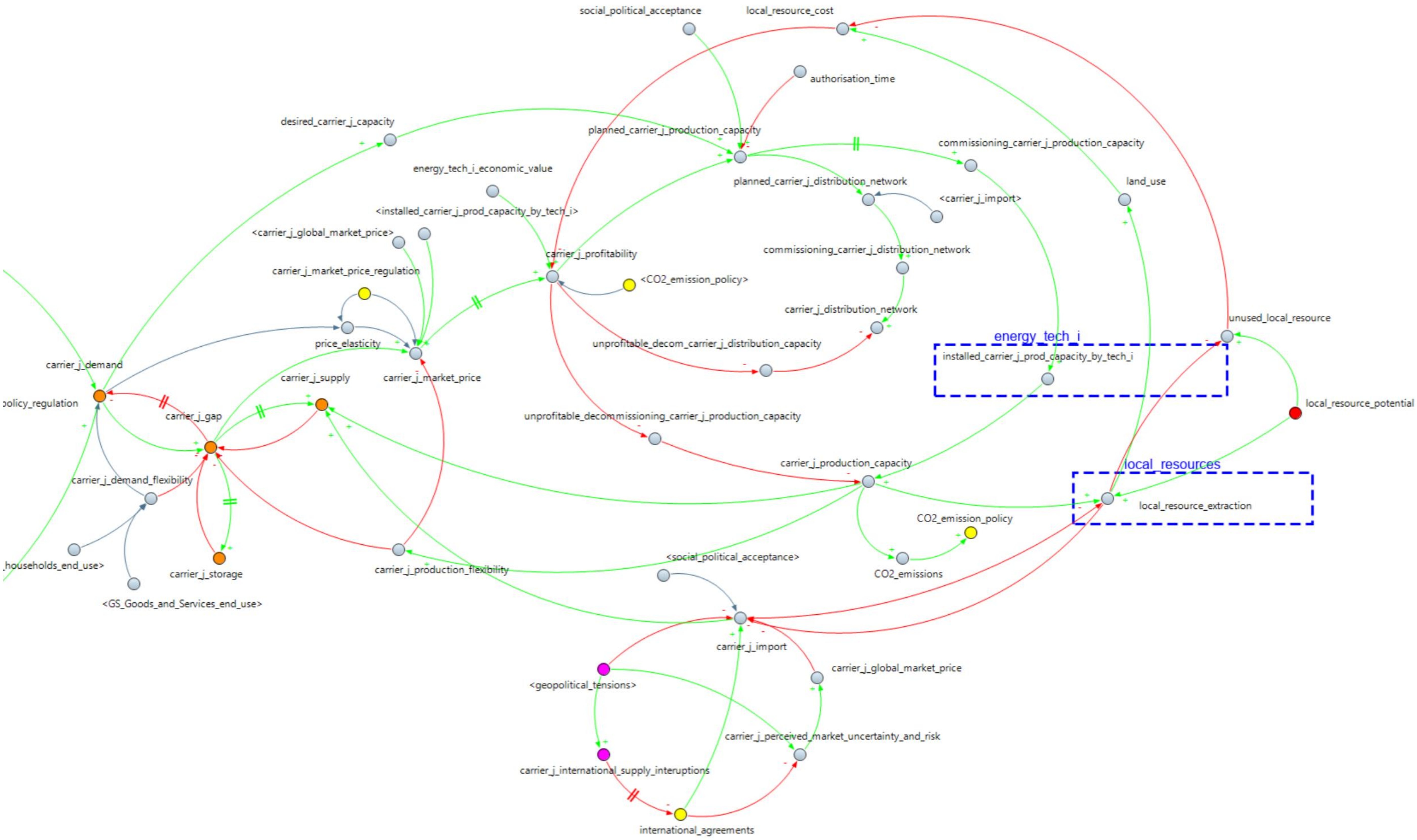


Figure 21: energy supply-side of the Ticino energy system mind map