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Deliverable report

Deliverable n°	D4.1
Deliverable name	Description of methodological improvements of the utility function in the BSM
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sweet swiss energy research for the energy transition

Summary

This report of deliverable D4.1 addresses several methodological developments to improve the spatial building stock model (sBSM) and the related spatial energy assessment toolbox (SEAT).

As an introduction, the report describes the overall goal of the WP4, i.e. the analysis and assessment of different building stock decarbonization pathways to explore typical research questions related to resilience and sustainability that are being addressed in the SURE project. This is followed by a concise introduction to building stock modelling in general and more specifically the role and formal expression of the utility function of the model decision module, which is pivotal to the model.

The main focus of the work, the methodological improvements in the utility function related to building owners' choice behaviour modelling do concern several different topics. These topics can be categorised in (i) the interaction between the heating system and the building envelope, (ii) the influence of socio-economic variables, (iii) the “Perceived choice” set, (iv) the impact of spatial constraints and finally (v) the adjustment of energy cost calculation approach of the model.

For each topic specific findings and empirical fundamentals deducted from various data sources are laid out. For instance, the interaction of the heating system and building envelope is dependent from the owner’s financial situation and its commercial goals. Socio-economic variables address factors such as the age dependency of investment likelihood. Differentiating between the perceived and the actual choice set allows for explaining why some owners often stick to solutions which are not ncecessarily the most favourable. Spatial constraints address noise issues in relation to the installation of air-water heat pumps. Finally adjustments in the cost calculation approach allow for the integration of new tariff schemes. With the improved modelling method it will be possible to generate additional output parameters and to assess the resilience of the building related energy system.

A further methodological improvement concerns the calibration process of the newly introduced parameters. To ease understanding, a simplified representation of the model data flows between the different modules is displayed. Ultimately an outlook of the next steps in WP 4 is given. The final chapter concludes with remarks concerning further methodological improvements in relation to the availability of renewable energy sources and points to eh upcoming implementation of the methodological improvements described with his deliverable D4.1.

Zusammenfassung

Der Bericht zum Deliverable D4.1 adressiert mehrere methodische Weiterentwicklungen zur Verbesserung des räumlichen Gebäudeparkmodells (sBSM) und der damit verbundenen räumlichen Energieanalyse (REA).

Einleitend beschreibt der Report das übergeordnete Ziel des WP4, nämlich die Analyse und die Bewertung verschiedener Dekarbonisierungsszenarien, um die SURE Projekt entwickelten Forschungsfragen rund um das Thema Resilienz und Nachhaltigkeit zu adressieren. Dann erfolgt eine kurze generelle Einführung in die Gebäudeparkmodellierung. Diese wird vertieft, indem die wichtige Rolle der Nutzenfunktion als Bestandteil des Entscheidungsmoduls des GPM dargestellt und formal beschreiben wird.

Der Hauptfokus der Arbeit, nämlich die methodischen Verbesserungen der Nutzenfunktion in Verbindung mit dem Entscheidungsverhalten der Gebäudeeigentümer, betreffen viele verschiedene Aspekte. Die Determinanten des Entscheidungsverhaltens und die verschiedenen Komponenten der Nutzenfunktion lassen sich kategorisieren in (i) die Abhängigkeit zwischen Heizungssystem und Gebäudehülle, (ii) den Einfluss sozio-ökonomischer Variablen, (iii), die eingeschränkte Wahrnehmung der wählbaren Optionen, (iv) den Einfluss räumlicher Restriktionen und letztlich die Erweiterung der Energiekostenrechnung des Modells.

Für jeden Einflussfaktor werden spezifische Erkenntnisse und empirische Grundlagen, welche auf Basis vieler verschiedener Datenquellen gewonnen wurden, benannt. So ist beispielsweise für den Zusammenhang von Heizsystem und Gebäudehülle die finanzielle Situation und die wirtschaftliche Zielsetzung, mit dem das Gebäude betrieben wird, entscheidend. Bei den sozio-ökonomischen Variablen werden u.a. Faktoren wie die Altersabhängigkeit der Investitionsentscheidung und die Modellierung deren Wahrscheinlichkeit beschrieben. Beim Einflussfaktor «eingeschränkte Wahrnehmung der wählbaren Optionen» wird untersucht, warum manche Gebäudeeigentümer mit Lösungen verhaftet bleiben, welche unvorteilhaft für sie sind und warum sie stattdessen nicht bessere Lösungen wählen. Beim Einfluss «räumlicher Restriktionen» können beispielsweise entscheidungsrelevante Lärmemissionen, welche in Verbindung mit Luft-Wasser Wärmepumpen auftreten, abgebildet werden, während mit der Erweiterung der Energiekostenrechnung die Integration neuer Tarifmodelle in die Nutzenfunktion ermöglicht wird. Mit der so verbesserten Methodik können zum einen zusätzliche Ergebnisparameter generiert werden und zum anderen wird es ermöglicht, die Resilienz des Gebäude bezogenen Energiesystems zu untersuchen.

Eine weitere methodische Verbesserung betrifft den Kalibrierungsprozess der neu in die Nutzenfunktion eingeführten Parameter. Dieser wird durch eine vereinfachte graphische Abbildung der Modellzusammmenhänge, welche die Datenflüsse zwischen den verschiedenen Teilmodulen beschreibt, illustriert. Das letzte Kapitel schliesst mit der Erwähnung der künftig geplanten weiteren Modellverbesserungen in Zusammenhang mit der Verfügbarkeit erneuerbarer Energiequellen und dem Hinweis auf die als nächstes geplante Implementierung der vorgeschlagenen methodischen Verbesserungen.

Résumé

Ce rapport du livrable D4.1 traite de plusieurs développements méthodologiques visant à améliorer le modèle spatial de parc immobilier (sBSM) et la boîte à outils d'évaluation énergétique spatiale (SEAT).

En guise d'introduction, le rapport décrit l'objectif global du WP4, c'est-à-dire l'analyse et l'évaluation de différentes trajet de décarbonisation du parc immobilier afin d'explorer les questions de recherche typiques liées à la résilience et à la durabilité qui sont abordées dans le projet SURE. Cette introduction est suivie d'une brève présentation de la modélisation du parc immobilier en général et plus particulièrement du rôle et de l'expression formelle de la fonction d'utilité du module de décision du modèle, qui est est un élément crucial du modèle.

L'objectif principal du travail, les améliorations méthodologiques de la fonction d'utilité liées à la modélisation du comportement de choix des propriétaires de bâtiments, concerne plusieurs sujets différents. Ces sujets peuvent être catégorisés en (i) l'interaction entre le système de chauffage et l'enveloppe du bâtiment, (ii) l'influence des variables socio-économiques, (iii) l'ensemble des "choix perçus", (iv) l'impact des contraintes spatiales et enfin (v) l'ajustement de l'approche de calcul des coûts énergétiques du modèle.

Pour chaque sujet, des résultats spécifiques et des bases empiriques déduites de diverses sources de données sont exposés. Par exemple, l'interaction entre le système de chauffage et l'enveloppe du bâtiment dépend de la situation financière du propriétaire et de ses objectifs commerciaux. Les variables socio-économiques abordent des facteurs tels que l’effet de l'âge sur la probabilité d'investissement. La différenciation entre le choix perçu et le choix réel permet d'expliquer pourquoi certains propriétaires s'en tiennent souvent à des solutions qui ne sont pas nécessairement les plus favorables. Les contraintes spatiales traitent des problèmes de bruit liés à l'installation de pompes à chaleur air-eau. Enfin, des ajustements dans l'approche de calcul des coûts permettent l'intégration de nouveaux systèmes tarifaires. Avec la méthode de modélisation améliorée, il sera possible de générer des paramètres de resultat supplémentaires et d'évaluer la résilience du système énergétique lié au bâtiment.

Une autre amélioration méthodologique concerne le processus de calibration des paramètres nouvellement introduits. Pour faciliter la compréhension, une représentation simplifiée des flux de données du modèle entre les différents modules est présentée. Enfin, un aperçu des prochaines étapes du WP 4 est donné. Le dernier chapitre se termine par des remarques concernant les améliorations méthodologiques à apporter en fonction de la disponibilité des sources d'énergie renouvelables et indique la mise en œuvre prochaine des améliorations méthodologiques décrites dans le livrable D4.1.

1 Introduction

The following is a slight revision of the WP 4 description of SURE proposal.

To achieve a future sustainable and resilient energy system, energy demand needs to be especially addressed to understand drivers and appliances which are relevant to realize the benefits of such a system. Referring to the results of recent studies, e.g. on behalf of the "Heat Initiative Switzerland" (Wärmeinitiative Schweiz) and of the Energy Perspectives 2050+ of the Swiss Federal Office of Energy (SFOE), energy demand needs to be decarbonized until 2050 and appliances and buildings need to become more efficient to reduce overall energy demand. Although there are quite many elements available in the theoretical policy toolbox, it is still to be investigated which actions are most promising in practice to be set in motion to meet such targets. Declining industries or energy sectors such as the fossil industries are fighting for a survival in the market, partially counter-acting policy decisions or investment interests whereas renewable energy industries strive to expand their market shares. Additionally, investor decisions also impact the level of achievement for energy efficiency and decarbonization targets and non-compliance with the respective regulations has an impact on the energy performance gap as well as the energy decarbonization gap.

Besides the existing energy demand drivers, new energy demand patterns are expected to define future energy demand. Such drivers can be clustered as "digitalization of life", "new social and economic models" or "quality of life". These clusters integrate trends such as digitalization of services, sharing economy, circular economy approaches, "prosumer" concepts, energy poverty and others. These drivers are expected to significantly impact the use and demand of energy and related investments and are therefore of high interest to be included in the analysis.

As investment decisions have a long-term impact on the energy infrastructure, stringent policy frameworks need to be put in place to achieve a resilient and sustainable energy system. Additionally, investments in energy demand end use appliances are closely linked to the energy distribution system. Depending on the decarbonization pathway, the risk for stranded investments as well as the need for future grid expansion is varying and of high relevance. This relevance is even more pressing as grid development and infrastructure development need often long preparation times whereas the window of opportunities is closing to decarbonize the energy demand from the building stock.

Additionally, as we have learned from the most recent past, shocks can highly impact the energy demand in short time. However, it remains unclear if energy demand rather increases or decreases in case of or after such events and how the load patterns are affected. Depending on the shock scenario, diverging impacts on the overall energy system are to be expected.

To investigate different decarbonization pathways in the building stock and the services sector, as well as to investigate the defined shock scenarios, the existing spatial building stock model (sBSM) and the spatial energy assessment toolbox (SEAT) of TEP Energy will be used. However, to properly address the following research questions, the model needs to be improved by integrating additional decision parameters in the model´s underlying utility function, and by enhancing the load curve module. Also, the integration of SEAT and sBSM will be improved. The following research questions will be addressed to achieve aforementioned targets:

- Which impact have different investor decisions regarding investments in energy efficiency and energy demand appliances on the resilience of the overall energy system?
- What is the impact of such decisions on the energy efficiency gap as well as on the decarbonization gap and what is the level of uncertainties regarding the size of these gaps?
- Which new demand clusters will have a robust impact on energy demand and therefore need to be integrated in future energy demand models?
- How is the overall load curve affected by different decarbonization strategies and what is the impact of shock scenarios on the load curve?

- Which policy- or investment measures are robust in terms of achieving the resilient system and where the uncertainties are higher?
- What is the impact of investment decisions on material demand in the built environment?

To answer these research questions, the objective is to expand the utility function(s) of the sBSM:

- The decision function shall include further decision parameters and compliance parameters for existing and future regulations, considering specific relations towards resilience of the system.
- The utility function(s) shall be expanded to include new and robust demand and RES availability clusters.
- The utility function(s) shall be expanded to allow for integrating socio-economic groups with different preferences (re technologies and policy instruments) and to allow for uncertainty parameters to be included in terms of RES investment decisions and efficiency measures.

The sBSM is enhanced in terms of additional output parameters that are relevant to assess the resilience of the buildings related energy system.

- The model will be expanded in its functionality to better represent the material flow within the building stock as an input to the research question towards circular economy.
- The model will be expanded in terms of fully integrating load curves from the existing load profile database.

Based on these model expansions, energy demand developments will be assessed and the level of the energy performance gap and decarbonization gap will be analyzed:

- Simulation based scenario analysis of future energy demand on the level of single buildings or groups of buildings (GIS-based) that includes a comprehensive set of key decision parameters and preferences.
- Benchmarking and ranking of pathway and shock scenarios in terms of achieving a resilient energy system and their impact of the remaining energy performance- and decarbonization gap.
- Simulation of the overall load curve in dependency of the various scenarios as input to work package 6 and 7.
- Calculation of material demand in the built environment as input to work package 10.

This work package evaluates the energy demand development regarding different long-term pathway scenarios as well as selected shock scenarios. For this purpose, the existing sBSM is expanded based on a comprehensive methodological framework which (1) includes further stakeholder preferences; (2) uses advanced analytical techniques to systematically identify robust solutions and (3) evaluates trade-offs and co-benefits.

WP 4 is structured into the following sub-tasks:

- Task 4.1: Methodology to expand the functionality in the spatial building stock model
- Task 4.2: Integration of newly defined decision parameters in the BSM
- Task 4.3: Definition, implementation and analysis of pathway scenarios
- Task 4.4: Definition, implementation and analysis of shock scenarios
- Task 4.5: Material flow analysis and interface to WP10

This deliverable covers sub-task 4.1 which aims for improving and enhancing the methodology of the spatial building stock model (sBSM), particularly to expand several functionalities that are needed to be able to model both scenarios and shocks defined in the SURE project. The focus of the deliverable is on improvements of the utility function which is the core of the decision module. Further methodological developments and data related improvements need to be made (especially regarding potentials and restriction regarding renewable energy sources), to be reported separately.

2 Deliverable content: methodological improvements of the utility function in the BSM

This deliverable D4.1 describes the methodology to expand the utility function(s) to include further decision parameters and stakeholder preferences. Based on the existing utility function(s), the methodology addresses the impact of the new decision parameters as well as interlinkages between new and existing decision parameters on the overall expected outcome of the model results. Additionally, the sBSM is enhanced in terms of additional output parameters that are relevant to assess the resilience of the building related energy system. Moreover, new energy demand trends are investigated and analysed for integration into the overall BSM system. Our ongoing work in other research projects such as the H2020 project NewTrends and results of other members of NewTrends will be used as starting basis for such work, to be adjusted to the Swiss context.

2.1 Context: introduction to building stock modelling

Building stock modelling is an approach to explore the feasibility to achieve ambitious energy-efficiency and climate mitigation / decarbonization goals and to evaluate the needs and the effect of various instruments to achieve these goals. Various questions arise for different actors such as policy makers, authorities, building owners, energy suppliers. Depending on their requirements, various versions and modules of the Building Stock Model (BSM) can be used, e.g. to address the following purposes and tasks:

- Target verification and/or feasibility check
- Strategic and operative energy planning (such as (district) heating networks, use of local potentials of renewable energies)
- Network planning, conception and planning of energy services
- Impact analysis and evaluation of (planned) energy policy measures
- Urban planning and site/area development
- National and municipal energy statistics
- Management of building portfolios

With the Building Stock Model, past developments can be analysed, and possible future trends can be simulated, typically adopting scenario approach, see the study on decarbonizing the Swiss heat sector for an example Jakob et al (2020). Depending on the research topic the Building Stock Model yields the following evaluation indicators which are depending on the drivers listed in Table 1.

Table 1 Result (evaluation) indicators (left) and drivers (right) of the BSM

BSM evaluation indicators (output)	**Differentiation and resolution of drivers**
• Energy reference areas and employees • Demand for electricity • Energy demand, divided into fossil and renewable energy sources • Primary energy demand for the building for the phases "construction" and "operation" (according to SIA 2040) • CO_2 and greenhouse gas emissions (GHGE) (scope 1 to 3). • Material flows	• Differentiation according to building type (up to around 15 types) • Differentiation by economic sector (1-15) • Spatial differentiation (cantons, municipalities, zones, hectares) • Time resolution (1 to 5-year steps between 2000 and 2060) • Use of input data specific to individual buildings and building portfolios • Use of consumption data for calibration • Data from Geographic Information Systems (GIS)

The Building Stock Model is based on Swiss, cantonal and communal statistics, results of surveys, studies and potential analyses, data from the Buildings and Housing Register (GWR) and the Company Register. In addition, energy consumption data and waste heat sources, zone plans as well as maps of site uses, grid-bound energy supplies such as gas, district and local heating networks and renewable energies are used.

Typical research questions that can be addressed with building stock modelling (as implemented by TEP Energy and its partners), possibly in relation with SEAT, are the following:

- What is the impact of the following exogenous technical drivers and related policy instruments (codes and standards) on energy demand (by energy carrier) and related emissions:
  - Demand of floor area due to population growth and changes in labour force
  - Changes in zoning laws
  - New building standards
  - Higher retrofit rates
  - Standards for more efficient electrical appliances
  - Local availability of renewable energy sources in heating, cooling and electricity generation
- What is the impact of the exogenous economic drivers related policy instruments ?
  - End use energy prices
  - Energy tariff schemes and regulation (e.g. feed-in tariffs, capacity vs. energy pricing)
  - Energy and carbon taxes, preferential tariffs
  - Subsidies (e.g. for certain technologies or energy carriers)
  - Fiscal incentives (e.g. for building owners to invest in energy related measures)

To address such research questions building stock modelling (as implemented by TEP Energy and its partners), possibly in relation with SEAT, consists of the following steps:

1. Initialization of the building stock, either for the modelling starting year or by modelling the last ten to twenty years. In this step the building stock is described in terms of various attributes which are either available for each individual building (as in the case of smaller building stocks of municipalities and cities, see Jakob, Catenazzi, Sunarjo et al. 2015) or for synthetised building stocks (see Nägeli et al. 2018 for an example).[1]
2. Modelling the dynamics of the building stock, i.e. the alteration of (individual or synthetic) buildings and its components, e.g. the insulation of facades in the case of old, non-retrofitted buildings or the renewal of the heating system. This step might be implemented at different levels of sophistication, starting typically with the first of the following ones:
   a. Changes based on the lifetime of buildings elements and its appliances and energy systems: at each point in time (within the modelling time horizon) those elements are either retrofitted or changed against new ones if they have already reached the end of their service life (which might vary depending on the assumptions and on the scenario). The standards of the retrofitted or of the new elements replacing the older ones typically are more efficient or use other energy carriers. Respective assumptions about the frequency, structure (mix, market share), and the energy standard are specified by the modeller, which makes the result quite dependent on his or her expertise or preference.
   b. Instead of making assumption about the frequency, the structure (mix, market share), and the energy standard of retrofits or new building elements and technical systems, the choices of the owners might be simulated explicitly, as ultimately such choices yield in the abstract parameters of step 2a). Adopting such a decision modelling framework has some methodological and empirical challenges, but also has various advantages and allows for

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[1] Note that also the current state of buildings is not known for all the variables. Especially those regarding the retrofit state of the envelope are only known from sample-based surveys. As for the heating system, it depends on the data situation. For the city of Zurich (Case study of WP14) we expect quite accurate data, for the Swiss case still a lot of data is outdated (stems from 2000) and the evolution from 2000 to 2020 needs to be modelled.

modelling explicitly some of the research questions and policy instruments (see Nägeli et al. 2020a,b).

In practice the BSM has been developed in various national, international and local projects and therefore consists of various modules (of which more than one implementation version exists). Thus, part of the work to be implemented in SURE is to bring together different methodological streamlines and in doing so, improving the modelling framework and its consistency.

One important streamline of improvement is related to the decision modelling part of the BSM as decision modelling allows for explicitly taking into account (most of) the scenarios and shocks as they are currently being discussed in the project.

2.2 The role of the utility function in the BSM

As laid out in section 2.1 decisions of building owners are explicitly modelled in the BSM of TEP Energy and its partners. This decision modelling is based on the lifetime or service life of buildings and its components (Step 2a of section 2.1) and on the micro-economic discrete choice modelling (DCM) approach. In this approach economic agents (here: building owners) make choices based on the availability of options and the (relative) utility of these options.

In our BSM, decision modelling is implemented in two main areas:

- Building envelope: choice of implementing energy-efficiency measures (such as insulating walls and roofs) vs. simple repair or re-instatement measures (such as painting)
- Heating system: choice of the heating system in the case of new buildings or in the case of a needed heating system retrofit (at the point in time at which the end of service life is reached).

In a DCM approach the choice probability of a certain option based on the utility of that option in relation to the utility of the other options in the choice-set (Eq. (1)). The option is then randomly selected based on the calculated probability P i of each of the options in the choice set S (see Nägeli et al 2020a).[2]

$$P_i = \frac{e^{V_i}}{\sum_j^S e^{V_j}} \tag{1}$$

It should be noted that not all options are available for all buildings, e.g. due to technical reasons or due to missing energy infrastructure (such as gas or district heating grids). Availability of options also might be restricted by policy measures, e.g. by a limitation of CO_2-emissions or a ban of fossil energy based systems. Improving the BSM in this respect is also part of WP 14 of the SURE project.

On the one hand, the utility of each option depends on the attributes of these options (e.g. costs, environmental performance). On the other hand the utility of the options also depends on the decision maker since different economic agents (here: building owners) have different tastes and preferences. Some of the elements of the utility functions might be observed or surveyed (e.g. costs, environmental performance, local availability), but others are not directly observable. In the utility function *Vi* the coefficients that weight the different variables are derived from the past retrofit behaviour (revealed choices) or from choice experiments (stated choices), in this case from the outcome of the research project MISTEE (as part of the EWG programme of the SFOE).

In case of limited data availability concerning different elements of the utility function a simplified approach might be adopted. In such a simplified approach the utility of a given option i is calculated based on an assessment of the total costs of the options. Additional elements, e.g. preferences to choose the same heating system as before (status quo bias) or the specific preference for

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[2] Reproducibility is assured by fixing the starting point of the random seed of the initial state for each of the buildings (i.e. to keep it constant between different model runs).

environmentally friendly systems, might be added in the form of assumptions of positive (or negative) willingness to pay (WTP), as indicated in the following equation (2) (adopted from Nägeli 2020a). In the micro-economic literature, the term WTP often is labelled as so-called alternative-specific constant (ASC).

$$V_i = \beta_{AC} EAC_{I,i} + \beta_{MC} C_{M,i} + \beta_{EC} C_{E,i} + \beta_{WTP} WTP_i \tag{2}$$

$EAC_{I,i}$	Specific equivalent annual investment costs of option i in CHF/year m^2
$C_{M,i}$	Specific operation and maintenance costs of option i in CHF/year m^2
$C_{E,i}$	Specific energy costs of option i in CHF/year m^2
WTP_i	Willingness to pay for option i
β_n	Weighting factor for decision criteria n

In the micro-economic literature, the weighting factors correspond to coefficients that might be estimated by econometric models, either based on observed choices (revealed preferences) or based on hypothetical data gained through choice experiments (stated preferences, see Banfi et al. 2008 for an example). Similar choice experiments were conducted as part of the SFOE research project MISTEE and collected data are currently (spring 2022) being analysed.

2.3 Methodological improvements related to the choice behaviour

In BSM the WTP (or ASC) of equation (2) might be determined by adopting an iterative approach in which parameters are searched in a way to match the modelled decision with the observed decision behaviour (if such data is available). Such an iterative approach might be done semi-automated with scripts (as done in Nägeli et al. 2020) or with more sophisticated approaches described in literature. Programming or statistical packages offer libraries or tools, e.g. in python or R. Such approaches in principle are feasible to implement, but bear some disadvantages (e.g. being tricky, quite aggregate, non-transparent aka black box). They thus only represent a second-best approach. The best approach would be to add more explicit terms to the utility function and to differentiate the coefficients of equation (2) for different cases (e.g. types of buildings, types of building owners). For instance, private single-family house owners might value up-front investment costs differently than ongoing operational or energy costs. Private or institutional owners of larger buildings renting out to tenants too might value differenty. This would translate in a different coefficient β_{EAC} for these owners. Likewise, other preferences might differ across situation, building and owner types in which case respective coefficients would be differentiated in an analogous way.

Thus, the methodological improvements aim at expanding the utility function of the decision module of the BSM model. Specifically, the following elements should be modelled more explicitly. The focus in WP 4 of SURE is laid on the following aspects:

1. Interaction between the heating system, the building envelope, and other energy system components such as PV, storage, demand side management (DSM) measures.
2. Influence of socio-economic variables
3. Impact of spatial constraints
4. Perceived choice set as compared to the “real” choice set (limited perception, bounded rationality)
5. Expansion of energy cost calculation to better incorporate energy tariff schemes and regulation such as feed-in tariffs, capacity vs. energy pricing and taking into account the energy performance gap (EPG)

Such improvements are meaningful also because of empirical data that have been generated based on several ongoing and completed projects of TEP Energy and others:

- Findings from the SFOE research project MISTTEE offer data on both real and stated choices of building owners.

- In the project Low-Invest-Cost-Solutions (LICS) and in a subsequent private-sector project cost indicators have been surveyed which allow to update the techno-economic data base of the BSM.
- In various projects and scientific articles, the so-called energy performance gap (EPG) has been explored. The EPG describes the discrepancy between real and expected (calculated) energy consumption or energy saving. Thus, the EPG is relevant also for the decision modelling adopted in the BSM since one of the terms in the utility function deals with energy costs.

2.3.1 Interaction between the heating system and the building envelope (and other system elements)

As laid out above, decision modelling in our BSM is implemented in two main areas: the building envelope and the heating system.

- As the different heating systems have a different life-cycle cost structure, i.e. different share of capital costs and operational costs, and as their economy of scale (relation between thermal power and investment costs) is different, it is expected that heating system choices are different between efficient and inefficient buildings. Thus, an interrelation between heating system and the building envelope choices is expected, solely because of a rational cost-effectiveness calculus.
- In addition to this direct cost-effectiveness effect, an interaction between heating system and building envelope choices might also be driven by economic reasons, arising from budget constraints and spending preferences of building owners. Indeed, if a building owner has already spent a large amount for building envelope measures, he or she might be less inclined to subsequently spend more money for a renewable energy system. Reversely, after having invested in a renewable energy system, he or she might not be willing to invest in costly building envelope measures.[3] Indeed, such measures might not be cost-effective in this case or might be perceived as “not needed” as the heating system is already “green”, i.e. based on renewable energy sources.

Indeed, very recent (and preliminary) results of the econometric analysis of choice data gained in a survey implemented in the SFOE research project MISTEE reveal such an interaction between heating system and building envelope related choices. As indicated by the odds-ratio (OR) the choice probability for building envelope efficiency measures is stat. sign. lower for buildings with gas, district heating or heat pumps as a heating system (by a factor of 0.824, 0.806 and 0.847, i.e. by 15% to 20% as compared to a building with an oil heating system respectively). Moreover, building type and construction period display a considerable impact on the choice behaviour, see Figure 1. Whereas the impact of the construction period is already considered in the BSM, the new finding gained in the MISTEE project are directly useful to improve the modelling in the SURE project.[4]

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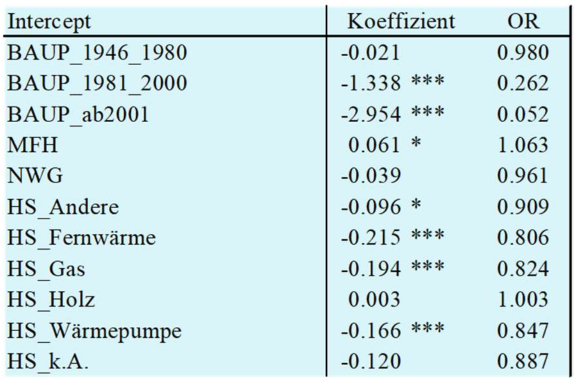
[3] The order at which decision in the domain of the building envelope or in the domain of heating systems are evaluated depends on the state of the different elements (more precisely: the time elapsed since the last decision was taken) and on the assumed life time or service life of the elements.

[4] Yet, due to data availability issues the costs of the alternatives (overhaul vs. retrofit) have not been included in the survey of the past retrofits. This means that the cost related coefficients of the first part of equation (2) may not be estimated from this data set. However, such coefficients are estimated based on the choice experiments conducted within the MISTEE project, both for investing into envelope measures and energy systems (heating, PV etc.) and for purchasing energy (heat, electricity).



Intercept	Koeffizient	OR
BAUP_1946_1980	-0.021	0.980
BAUP_1981_2000	-1.338 ***	0.262
BAUP_ab2001	-2.954 ***	0.052
MFH	0.061 *	1.063
NWG	-0.039	0.961
HS_Andere	-0.096 *	0.909
HS_Fernwärme	-0.215 ***	0.806
HS_Gas	-0.194 ***	0.824
HS_Holz	0.003	1.003
HS_Wärmepumpe	-0.166 ***	0.847
HS_k.A.	-0.120	0.887

Source: Müller, Jakob et al. 2022

Figure 1 Regression results of an adoption probability model (excerpt, part 1) that elicits the probability of an energy-efficient retrofit as a function of building and owner related attributes (preliminary results, for illustration purpose only).

In a next step it will be explored on how these empirical findings might be reflected by the current implementation of the BSM (which already takes into account the first interaction effect, i.e. the one related to energy carrier dependent costs) or whether an structural change of the DCM needs to be implemented. Such a structural change could consist in a so-called nested approach or in a conditional approach:

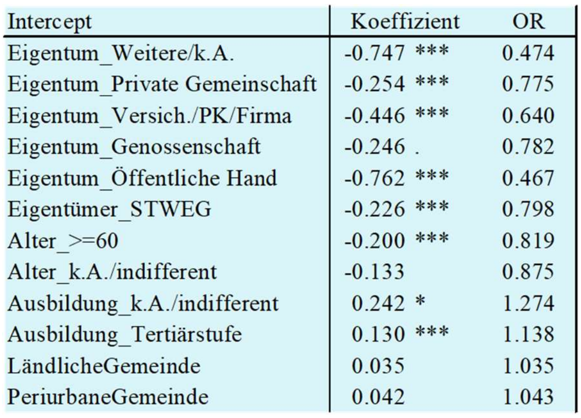
- In a nested approach, first the choice whether investments are made in the area of the envelope or in the area of the heating system is assessed and in a second step the choice within each of the two main areas is modelled
- In a conditional approach, the probability of choosing a certain heating system depends on whether a previous investment into the envelope has been made (and vice versa).

Likewise, additional elements might be included in the decision modelling framework of the BSM. In this respect PV systems with or without batteries are of particular interest. Depending on the results of the analysis of the choice experiment data gathered as part of the MISTEE project it will be decided whether such choices are independent from heating system and building envelope choices or whether a more sophisticated approach needs to be adopted (e.g. a nested approach or an approach that models the choice of investment packages rather than the choice of individual measures). So far, one interdependence has been identified: the one between DSM (load management) and batteries: there is only a willingness to invest in DSM if it is combined with a battery (but not for DSM alone).

2.3.2 Influence of socio-economic variables

Recent (and preliminary) results from the same econometric analysis of choice data gained in the MISTEE survey also suggest an influence of socio-economic variables on the choice of regarding building envelope measures. This implies that the utility function needs to be expanded by such variables. Typically, equation (2) would be complemented by additional terms. In a simplified approach where a binary choice is modelled (between energy-efficient and non-energy-efficient measures) and where socio-economic variables consist of so-called dummy variables, simple coefficients which might be positive or negative are added to equation (2). Examples for such coefficients are displayed in Figure 2

As indicated by the odds-ratio (OR) the choice probability for building envelope efficiency measures of elder building owners (aged over 60 years) is lower by a factor of 0.819, i.e. about 18% lower. Likewise, the choice probability of highly educated owners (education might be considered as a proxy for their income) is higher (by about 14% for owners with a tertiary education as compared to others). Moreover, the owner-type displays a considerable impact on the choice behaviour.



Intercept	Koeffizient	OR
Eigentum_Weitere/k.A.	-0.747 ***	0.474
Eigentum_Private Gemeinschaft	-0.254 ***	0.775
Eigentum_Versich./PK/Firma	-0.446 ***	0.640
Eigentum_Genossenschaft	-0.246 .	0.782
Eigentum_Öffentliche Hand	-0.762 ***	0.467
Eigentümer_STWEG	-0.226 ***	0.798
Alter_>=60	-0.200 ***	0.819
Alter_k.A./indifferent	-0.133	0.875
Ausbildung_k.A./indifferent	0.242 *	1.274
Ausbildung_Tertiärstufe	0.130 ***	1.138
LändlicheGemeinde	0.035	1.035
PeriurbaneGemeinde	0.042	1.043

Source: Müller, Jakob et al. 2022

Figure 2 Regression results (excerpt, part 2) of an adoption probability model that elicits the probability of an energy-efficient retrofit as a function of building and owner related attributes (preliminary results, for illustration purpose only).

2.3.3 Perceived choice set (limited perception, bounded rationality)

Various empirical studies revealed that consumers and investors, particularly building owners often do not take into account all feasible options when they decide on purchasing appliances or on building related investments. Rather than on a comprehensive evaluation of all available options, decisions are based on heuristics. In the literature this is referred to as bounded rationality (), behavioural economics, or energy illiteracy (e.g. Brounen et al. 2013). An example is a so-called status quo bias, i.e. the preference to stick with the current situation rather than to change it. For this reasons, old appliances are non-replaced (Blasch and Daminato 2020) and energy carriers are kept in the case of heating systems renewals. In economic valuations terms, this partly is explained by a special value that is attributed to stay with the status quo (status quo bias). Schleich et al. (2016) refer to the Status quo bias “to the empirical observation that individuals tend to stick with the status quo even if changing behavior would be preferable.” Status quo biases (or nudging effects) are observed in many fields of life[5] and also in the field of energy where it could lead to a postponement of changes (e.g. Johnsen 2016). Status quo or nudging is also used by energy utilities (offering a more environmentally friendly product as the standard product while the client needs to become active if she or he would like to receive the cheaper one) or by policy makers.

In the case of heating systems, bounded rationality implies that house and building owners stick with their previous heating systems or evaluate perhaps one additional option rather than including all feasible options at their location (status quo bias). The status quo bias is all the more pronounced as maintenance companies and installers often recommend to keep the same type of heating system[6] (Lehmann et al., 2017). Also, the (revealed) heating system related choices gathered by an extensive survey implemented in 19 Cantons shows high shares of building owners keeping the same system type or energy carrier (it should be noted however that this empirical finding is not necessarily an evidence for a status quo bias; it should also be investigated whether changing really would have been favourable).

These effects are implemented in the model by “hiding” some of the options in the decision model. This is done not for all, but only for a selection of owners. This approach allows for modelling (i) a status quo bias, (ii) increasing awareness (e.g. through exogenous events or policy measures in the form information campaigns or point of sale actions) and (iii) additional offers.

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[5] Most prominently, individuals adhere to (externally set) defaults. As evidenced by Madrian and Shea (2001) participation in retirement plans increases dramatically if the default is set to participation. Likewise, Abadie and Gay (2006) find that organ donorship is higher in countries where donating is the default compared to countries where donating is not the default. Thus, the status quo bias tends to increase the IDR.

[6] Note that such recommendations have been not always in the best interest of their clients and certainly not in environmental terms.

2.3.4 Impact of spatial constraints

For obvious reasons spatial constraints impact on the decision of building owners, particularly in terms of their choice of the heating system: if no gas or district heating grid is available at the building location respective systems cannot be chosen, in which case such options are not part of the choice set for the respective buildings and their owners. Yet, as recent GIS analysis of TEP Energy reveal, the choice of heating systems is also constraint by less obvious reasons: air-water heat pumps need to meet noise regulation. Therefore, such systems need space (to keep enough distance to their neighbouring building, but also to their own) or additional noise protection measures need to be implemented. As respective costs are often not negligible (see SFOE project LICS), they have an impact on the choice behaviour.

Spatial determinants on the choice of heating systems are also discussed in literature. McCoy and Curtis (2018) explored the spatial and temporal determinants of gas central heating adoption and Curtis et al. (2018) show that proximity to gas network is a key determinant of home-owners home heating choices.

2.3.5 Adjustment of energy cost calculation approach

Currently, the implementation of the energy cost calculation approach is quite simplified (see equation 2). The goal of the methodological improvement is to better incorporate energy tariff schemes and regulation such as feed-in tariffs, capacity vs. energy pricing. To this end, additional terms are added to equation (2). To specify respective data, the energy consumption procedures need to be amended, particularly in terms of building related energy production (e.g. from PV), the calculation of own consumption vs. feed-in energy, the effect of thermal or electric storage etc. Also, the so-called energy performance gap (EPG) will be incorporated, which means to adjust demand calculation based on SIA 380/1 (e.g. by adjusting indoor temperature levels). First respective attempts have been undertaken in Jakob et al. (2021) and the subsequent application of the methodology developed therein (Jakob et al. 2022).

2.4 Calibration of the parameters of the decisions functions

At the national scale and for the purpose of national ex-post analysis (results for Switzerland broken down by various dimensions, e.g. energy carrier, sub-sector, building type), the BSM currently is calibrated as follows:

- The current data from the global energy statistics (SFOE, 2021b) and the electricity statistics (SFOE, 2021c) form the basis for the calibration of the model. For the tertiary sector, another important source is the survey of energy consumption in industry and the service sector by sub-sector (Helbling Beratung + Bauplanung AG, 2021). The model input data and parameters are adjusted to the first two data sources in such a way that the level as well as the trends and their changes correspond on average, but without scaling the individual annual values to the energy statistics. This approach is justified, among other things, by the uncertainties of the bases with regards to year-to-year changes.
- At the sub-sector scale of, the model results are compared with the energy consumption survey (Helbling Beratung + Bauplanung AG, 2021) and individual model parameters are iteratively adjusted in such a way that the level and trend in the model are brought into line with the empirical bases, provided that the empirical data are judged to be sensitive.

To improve calibration with regard to modelling the effect of policy measures and of shocks, and for local applications of the sBMS (e.g. for the case study Zurich in SURE’s WP 14), new calibration routines need to be developed. The principal approach shall remain the same: uncertain model input data and model parameters are adjusted with an adequate approach (e.g. iteratively or with other feedback-based approaches, to be explored) in such a way as to improve the fit between model output and empirical data.[8] However, such adjustments shall only made within “reasonable” boundaries. This means that

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[8] More specifically, modelled energy consumption (final energy by energy carrier) is compared with measured energy consumption.

data and parameters are only varied within plausible and meaningful ranges to maintain interpretability of such data and parameters.

A better fit between models and empirical data is achieved by the following steps:

1 Improving the data base, particularly regarding the feasible choice set of energy options (respective fundamentals have been achieved in earlier projects of TEP Energy and further improvements are ongoing, to be described separately)
2 Improving and expanding the decision module
   a. Differentiating the utility function of the different decision modules (e.g. regarding owner attributes)
   b. Base parameters of the utility functions on empirical data
   c. Re-design the utility function (e.g. to take into account interaction effects)
3 Further developing the calibration approach
   a. Taking into account additional types of output (e.g. market shares or sales data)
   b. Develop a calibration routine (feedback loop or stochastic optimisation) with a focus on the lower part of Figure 3, i.e. taking into account decision module, different output dimensions, and respective empirical data.

Once step 1 is concluded the sub-sequent steps are implemented. Next to implementing the improvements regarding step 2, a calibration routine needs to be developed (so far calibration is done manually based on an iterative approach).

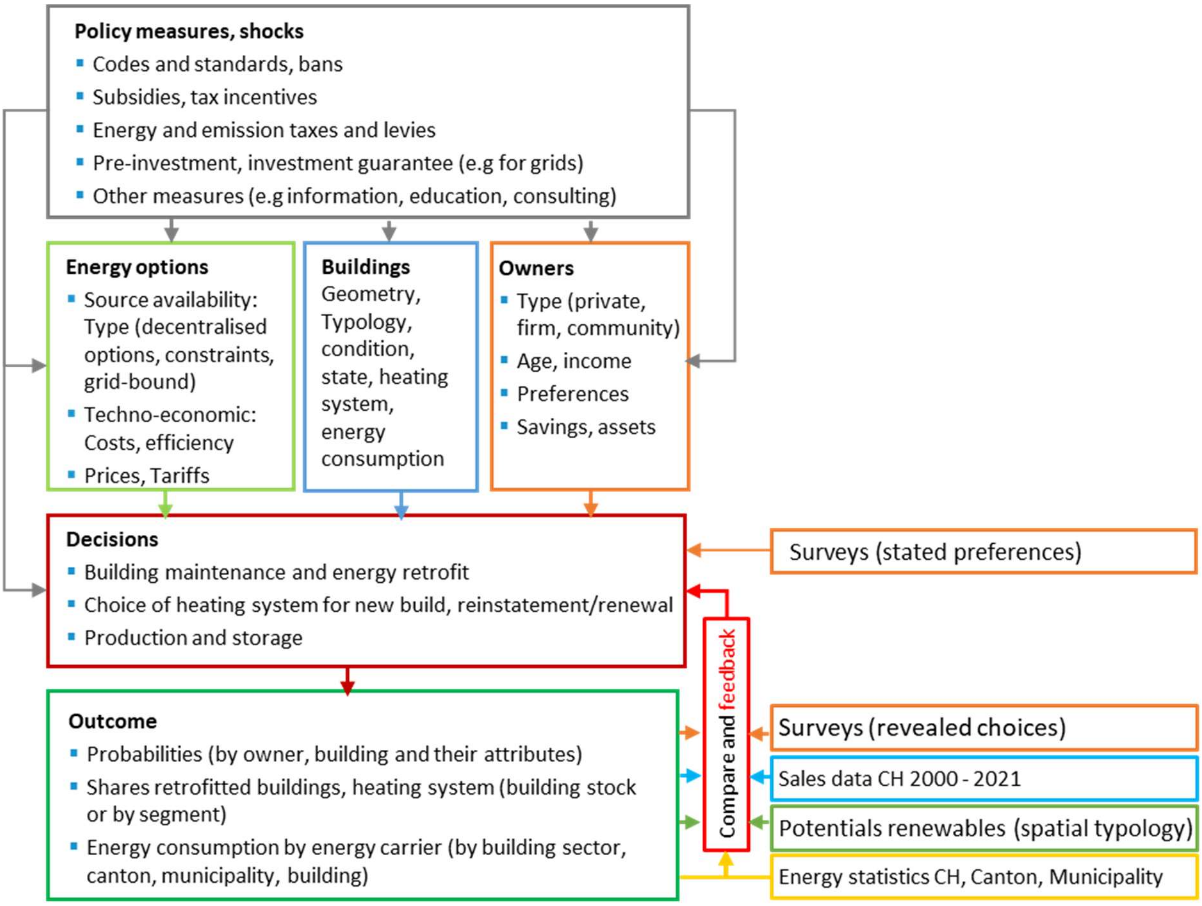

Figure 3 Structure of the sBSM: simplified representation with a focus on the decision module and its calibration.

3 Conclusion

This report addresses several methodological developments to improve the spatial building stock model (sBSM) and the related spatial energy assessment toolbox (SEAT). The main focus is put on a central element of the sBSMthat enables to steer various scenarios. Scenarios and shocks as defined in the SURE project are modelled more adequately with the proposed improvements.

In a next step the different methodological improvements need to be implemented. Such an implementation requires both coding and iterative parameter adjustments. The latter particularly is needed to determine the parameters (coefficients) of the different decision functions.

Further methodological improvements (e.g. improve the methodology of spatial constraints and renewable energy source availability within SEAT and the automation of the exchange between the sBSM and SEAT) will be defined and described separately. Also, the outcome of the implementation of the methodology will be reported in further deliverables of SURE and/or papers.

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Appendices

4.1 Appendix 1: List of abbreviations

BSM	Building Stock Model
DC	Discrete Choice
DSM	demand side management
EPG	Energy Performance Gap
EU	European Union
FOS	Federal Office of Statistics
GWR	Gebäude- und Wohnungsregister (Buildings and Dwellings Register)
LICS	Low-Invest-Cost-Solutions
MISTEE	Motivations to Invest in Smart Technologies and Energy Efficiency
R&D	Research and Development
PV	Photovoltaic
RFA	Reference floor area
sBSM	spatial Building Stock Model
SEAT	Spatial Energy Assessment Toolbox
SFOE	Swiss Federal Office of Energy
STATENT	Statistique structurelle des entreprises (structural statistics of enterprises)
SURE	SUstainable and Resilient Energy for Switzerland
TEP	Technology Economics Policy
WIS	Wärmeinitiative Schweiz
WP	Work Package
WTI	Willingness to Invest
WTP	Willingness to Pay

4.2 Appendix 2: Description of the building stock model (BSM) and of the Spatial Energy Analysis (SEA)

Structure and calculation approach

In SURE's WP 4 energy demand is calculated using the TEP BSM model (residential, tertiary and industrial buildings sectors). The BSM covers the physical sphere (building stock), the techno-economic sphere (building technologies, efficiency measures), the socio-economic sphere (owners and their decision behaviour), the policy sphere, and the contextual sphere (availability of energy sources and infrastructure). An overview of the model structure and the dependencies between these spheres is given in Figure 4 below.

The TEP BSM model follows an agent-based bottom-up approach that differentiates between economic sub-sectors groups (31 sub-sectors in the service sector and one in the agricultural sector) and between different energy applications (see SFOE projects Building Technology Potentials (Jakob et al. 2016a) and GEPAMOD (Jakob et al. 2016b)).

The model describes a large number of (virtual or individual) buildings with different geometries and different use mixes, whereby their statistical distributions are based on corresponding fundamentals:

- For the geometry (building form), different building types are created using data from the swisstopo Swiss 3D model.
- The mix of uses is based on the sector mix according to STATENT and, with regards to the proportions of the different building periods, on the FOS GWR.

The results calculated on the basis of the virtual buildings are scaled to the effective energy reference areas at the end (per sector and building period).

Based on this approach of representatives, the structure of the BSM is similar to that of well-known botton-up models in the building sector: a quantity structure (here mainly RFA, partly employees) is linked to specific consumption values. The resulting useful energy demand is then covered by different technologies. In the heating sector, technologies with various energy sources are used for this purpose; for the other applications such as lighting, ICT, etc., usually only electricity is used (for cooling, district cooling can also be used). These different elements of the bottom-up approach are discussed in more detail below.

Quantity structure

For the model calculations, the framework data for employees in the sense of full-time equivalents (based on the following FSO sources: STATENT, BESTA, ETS), energy prices and numerous other model input data are updated for all years. Other data relate to individual uses such as the annual SLG lighting market study and further, more detailed data from the SLG for the lighting sector. The adjustment to the current weather conditions (by means of HGT and CDD) is carried out individually for the individual uses in a later work step.

Heat demand

The calculation of the heat demand is based on the calculation standard SIA 380:1:2016. The input variables required for this relate to:

- Geometry data: Areas of walls, roofs, windows and glazing, etc., derived from the Swisstopo 3D model and evaluations by TEP Energy via Google Street View.
- Energy-relevant building parameters: U-values and g-values as well as shading factors based on various studies, research reports, SIA principles and energy regulations of the last decades,

differentiated according to the construction period of the buildings and according to energy renovation status.[9]

- Occupancy data: Assumptions on internal heat loads due to people and equipment as well as on thermally relevant air exchange depending on the sector mix in the buildings.
- Operational data such as assumptions on time of use and use of solar shading.

The TEP BSM model also takes interaction effects into account: This applies in particular to the area of air exchange, i.e. the year of installation of windows (due to tightness), the presence of a ventilation system (with or without heat recovery) are integrated into the simulations. In the area of space heating, the effects of internal heat loads are directly linked in the model to the electricity consumption of corresponding applications.

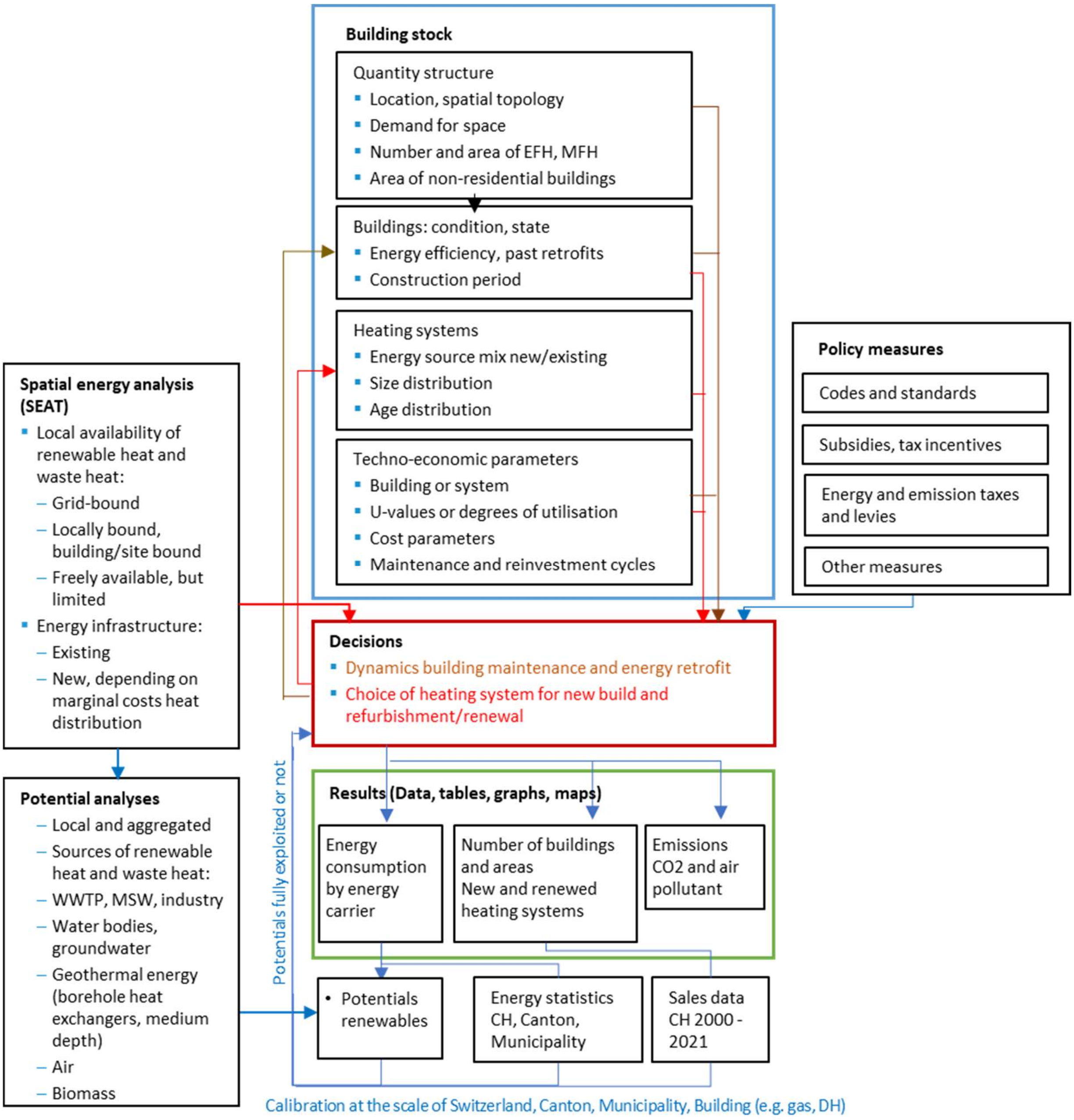

Figure 4 Structure of the spatial Building Stock Model (sBSM) and Spatial Energy Assessment Toolbox (SEAT)

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[9] For an example, the reader is referred to the Technical Report of the Energy Perspectives 2050+ of the SFOE where an overview of the assumptions on the U-value development is given. Data is displayed for new buildings in the WWB scenario (Table 113) and for renovations in the ZERO Basis scenario depending on the depth of renovation (Table 114 to Table 116)

Choice of heating system and energy source

The choice of the heating system or the energy carrier(s) for new buildings and for heating system renovations is made per representative via a micro-economic decision module. The decision of the building owners and investors is simulated by means of a utility function. This takes into account investment, operating and maintenance costs as well as other criteria. In particular, the availability of market supply and of grid-bound energy sources as well as restrictions (e.g. due to space and noise problems) are also taken into account. The latter are determined by means of dedicated GIS analyses (see corresponding chapter in the main part of the Technical Report of Energy Perspectives 2050+).

Because both investment and running costs for energy and maintenance are included in the benefit function, various energy and climate policy instruments can be mapped directly. This applies, for example, to subsidies, tax concessions, the CO2 levy, special tariffs, etc. The parameters of the benefit function and the behaviour of the building owners (choice decisions, trade-offs) are validated by means of empirical studies, which are carried out e.g. within the framework of the EWG programme of the SFOE.

An important basis of this decision module is formed by various techno-economic data such as investment costs and utilisation rates (see corresponding assumptions in the main part of the report). These are determined on the basis of current studies such as the SFOE projects INSPIRE and Low Invest Cost Solutions (LICS), differentiated by building type. In particular, it is taken into account that when switching to a different heating system, conversion and adaptation costs are incurred (often also on-site), which can be considerable.

Electricity-based energy applications

With regard to energy applications, the model is based on the version of SIA 380/1 (SIA, 2016) that came into force in 2018, the current version of the standard utilisation conditions SIA 2024 (SIA, 2015) and the latest findings that have emerged in the course of revising this code of practice. This applies to both calculation methods and characteristic values. This makes it possible to achieve a good demarcation between the areas of drives, process heat and air conditioning, ventilation and other building services.

The specification of energy efficiency measures (so-called Energy Saving Options, ESO) is also partly based on the aforementioned principles. In addition to these SIA principles, findings and data from various projects of the SFOE and TEP Energy were included, e.g. on the topic of ventilation and cooling (TEP Energy, 2013), the SFOE project on the potential assessment of measures in the area of building technology (TEP Energy, 2016a) and the FOEN project on the sub-sidiary ban of fossil heating systems (INFRAS and TEP Energy, 2017, p. 2017). Compared to past analyses, this allows for a better empirical foundation of the model. Other specific energy applications, namely those outside the building sector (e.g. transport and communication infrastructure), were introduced into the model as required. The model also covers the buildings of the transport sector and the agriculture sector. The allocation matrix between energy applications according to the TEP BSM and the uses distinguished in the Energy Perspectives 2050+ is shown in Table 112 of the Technical Report of the Energy Perspectives 2050+.

System boundary

The heat energy and electricity consumption per energy use determined with the TEP BSM model is then aggregated to different uses. For heat energy, space heating on the one hand and hot water and process heat on the other hand are modelled separately. The consumptions are aggregated in such a way that they correspond to the specified uses of the total aggregation. For fuels, it is assumed that the entire consumption of the service sector occurs within the buildings. As for electricity, building related outdoor consumption and consumption of non-heated floor area, e.g. in basements, storage rooms and parkings, are also considered. Respective consumption, particularly for lighting and ventilation, is determined with individual ad-hoc approaches.