Matching energy targets, stakeholders' needs and modelling choices in developing urban energy scenarios

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Abstract In order to meet greenhouse gas reduction goals, cities need to develop robust energy transition strategies relying both on the local capacity of combining social, economic and environmental perspectives in the decision-making process and on the collaboration between different actors to achieve knowledge and data integration. Scenarios are well-established methodological instruments to guide decisions in energy and spatial planning and have been employed to compare possible future pathways and envision the consequences of implementing decarbonization measures. However, qualitative and quantitative scenarios approaches are often disconnected. With the primary goal of supporting the implementation of the energy plan, this study develops for the City of Gothenburg a participatory method to support the alignment of qualitative and quantitative scenarios approaches. Decarbonization actions and drivers of change were discussed and prioritized in workshop sessions with representatives from the energy supplier(s), municipal administrations (city planners, environmental department), and researchers to develop relevant qualitative scenarios descriptions. Based on this, a list of requirements for quantitative scenarios analysis is developed to be, in a next step, translated and integrated into urban building energy models. Findings indicate the importance of early knowledge integration from different fields and highlight the lines of advancement in urban energy modelling to facilitate decision-making towards successful implementation of decarbonization targets.

Keywords: Building stock, scenario method, stakeholders engagement, energy demand, urban building energy model

1. Introduction

Municipalities and regions play a crucial role in climate and energy transition processes. In Europe, to meet the challenging target set for 2030 [1], city and regional communities are engaged in developing comprehensive plans to define and implement effective energy strategies to reduce greenhouse gas (GHG) emissions, increase production from renewable sources, and increase energy efficiency. The development of robust urban strategies requires analyses and instruments to support decision-making. Specifically, taking decisions about the energy future of cities means dealing with highly complex systems, a high level of uncertainty and a variety of actors that bring their perspective and expertise which makes it difficult to identify common/shared pathways to follow. Thus, despite setting common visions is fundamental to align the implementation of measures and prioritize interventions, it is a challenging task for urban communities.

In the context of energy and urban planning, scenarios are widely applied instruments as they allow to explore and evaluate the possible impacts of long-term decisions. Scenarios can be defined as descriptions of alternative images of the future, created from models that reflect different perspectives [2] and can be classified into three major categories according to the objective of the investigation [3]: a) Predictive scenarios address the probability of events, b) explorative scenarios explore the results of possible decisions or change in conditions, while c) normative scenarios analyse how a certain target can be reached. Another classification divides scenarios based on their qualitative and quantitative approach. While quantitative scenarios approaches enhance the description of possible futures through numerical assessments and complex modelling methods [4], qualitative ones, through participatory activities, allow to develop common visions and analyse multidomain processes that cannot be entirely quantified [2].

Although a few attempts in integrating qualitative and quantitative approaches have shown that combined methods increase the robustness of scenarios and their value for informing decision-making [5,6], the large majority of scenarios developed in the energy fields continues to apply solely quantitative approaches and neglects the important trade-offs between social, technological and economic factors. According to Eker *et al*. [7, p.27] involving stakeholders in model-based representations can "*enhance learning and credibility, and can extend the analysis to identify (socially) robust policies*". However, generally model-based and analytical methods employed in energy scenarios, do not take into account the multiplicity of stakeholder perspectives. Additionally, assessments of climate and energy policies "*lack a simple, transparent, interactive and structured way to incorporate stakeholders' views and objectives"* [8, p.436].

To meet this demand and support the development of exploratory instruments that can better inform decisions in the energy transition context, a method is being developed in the ongoing research project "Digital twin for modelling future energy demands in the Gothenburg building stock", which employs a participatory approach to support the energy transition in practice in the City of Gothenburg with focus on building stocks. The aim of the research project is to develop instruments to help local decision makers in the process of selecting and prioritize energy strategies and further assess the consequences of their implementation. As a part of the project, this study introduces a scenario method to identify key drivers of change and decarbonization actions and envision the possible impacts on energy supply and demand in the form of qualitative scenarios (QLs). The application of the method on the Gothenburg case study is described and resulting scenarios are presented. Finally, the study discusses what characteristics UBEM should have in order to support the translation from qualitative to quantitative scenarios (QTs).

2. **Methodology**

Building on the need for combining qualitative and quantitative scenarios approaches, literature studies and scenario development have been applied together with a participatory method. A half-day online workshop was carried out with invited local stakeholders, representing energy supplier(s), municipal administrations (city planners, environmental department), and researchers. The methodology can be divided into 4 steps.

The first step had the goal of identifying key decarbonization actions and drivers of change and to select the categories of scenarios to be applied. Based on a review of scientific literature and the Gothenburg Energy Plan (GEP) [9] a list of potential actions and drivers for future development paths was compiled by the researchers. The actions identify energy measures that can be implemented in the future to reduce energy-related GHG emissions, while the drivers are independent external factors that can modify the speed of the energy transition and are not directly controllable by local actors, but rather depend on global and national processes. For the QLs, explorative scenarios were selected as they allow to explore results of possible decisions or change in conditions following the distinction between external and strategic scenarios [3]. The second step aimed at prioritizing the listed decarbonization actions and drivers of change to investigate. In the workshop the participants were asked to score the relevance of both decarbonization actions and drivers of change individually and thereafter the 3 highest ranked actions were discussed in more depth in groups and documented using the online collaboration platform Miro. The third step investigated the possible consequences of systemic changes on the energy transition of the building sector by using QLs.

External and strategic scenarios were developed and the workshop participants were asked to describe two sets of possible visions based on the three actions and drivers identified as highly important. External scenarios explored the consequences of urban and national drivers that can hardly be influenced by local actors but modify the context in which energy strategies have to be implemented and thus should be addressed to build robust strategies. These scenarios answered the question “how the drivers can influence the system?”. Strategic scenarios explored the consequences of decisions answering to the question “what can happen if we act in this way?”. Additionally, actors indicated the quantitative studies necessary to further investigate the scenarios’ results. In the last step, the characteristics of UBEM were analyzed by the researchers to understand how to translate and support the modelling of QTs aligned with the stakeholders’ request for assessment.

3. **Results**

In this section the discussed decarbonization actions and drivers of change are presented followed by the three elaborated strategic scenarios (Smart scenario, Building intensity scenario, and Green intensity scenario) and the three external scenarios (Extreme climate scenario, Electricity price scenario, and Electrified mobility scenario). For each of the QLs, assessment points for conversion into QTs have been identified.

3.1. Decarbonization actions and drivers of change

The identified listed actions can be divided in three categories: building, transport and city-oriented. Regarding buildings, actions to reduce energy consumption include i) improvement of the building design such as increasing the building compactness to reduce thermal losses or application of solar shading and passive solutions to reduce cooling related demand, ii) installation of efficient energy systems such as heat pumps, iii) solutions to support behavioral changes such as lowering indoor temperature to 20°C, installation of smart meters, individual meters in multifamily houses, and control temperature systems in offices [10,11], and iv) economic incentives to promote response to a flexible electricity market and to encourage builders to employ more efficient solutions in construction [10].

For the transport sector the actions comprise implementation of planning models for supporting biking and walking modes, and improving efficiency and accessibility of public transport by increasing built density [12]. Additionally, increasing the access to electric vehicles (EVs) chargers is a measure to support the electrification of private transport. Finally, city-oriented actions propose interventions i) to reduce the need for cooling by increasing vegetation coverage and implementing heat mitigation measures and ii) to support clean energy supply by reusing waste heat and cold at the neighborhood and by producing electricity with photovoltaic (PV) panels and implementation/extension of district cooling network.

The list of drivers includes climate, economic, and social-technical factors that can influence the energy transition process and accommodate both risks and potentials for the energy plan implementation and achievement of secure energy systems. Among climate drivers, the urban heat island (UHI) effect, overall global warming, and extreme events are listed as phenomena that can modify building energy loads and put at risk a secure supply [13,14]. Economic drivers, such as the change in property values through energy performance certificates (EPC), change in electricity price, cost of green electricity and materials, can affect the velocity of transition as well as the investments [15]. From a technological perspective the drivers in the list concern the level of penetration in society of techno-oriented solutions such as EVs, smart energy systems and efficient appliances in houses, high performative materials, and air conditioning [16]. These factors can drive changes in future energy consumption. Additionally, the list contained social drivers that can influence energy demand and the investment capacity such as changes in income level, composition of households, population age, the floor space per capita, and the total floor area used in the city for different purposes (housing, offices, production) that can variate in time. Among drivers with a social dimension, the list includes the level of education of builders, building owners and tenants on the use of energy efficient solutions, system approach and request of EPC respectively [17].

By scoring the relevance of actions, the workshop participants identified the introduction of smart energy systems, the increase in built density and green coverage in the city as highly important. For the drivers of change three key factors were identified: extreme climate events, electricity price and EVs penetration, see Table 1.

Table 1. Importance of decarbonization actions and drivers of change rated by local actors in workshop. *Rated relevance. 1=high relevance

R*	Actions	Drivers
1	-Smart energy systems (smart control/storage)	-Extreme climate events (heatwave, flooding)
2	-Increase of urban density	-Electricity price
3	-Increase of urban green coverage -Incentives for builders to push efficient but costly options in construction	-Penetration electric vehicles
4	-Plan areas to reduce energy-intensive transport -Solar electricity production	-Income level
5	-Implement urban heat mitigation measures -Reuse of waste heat/cold at neighbourhood scale -Electrification of private transport-increase access to charges points	-Material recycling rate -Global warming (average temp. increase) -Cost of green electricity -Floor space per capita
6	-Apply passive energy measures -Heat pumps installation -Incentives to promote response to flexible market -Lower indoor temperature	-Waste to energy -Costs of materials -Consumer response to flexible energy system -Number of people per household
7	-Control indoor temperature in office -Increase solar shading -Individual metering in multi-family houses	-Use of electric equipment in houses
8	-Implement district cooling network -Increase building compactness	-Urban Heat Island -Penetration of high performative materials -Owner knowledge on system approach -Builders knowledge on new technology
9		-Property value based on EPC -Population age -Tenant demand for EPC -Penetration of air conditioning

3.2. Strategic Scenarios

The strategic scenarios, are explorative scenarios that present possible impacts in applying decarbonization actions and lists quantitative analyses necessary for assessing the energy consequences of the qualitative storylines. The scenarios were identified through ranking during the workshop.

3.2.1. Smart scenario

Using smart energy systems in buildings is one of the stakeholders' highly ranked decarbonization actions. This first scenario depicts a future based on the widespread diffusion of smart meters and energy storages. Peak demand in buildings is reduced because users are more aware of their demand and are better informed when their appliances are activated. Data from smart meters are shared with energy providers and researchers supporting more accurate predictive analysis of energy consumption and user behaviors. Further, the gathering of real-time data allows providers to manage the supply to the electricity grid, district cooling, and heating network in a smart way and, by that, to reduce the risk of supply disruption. However, the massive introduction of this technology has a considerable environmental footprint in terms of new raw materials and CO_2 emissions for production of components, assembly and distribution. From the user perspective, people with low-tech interests or limited education are left behind and the increase of cyberattacks requires further improvement in security to protect private information.

To estimate possible consequences of smart energy systems, QTs should assess: 1) Patterns of energy demand and peaks among group types (building functions, behavioral models); 2) Impacts of flexible models to reduce peak demand.

3.2.2. Building intensity scenario

This scenario is based on the sustainable compact development model for the city, which implies the increase of built density as alternative to a horizontal expansion. The application of this measure in a long-term perspective contributes to reducing carbon emissions by providing more efficient land use, avoiding car-dependent diffused urbanization (sprawl) and saving space for food production and natural environment. GHG emissions are exponentially reduced because in a high density and compact urban environment, public transport means deliver a good service in terms of frequency and coverage, becoming a strong competitor to private cars. The high density of services and activities as well as the high level of accessibility also encourage 'slow' mobility (biking, walking). Additionally, the energy distribution of district heating and cooling is more effective because of the low-temperature losses of pipes. The closeness of different building functions creates more opportunities for creating synergies among them, exploiting and reusing waste heat and cold. On the other side, less open space is available to accommodate energy transition measures (i.e., production through renewables, infrastructure for EVs), stormwater management solutions, ecosystem services, enhancing the competition for the use of soil and sub-soil. From a climate perspective, higher density causes an increase in the magnitude of UHI effect. Urban warming combined with higher global temperatures raises energy consumption for the space cooling of buildings. Energy production facilities and networks being more densely concentrated become also more vulnerable to extreme events caused by climate change, such as heavy rainfall and river-flooding.

To understand the consequences of increased built density, QTs need, according to the workshop participants, to assess: 1)Energy demand and GHG emissions for the transport and building sector in future conditions of higher urban density; 2)Impact of land cover and density scenarios on energy production through renewables and on use of waste energy flows; 3)Effect of density on UHI effect on yearly buildings' energy demand and peak loads.

3.2.3. Green intensity scenario

The scenario embraces the action of increasing vegetation coverage as a possible decarbonization solution. In this scenario, green areas in the city reduce the negative impacts of heat waves on people's well-being and reduce the magnitude of UHI effect. A highly green urban space provides (high level of) thermal comfort to perform outdoor activities, accommodate nature-based solutions for stormwater treatment and ecosystem service. A high level of vegetation coverage contributes to lower energy consumption for cooling buildings during summer and extreme hot events. Additionally, trees function as a natural carbon sink due to photosynthesis processes. However, dedicating more space to parks and green areas within cities has a result on the urban development model, supporting the horizontal expansion and diffuse forms of urbanization (sprawl), which in turn increases car mobility and the cost for energy infrastructures that have to cover larger areas.

The translation from QLs to QTs should support the assessment of: 1)Annual building energy demand in scenarios of high and low green coverage; 2) CO_2 balance between anthropogenic production and sinking due to vegetation; 3)Size effect and distribution of green areas on urban temperatures and building cooling demand; 4)The cooling benefit of multiple green solutions, such as green roofs and envelopes.

3.3. External Scenarios

Driving urban energy systems towards a decarbonized future implies achieving security and resilience regarding service disruptions. The workshop highlighted three main drivers of change that require urgent investigations as they might challenge the security of provision and the speed of the decarbonization process. Drivers of change are usually external factors that cannot be influenced but to which the urban energy system need to adapt.

3.3.1. Extreme climate Scenario

This first scenario builds on the changes induced by a climate driver. Climate change and increased average temperatures reduce heating days and increase cooling days per year in the Nordic climate zone. However, the higher frequency of extreme events challenges the security of provision, requiring big investments to increase robustness and the resilience of the supply infrastructure, to reduce potential disruptions of the service. More frequent heavy rainfalls translate into more frequent flood events posing at risk the distribution of energy and the integrity of infrastructures in the subsoil. Cold and heat waves result in high peak demand for cooling and heating of buildings. The management of district cooling and heating infrastructures presents an optimization problem. On the one hand, the average daily demand for cooling and heating decreases due to overall climate warming and the increased efficiency of buildings. On the other hand, the production is dimensioned upon peak demand calculated for extreme and winter temperatures, resulting in substantial economic investments for construction and maintenance of the infrastructure.

To convert this QLs, energy QTs should assess: 1)Building energy demand in scenarios of climate change; 2)Spatial distribution of building peak loads during extreme cold and heat events; 3)Supply infrastructure vulnerability analysis due to extreme events.

3.3.2. Electricity price scenario

This scenario builds on the uncertainty in electricity prices identified by stakeholders as the second important driver. The scenario conveys the close interconnection between the economic dimension and the speed of the decarbonization process. Specifically, the increase or decrease of electricity price was described as a major factor influencing both demand and supply. Assuming that district heating and cooling remain stable systems, electricity is used predominately for appliances, private and public transport and industry. High electricity price encourages reducing electricity consumption and pushing consumers to monitor their demand and their appliances use, as well as companies to provide more details about products and their efficiency. Producing green electricity becomes more profitable also at the small scale, motivating private investments for PV systems installation and EVs. At the opposite, low electricity price results in electricity consumption increase and reduces investments in renewable production.

An important point highlighted is also the fluctuation in the short and long term, since investments decisions are based on long term forecasts. Specifically for energy-intensive industry, the prognosis of future electricity price is a driver for the transition towards more efficient energy systems and equipment. Investments however happen only if electricity price is expected to be high in a long-time span. To quantify the consequences of electricity prices, economic and energy assessment models should focus on behavioral change in energy consumption and investments.

3.3.3. Electrified mobility scenario
This third scenario is driven by the uncertainty that accompanies the penetration of EVs in the Gothenburg context. Electric private vehicles are promoted in the GEP as a solution for reducing carbon emissions. However, the level of penetration in market and society can drive significant variations in urban electricity consumption and it's governable to a certain degree. The energy providers are responsible for preparing the grid for handling charging loads and guaranteeing access to charges. A high level of penetration results in exponential rise in electricity demand and peak loads, requiring significant investments to raise the power supply and redesign public spaces and facilities to accommodate parking and chargers. Car traffic remains a major problem. A lower level of penetration results in a moderate increase in electricity demand and investments can be equally distributed for improving public transport efficiency and accessibility.

To convert this QLs, QTs should assess: 1)EVs electricity demand in scenarios of high and low penetration; 2)Spatial distribution of electricity loads due to EV (low and high penetration).

4. **Discussion: UBEM characteristics for quantitative assessments**
Strategic and External QLs clearly highlighted uncertainties and concerns for a successful city transition. Stakeholders pointed out that quantitative analyses need to be carried out to provide energy assessments and support decision-making. Concerning the translation from QLs to QTs, this section discusses data and energy modelling characteristics that would allow such a translation specifically for building stocks. The translation in a future stage would allow to estimate the effectiveness of measures and the impact of drivers, but also to advance the analysis of the trade-offs between of aspects that were now kept separate in the QLs (for example, increasing building density might result in decreased available space for vegetation).

Although more holistic approaches allow integrated modelling of energy generation, distribution and consumption (eg.City Energy Analyst, CityGML ADE) when focusing on building stocks, urban building energy models (UBEM) are an important and widely used support for understanding the overall energy performance of buildings at the city scale.

UBEMs can be divided into top-down and bottom-up models [18]. Existing studies have proven bottom-up approaches to be advantageous for in-depth building analysis because of their clustering of building characteristics at a fine level. [19]. Top-down approaches, at the opposite, use statistical data and macro predictors resulting in large scale analysis with a course resolution and therefore they can predict future trends only based on past interconnections without spatial or temporal details [20].

While scenarios on Electricity Price fluctuation can be carried out based on past data through top-down models, the scenarios Smart, Building Intensity, Green Intensity, Extreme Climate, and Electrified Mobility should use bottom-up UBEM at a finer data resolution. Bottom-up UBEMs employ physics-based approaches and have been applied in similar categories of studies [21]: planning and design of new developments, energy saving when applying retrofitting measures, building level optimization measures and building-to-grid integration. However, in order to model the identified scenarios a few requirements need to be satisfied. Bottom-up UBEMs require geometric data (building shape, height, floor area), building thermal properties (envelope characteristics), information about occupant behaviors (occupancy factor, schedule) and employed energy systems. Thus, datasets containing geometrical and non-geometrical parameters of buildings are essential for setting energy simulations and are usually extracted from municipal data. Increasingly data standards such as CityGML and GeoJASON are used for storage within digital twin platforms. However, to model energy demand, production and reuse in Green Intensity and Building Intensity Scenarios spatial data about the future urban development should be created in coherence with planning instruments and city visions that usually employ different data formats. Additionally, to model future building stock scenarios requires the development of assumptions regarding technical façade solutions, construction materials for new buildings, and degree of retrofitting of the existing building stock. Usually, data on building systems and their efficiency are retrieved by EPCs or assumed based on archetypes [22]. When simulating future urban developments or long-term scenarios, assumptions are needed on the penetration of efficient energy systems (e.g., heat-pumps).

Scenarios modelling for Electrified private mobility requires estimation of electricity loads at the building level taking into account EV charging loads. However, today typical UBEMs do not allow to calculate the demand for private transport charging. As pointed out by Sola et al. [23] transport-related energy demand is mainly assessed through Land Use and Transportation models which are usually targeted on agent-based models and need further integration in multidomain simulation environments.

Significant inputs in UBEMs are also occupant-related parameters. Generally, deterministic occupant schedules are used due to the lack of more accurate data to determine dynamic schedules. According to Dabirian et al. [24] sub-modules for occupancy simulations should be considered for more accurate estimation of internal heat gains, setpoint temperatures and appliances and lighting schedules. Similar sub-modules are required for the simulation of Smart scenarios, where smart meters use and flexible behaviors should be modelled to assess reduction on electricity peak demand. This requirement is connected to what pointed out by Ferrando et al. [20] whom suggest advancements in UBEM to account for the impact of behavioral changes over time on energy demand of buildings. In a longer perspective, data driven modelling would be possible due to data gathered through smart energy monitoring and would create more accurate results.

For Building Intensity and Extreme climate scenarios, local actors highlighted the importance of modelling energy demand accounting for the future climate in which buildings will perform. However, the majority of UBEM methods rely on a Typical Meteorological Year containing hourly values for a number of climate variables retrieved at rural weather stations and manipulated statistically [25]. QTs to address future climate extremes and UHI thus require the use of different climate datasets more accurately in picturing climate change and urban temperatures. At the city scale, there is a need to consider urban climate phenomena and the trade-off between spatial characteristics and energy demand for cooling and heating [26]. Chain and coupling methods between urban climate and energy models have been tested at different scales [27] and can also be used for more accurate estimation of the impacts of extreme climate events and temperature change on energy demand of buildings [28]. However, the main limitation concerns the computational costs of microclimate modelling tools, that do not allow an annual simulation on an hourly data resolution [29].

Additionally, to model the comprehensive effects of Building and Green Intensity Scenarios on building energy demand, heat flux between surfaces (buildings, pavements, soil) and vegetation needs to be calculated within UBEM. Vegetation including trees, green roof and facade solutions have an effect on shading, airflows and heat exchange and thus on buildings thermal behaviors [30], while pavements and materials modify the level of heat absorption. However, traditionally building simulations simplify heat exchange and long wave radiations. Only a few simulation engines, such as CitySim and EnergyPlus include features to increase the accuracy for such calculations [31]. Regarding data, characteristics of trees and other green solutions on facades and roofs should be included in datasets reporting relevant parameters such as geometry, Leaf Area Density and thermal characteristics of species.

5. Conclusions

The presented scenarios method contributes to advance the development of knowledge and instruments required to support decision-making in achieving decarbonization goals. The participatory approach, built around the integration of qualitative and quantitative scenarios approaches, supports creation of a multidisciplinary common ground to explore potentials and risks of decarbonized actions and drivers of change. Although the research departs from well-established decarbonization actions, derived from both literature and the GEP, the approach supports the setting of priorities in the research agenda to meet the needs posed by their implementation in local contexts.

Its application in the Gothenburg context shows that actors were able i) to score the relevance of actions and drivers, ii) to describe through QLs possible consequences on transition paths and future energy security, and iii) to convert qualitative descriptions into a list of needed quantitative analysis. Strategic scenarios highlighted the urgency of addressing the consequences of introducing smart energy systems, increasing built and green density on building energy demand. External scenarios underlined the necessity of analyzing how changes in climate, electricity prices and penetration of EVs might affect a secure energy supply. QTs would allow in the future to assess the magnitude of actions and drivers impacts and thus to finally evaluate the importance of their prioritization. Moreover, QLs have focused on individual aspects, reducing the level of complexity of urban systems while QTs can be further used to assess the results of combined actions.

Finally, a discussion was carried out on the data and UBEMs' characteristics that are required to satisfy the needs of decision makers. Specifically, the translation from QLs to QTs highlights that the agenda for energy models' advancement should address i) assumptions' projection for modelling future urban developments (eg. occupancy, retrofitting rate, penetration of efficient energy systems), ii) inclusion of UHI and climate change projections as climate boundary conditions, and iii) increasing the accuracy of long-wave and heat flux calculation.

Future research in the undergoing research project will focus on the quantitative assessments to estimate the magnitude of changes identified and the effectiveness of actions. Additionally, sensitivity analysis might further allow to identify the relevance of system variables.

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References
[1] European Commission 2020 Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562
[2] van Notten, P.W.F., Rotmans, J. (2003). "An updated scenario typology." Futures 35(5): 423-443.
[3] L. Börjeson, M. Höjer, K. Dreborg, T. Ekvall, and G. Finnveden, "Towards a user's guide to scenarios–a report on scenario types and scenario techniques," R. Inst. Technol., no. November, pp. 1–53, 2005.
[4] V. Varho, P. Tapio, Combining the qualitative and quantitative with the Q2 scenario technique — The case of transport and climate, Technol. Forecast. Soc. Chang. 80 (2013) 611–630.
[5] P. Fortes, A. Alvarenga, J. Seixas, and S. Rodrigues, "Long-term energy scenarios: Bridging the gap between socio-economic storylines and energy modelling," Technol. Forecast. Soc. Change, vol. 91, pp. 161–178, 2015, doi: 10.1016/j.techfore.2014.02.006.
[6] K. Kowalski, S. Stagl, R. Madlener, and I. Omann, "Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis," Eur. J. Oper. Res., vol. 197, no. 3, pp. 1063–1074, 2009, doi: 10.1016/j.ejor.2007.12.049.
[7] S. Eker, E. van Daalen, and W. Thissen, "Incorporating stakeholder perspectives into model-based scenarios: Exploring the futures of the Dutch gas sector," Futures, vol. 93, no. June, pp. 27–43, 2017, doi: 10.1016/j.futures.2017.08.002.
[8] S. Grafakos, A. Flamos, V. Oikonomou, and D. Zevgolis, "Multi-criteria analysis weighting methodology to incorporate stakeholders' preferences in energy and climate policy interactions," Int. J. Energy Sect. Manag., vol. 4, no. 3, pp. 434–461, 2010, doi: 10.1108/17506221011073851.
[9] City of Gothenburg 2020 Göteborgs Stads energiplan 2022-2030. Remiss Version
[10] G. Savvidou and B. Nykvist, "Heat demand in the Swedish residential building stock - pathways on demand reduction potential based on socio-technical analysis," Energy Policy, vol. 144, 2020, doi: 10.1016/j.enpol.2020.111679.
[11] A. Sasic and F. Johnsson, "Energy usage and technical potential for energy saving measures in the Swedish residential building stock," vol. 55, pp. 404–414, 2013, doi: 10.1016/j.enpol.2012.12.023.

[12] A. Månsson, "Energy security in a decarbonised transport sector: A scenario based analysis of Sweden's transport strategies," Energy Strateg. Rev., vol. 13–14, pp. 236–247, 2016, doi: 10.1016/j.esr.2016.06.004.
[13] A. Damm, J. Köberl, F. Prettenthaler, N. Rogler, and C. Töglhofer, "Impacts of +2 °C global warming on electricity demand in Europe," Clim. Serv., vol. 7, pp. 12–30, 2017, doi: 10.1016/j.cliser.2016.07.001.
[14] V. M. Nik, E. Mata, A. Sasic, and J. Scartezzini, "Effective and robust energy retrofitting measures for future climatic conditions — Reduced heating demand of Swedish households," Energy Build., vol. 121, pp. 176–187, 2016, doi: 10.1016/j.enbuild.2016.03.044.
[15] N. Brown, T. Malmqvist, and H. Wintzell, "Owner organizations' value-creation strategies through environmental certification of buildings," Build. Res. Inf., vol. 44, no. 8, pp. 863–874, 2016, doi: 10.1080/09613218.2016.1099031.
[16] E. Koliou, C. Bartusch, A. Picciariello, T. Eklund, L. Söder, and R. A. Hakvoort, "Quantifying distribution-system operators' economic incentives to promote residential demand response," Util. Policy, vol. 35, pp. 28–40, 2015, doi: 10.1016/j.jup.2015.07.001.
[17] M. Nilsson, A. Dzebo, G. Savvidou, and K. Axelsson, "A bridging framework for studying transition pathways – From systems models to local action in the Swedish heating domain," Technol. Forecast. Soc. Change, vol. 151, no. March 2017, p. 119260, 2020, doi: 10.1016/j.techfore.2018.04.003.
[18] L.G. Swan, V.I. Ugursal, Modelling of end-use energy consumption in the residential sector: a review of modelling techniques, Renew. Sustain. Energy Rev. 13 (8) (2009) 1819–1835.
[19] U. Ali, M. H. Shamsi, C. Hoare, E. Mangina, and J. O'Donnell, "Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis," Energy Build., vol. 246, p. 111073, 2021, doi: 10.1016/j.enbuild.2021.111073.
[20] M. Ferrando, F. Causone, T. Hong, and Y. Chen, "Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches," Sustain. Cities Soc., vol. 62, no. June, p. 102408, 2020, doi: 10.1016/j.scs.2020.102408.
[21] Y. Q. Ang, Z. M. Berzolla, and C. F. Reinhart, "From concept to application: A review of use cases in urban building energy modeling," Appl. Energy, vol. 279, p. 115738, 2020, doi: 10.1016/j.apenergy.2020.115738.
[22] Y. Chen, T. Hong, X. Luo, and B. Hooper, "Development of city buildings dataset for urban building energy modeling," Energy Build., vol. 183, pp. 252–265, 2019, doi: 10.1016/j.enbuild.2018.11.008.
[23] A. Sola, C. Corchero, J. Salom, and M. Sanmarti, "Multi-domain urban-scale energy modelling tools: A review," Sustain. Cities Soc., vol. 54, no. October 2019, p. 101872, 2020, doi: 10.1016/j.scs.2019.101872.
[24] S. Dabirian, K. Panchabikesan, and U. Eicker, "Occupant-centric urban building energy modeling: Approaches, inputs, and data sources - A review," Energy Build., vol. 257, p. 111809, 2022, doi: 10.1016/j.enbuild.2021.111809.
[25] Bueno B, Norford L, Pigeon G, Britter R. A resistance-capacitance network model for the analysis of the interactions between the energy performance of buildings and the urban climate. Build Environ 2012;54:116e25.
[26] Ciancio, V., Falasca, S., Golasi, I., Curci, G., Coppi, M., & Salata, F. (2018). Influence of input climatic data on simulations of annual energy needs of a building: Energyplus and WRF modeling for a case study in Rome (Italy). Energies, 11. https://doi.org/10. 3390/en11102835.
[27] N. Lauzet et al., "How building energy models take the local climate into account in an urban context – A review," Renew. Sustain. Energy Rev., vol. 116, no. August, p. 109390, 2019, doi: 10.1016/j.rser.2019.109390.
[28] V. M. Nik, A. T. D. Perera, and D. Chen, "Towards climate resilient urban energy systems: A review," Natl. Sci. Rev., vol. 8, no. 3, 2021, doi: 10.1093/nsr/nwaa134.
[29] X. Li, Y. Zhou, S. Yu, G. Jia, H. Li, and W. Li, "Urban heat island impacts on building energy

consumption: A review of approaches and findings," Energy, vol. 174, pp. 407–419, 2019, doi: 10.1016/j.energy.2019.02.183.
[30] C. P. Skelhorn, G. Levermore, and S. J. Lindley, "Impacts on cooling energy consumption due to the UHI and vegetation changes in Manchester, UK," Energy Build., vol. 122, pp. 150–159, 2016, doi: 10.1016/j.enbuild.2016.01.035.
[31] Xuan, L., & Hong, T. (2019). Modeling thermal interactions between buildings in urban context. In: Proc. BS2019.