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Citation for the original published paper (version of record):

Maiullari, D., Palm, A., Wallbaum, H. et al (2022). Pathways towards carbon neutrality: A participatory analysis of the Gothenburg's energy plan. IOP Conference Series: Earth and Environmental Science, 1085(1). http://dx.doi.org/10.1088/1755-1315/1085/1/012041

(article starts on next page)

PAPER • OPEN ACCESS

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To cite this article: D Maiullari *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1085** 012041

Pathways towards carbon neutrality: A participatory analysis of the Gothenburg's energy plan

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Abstract. Among International Energy Agency members, Sweden is one of the upfront countries in implementing energy policies to achieve zero net emissions. Despite having the lowest share of fossil sources in its primary energy supply, becoming carbon neutral by 2045 is a challenging target. To meet the national goal, cities' roadmaps and strategic plans have a leading role in facilitating the implementation of energy efficiency measures and renewable production systems. However, succeeding in city energy transitions requires envisioning and understanding of risk and vulnerability levels of the new socio-technical energy system. This study presents a review of the City of Gothenburg's Energy Plan 2022-2030 and discusses potential challenges for its implementation. Based on a document study, stakeholder workshop, and interviews the research identifies four key aspects: i) the coordination between energy and urban planning, ii) the future stability of district heating and cooling, iii) the balance in electrification of the buildings and transport, iv) communication and tools in decision-making processes. Finally, the study suggests new measures that should be allocated in the plan to guarantee the development of instruments and analysis for addressing the identified challenges.

Keywords: decarbonization, stakeholders engagement, energy plan, implementation challenges, Gothenburg

1. Introduction

Following the Paris Agreement, all the member States in the European Union are strongly engaged in the socio-economic and environmental transition toward a carbon-neutral society. The primary European targets to meet by 2030 include the reduction of greenhouse gas emissions (GHG) by 40%, the increase of renewable energy production by 32% and the increase of energy efficiency by 32.5% [1]. Sweden, among others, has set even more ambitious targets with the goal of achieving carbon neutrality by 2045. The Integrated National Energy and Climate Plan [2] establishes as intermediate targets for 2030 i) 63% reduction in GHG emissions compared to 1990 ii) 65% share of renewable energy iii) 50% more efficient energy use compared to 2005. Municipalities and regions play a crucial role in the process of climate and energy transition driving local developments through their tasks in town and country planning. In particular, they are responsible for developing comprehensive governing plans to support the definitions and the implementation of effective strategies. In this perspective, the City of Gothenburg has drawn up an exemplary Environmental and Climate Programme 2021-2030 [3] based on three environmental goals for nature, climate and people, that aim to boost biodiversity, a near-zero carbon footprint and a healthy living environment. Additionally, Gothenburg is a member of the Climate Neutral Cities 2030 [4] initiative and has signed the agreement Climate City Contract 2030, a contract between cities, government agencies and the strategic innovation programme Viable Cities in which all parties commit to making concrete contributions to speed up the climate transition. Regarding the climate target 2030, Gothenburg needs to reduce emissions by at least 7.6 % annually. This translates into reducing primary energy consumption in residential buildings and facilities by 30% (compared to 2010), reducing transport-related emissions by 90% (compared to 2010), converting fossil-based generation plants (district heating, cooling, electricity) to renewable sources, reducing emissions from purchases in a life cycle perspective. However, the process of developing effective actions and implementation guidelines from the above goals is still undergoing. Only recently, a preliminary version of The Gothenburg Energy Plan (GEP) [5] has been published. The plan identifies lines of action and related measures that should be implemented between 2022 and 2030. Additionally, it attempts to highlight drivers of change and challenges to address. However, the factors identified partially overlook the potential challenges arising from the dynamic interconnection between innovative practices, set of rules in the local context and long-term exogenous trends, or in other words from the transition of the urban energy system intended as a socio-technical system [6].

In the process of policies and city instruments development and implementation, participatory approaches can help to engage local communities and boost knowledge exchange [7,8]. These, along with the plan development, can not only contribute to identifying transition paths more suitable to the local context but can also point out overlooked dimensions and potentials arising from the interconnections between socio-technical spheres [9]. Thus, the scope of this paper is to analyse the state of the GEP and identify, through local stakeholders' engagement, the specific challenges and potential bottlenecks related to the integration of the social, technological, and spatial dimensions. The goal is to contribute to the future improvement of the GEP and to inform the development of more robust energy strategies. Additionally, since Gothenburg shares many characteristics and sustainability challenges with numerous cities around the world, a study of its energy plan can provide important transferable lessons and can offer valuable insights for researchers and practitioners interested in urban transitions outside Sweden.

The study is part of an ongoing research project "Digital twin for modelling future energy needs in the Gothenburg building stock", which supports the energy transition in practice with a focus on the whole building stock (residential and non-residential) in the City of Gothenburg. The paper starts with a short overview of the actions presented in the published GEP and the identified pressures to achieve the targets. Next, it presents the main challenges identified by local stakeholders as the key factors that need to be addressed in the near future. Finally, conclusions and recommendations are drawn, highlighting critical aspects for the improvement of the GEP.

2. The Gothenburg Energy Plan

The GEP describes the city's mission and represents the joint effort of city authorities to identify the spheres of intervention, offering a comprehensive summary of the paths for the transition of the urban systems. The plan defines eight areas of action, each contains a set of measures for the city to transform its energy system. It also identifies five main challenges related to its energy system.

2.1. Actions and Measures

Table 1 presents GEP's eight action areas and examples of respective measures. Measures to achieve a <u>flexible and capacity-secure energy system (action 1)</u> primarily focus on the investigation and testing of smart control and storage to reduce electricity and heat demand peaks, tests of flexible market and new technologies, development of regional hydrogen strategies and electricity network. Addressing <u>energy efficiency in the municipal sectors (action 2)</u>, the plan identifies measures for retrofitting the existing building stock owned by municipal companies, promoting environmental-friendly constructions, energy saving analysis, and upgrading the technical equipment. For <u>energy efficiency in the private sector (action 3)</u>, the measures primarily include disseminating knowledge on energy efficiency and more explicitly optimizing the return temperatures in district heating and cooling. T<u>hree actions have a focus</u>

on renewable and energy, electricity (action 4), heat (action 5) and cooling (action 6), heat and cooling also includes energy reuse. Related measures promote small and large-scale solar energy plans and the investigation on land use requirements for installations of electricity production. For cooling and heating, both district systems, measures include the exploration of potentials to expand the networks while encouraging heat and cold recovery. Action 7, energy-efficient and fossil-free transport addresses the mobility sector. Measures promote reduction of car traffic in favour of private and shared sustainable alternatives by raising the cost of parking and accommodating space for biking and carpooling. For fossil-free vehicles, measures aim to facilitate access to charging stations for light and heavy transport. Finally, measures for carbon capture storage (CCS, action 8) promote the investigation of new cogeneration plants, biochar production and carbon capture and storage facilities.

For each action, the GEP assigns responsible stakeholders for implementation of the measures, either boards/committees of the city or municipally owned companies (Figure 1). When relevant, measures have a timeframe for completion. The overview of the measures (Appendix GEP) shows that the energy utility company Göteborg Energi (GE) is responsible for the largest number of measures, spread in all eight fields of actions.

Table 1. The Gothenburg Energy Plan's eight action areas, as well as (shortened) examples of their respective measures.

Area of action	**Example measures**
1. Flexible and capacity-secure energy system	a) Introduce technologies/services to reduce peaks in heat and electricity demand; b) Develop a hydrogen strategy; c) Ensure saving in district heating; d) Stabilize electricity need; e) Create conditions to secure energy infrastructure and facilities.
2. Energy efficiency in the municipal sector	a) Investigate energy efficiency measures for owned building stock and street lighting; b) Perform a cost and energy efficiency analysis for existing buildings and new constructions; c) Provide information/incentives for tenants to reduce their energy consumption.
3. Energy efficiency in the private sector	a) Provide advice to private actors (district heating and cooling customers, companies, associations).
4. Renewable electricity	a) Establish a solar energy plan and contribute to small-scale production
5. Renewable and reused heat	a) Investigate combinations of district heating and heat pumps; b) Promote reused heat.
6. Renewable end reused cold	a) Favour district cooling if feasible and make it a competitive alternative.
7. Energy efficient and fossil-free transports and machinery	a) Investigate adjustment congestion charge to reduce car use; b) Ensure charging stations for light/heavy electric vehicles; c) Use sustainable machinery; d) Deploy bicycle parking to meet the needs.
8. Carbon Capture and Storage	a) Investigate conditions and benefits for CCS plants in Gothenburg

2.2. Challenges

The measures aim to achieve energy related goals while attempting to address five main challenges described in the GEP. The first challenge relates to the risk of power shortage and specifically the electricity grid capacity. Electrification of transport, industry and service sector are expected to double peak power demand, while weather-dependent renewables make electricity production more irregular. Assessments show that the local electricity grid has sufficient capacity until 2030. However, long term solutions are required to increase grid capacity and establish a flexible market to allow producers and consumers to match needs to the grid capacity. The second challenge concerns climate change impacts and mainly the pressure of heat waves on district cooling and the electricity network. Energy supply needs to meet the increased energy demand for cooling, while heat mitigation measures should be implemented to decrease urban temperatures. Thirdly, the population growth of 60.000 inhabitants by 2030 suggests a further increase in energy consumption if no drastic behavioural change and efficiency of the systems occur. The fourth challenge regards the impacts of national and European policies and the unpredictability of their effects at the local scale. Waste incineration tax specifically affects a system that relies on cogeneration plants for district heating and electricity production. Higher taxation on waste incineration and higher incentives on recycling might affect the heat supply capacity. The fifth challenge is the availability of resources to make decarbonization happen. Staff, knowledge and money for investments are necessary. However, once available, resources have to be used wisely, supported by solid business plans for investments and collaboration between municipality and companies.

Figure 1. Municipal stakeholders with dedicated measures in Gothenburg Energy Plan, stakeholders 1-4 have key measures. Black: boards/committees. Grey: companies owned by City of Gothenburg.

3. Method

The research is based on a document study, in which the GEP (71 pages in total, 29 pages core text) has been analysed and discussed with experts in the energy sector and city representatives. Twelve interviews and one workshop with 18 participants representing stakeholders from the energy utility company, municipality, researchers and consultants were carried out between September and December 2021 to understand potential challenges in the implementation of GEP. Specifically, representatives of the energy utility company, the Premises Committee, the Parks and Landscape Committee, and the Environment and Climate Committee were involved (Figure 1) because the GEP has been assigned a set of key measures to these authorities. Other stakeholders are experts in the energy field but external to the GEP implementation process. The interviews were semi-structured and questions aimed at identifying the progress on the measures and the related debate on how to implement them. The interview was divided into three sections focusing on i) the overall challenges for the energy system of the city, ii) the involvement in the GEP and actions undertaken, as well as iii) the potential bottlenecks in implementations of the GEP measures. The half-day workshop was carried out online using collaboration platform Miro. First, the participants were asked to, score the relevance of both decarbonization actions and drivers of change, and second to discuss more in depth overall challenges in the implementation of the plan.

4. Challenges and uncertainties for the implementation of the GEP

The challenges summarized above and actions described in the GEP mainly address the risk of shortage. From our interviews and the stakeholder workshop, several complementary challenges have emerged. These challenges regard the alignment of urban development and energy plan (4.1), district heating and cooling (4.2), electrification of buildings and transport (4.3), and communication and tools (4.4).

4.1. The challenge of aligning urban development and energy plan

Today, estimates of future power demand and investments in power production capacity are to a large extent based on the prognosis of population development and city growth. These scenarios do not have a high resolution in time and space and are challenged by the high level of uncertainty in urban planning processes. However, coordination between urban development and energy planning is crucial to ensure goals' alignment.

For the coming years, the development model for Gothenburg promotes an increase in density in the existing urban areas. The vision of a denser Gothenburg follows the sustainable compact city paradigm and aims to limit urban sprawl and individual transport in favour of transit-oriented development. While the benefits of this model are clear in terms of land-use and mobility-related energy consumption, the influence on the building stock and vulnerability of the energy systems require further investigations. Local stakeholders pointed out four critical challenges for the urban energy system: urban heat island effects, flooding, competition of land use, and mismatch of planning processes. Higher density might influence the magnitude of urban warming phenomena (urban heat island effect, heat waves) and exponentially increase cooling demand during summer periods. Mitigation measures need further investigation to better understand, for example, the impact of vegetation and green roofs on local climate and thus on energy loads. The size and quality of green coverage are also considered crucial for its contribution to rainwater treatment, ecosystem service, and carbon sink functions. The level of infrastructure vulnerability would increase due to disruptive events such as rain and river flooding because of the concentration and high density of the supply network. A further challenge regards the availability of space and the competition for use. When urban density increases, public and private space available for energy production and infrastructures is reduced (to allocate solar panels, smart storage and mobility infrastructure). The urban development model through infill and densification processes also poses the challenge of upgrading the supply infrastructure within consolidated areas in the city. The decisions on energy systems for new buildings are crucial. Connecting a building to district heating and cooling or full-electrification (installing heat pumps) need a re-dimensioning of production and distribution of energy either for district supply or for electricity. New production plants and related networks require a longer planning and construction period than developments of conventional buildings (housing, offices, etc). Due to this timing difference, many decisions on the dimensioning of the energy infrastructures are taken before having design and system details about new buildings and their level of efficiency. Additionally, in the short-term, construction projects can be delayed while infrastructural planning and investments are already going on. The risk for increased infrastructural costs is, thus, very high in both cases of underestimating or overestimating the demand.

The interviewees seemed to agree on the need for better coordination between the city administration, planning offices and energy providers for new urban developments and the exploitation of local waste heat. Representatives from GE pointed out that facilitating synergies in early planning phases for surplus heating and cooling requires new frameworks and integrated planning workflows to understand the hidden local potentials and possible symbiosis. City representatives stressed that energy providers should take a proactive role to indicate potential heat excess that can be recovered and to suggest clusters of functions that benefit from closeness, informing a more systemic planning approach to guide the developments towards areas with higher potential and needs for infrastructures.

4.2. Challenges for district heating and cooling

In the long term, district heating and cooling have to deal with the uncertainties of phasing out fossil energy sources and the availability of waste for production plants, while the distribution is challenged by the risk of suboptimization and efficiency losses. The GEP sets decarbonization goals for district heating and cooling, which require the replacement of existing energy production facilities with non-fossil-energy-based production plants. This implies planning a careful transition to ensure a secure and continuous energy supply. For example, the phasing out of one of the power plants by 2030 (centrally located) might pose problems for the supply of district heating and cooling in the central areas of Gothenburg and require new investments for production and distribution networks (increasing pipe sections). These measures are not allocated in the plan. Interviewees and workshop participants also expressed concern about the uncertainties regarding the future energy production from waste incineration and waste heat from refineries, one of the main sources today for district heating and cooling. A higher recycling rate is expected to progressively reduce waste for incineration while refineries are at the end of a cycle. For heat recovery, mentioned challenges concern the management of the transition and the coordination of decision making between waste-heat providers and energy providers. Waste-heat providers are in charge to identify sustainable sources and transforming their production. The transition towards CCS, hydrogen and electrification might result in a change in temperature levels and the total provision of annual waste heat. Energy providers are responsible for a reliable energy provision along with the transition of production systems and adaptation to the new level and characteristics of waste-heat supply.

While the above can be considered macro factors of change, experts from the energy sector also pointed out challenges to the system's efficiency. Some interviewees commented on the lack of a larger comprehensive framework to facilitate symbiosis between decentralized and centralized systems and the risk of having multiple, efficient systems that work against each other. Specifically, the increased installation of heat pumps in areas served by district cooling and heating networks might have negative effects on the overall efficiency of the urban energy system. This process could not only affect the return temperatures, but it is also environmentally costly from a life-cycle perspective and economically for customers and providers. Heat pumps would further increase electricity demand, increasing the risk of power shortages. On the other side, combined solutions of district heating and heat pumps lack a business and management model. Local production owned by others than the city energy provider requires adaptation of legal agreements and new management models to share the responsibility of energy provision. Meanwhile, supply infrastructures for cooling are also challenged by factors that undermine their efficiency of production and the security of the service. In the last years, the City of Gothenburg has invested in the development of a district cooling system in the city centre to double the production capacity and further expand the network in the coming years. Sources for district cooling can be considered already decarbonized ones (free cooling from the river, surplus heat, etc.). However, experts from the city energy provider stressed that increasing the delta T (temperature difference between supply and return), and thus improving the efficiency of the district cooling system require interventions by buildings users. Another factor that requires further investigation is the future distribution of the service. Today, the district cooling network supplies data centres, office buildings, hotels, hospitals and commercial malls. Workshop participants highlighted that higher outdoor temperatures and heatwaves will likely increase space cooling demand in residential buildings. This future demand would probably rely on electricity sources (small scale cooling systems) and exacerbate peak loads and risk of disruptions if no measures are taken to encourage connection to district systems. Although it is undeniable a benefit to connecting multifamily houses to the district cooling network, this will require a technical upgrade of building systems, new business models and economic incentives.

4.3. The challenge of electrification of transport and buildings

Reducing energy demand in all forms is a key goal for the city. However, the predominant discourse about the shift from fossil-based sources to electricity tends to hide the priority of decreasing energy use also in the form of electricity. Decarbonization translates almost directly to electrification for the transport and industry sector, which will result in an exponential increase in electricity demand, posing challenges of sufficient production and load of the grid. Major uncertainties, highlighted by the representatives of the energy provider, regard the extent of such demand increase. Questions arose on what to prioritize for electrification and how to ensure a balance between production and consumption; i.e., what measures should be implemented for saving electricity and what economic incentives should be created to guide the prioritization. Electric vehicles (EVs) for private use are promoted in the GEP as a solution for reducing carbon emissions. Highlighted by all workshop participants, the level of penetration in the market and society will have consequences on the level of electricity demand rise. The questions are to what extent can the existing power grid sustain an electrified transport system, and what are the impacts of the increased demand on electricity production plants and supply networks? The city-owned energy provider is aware that for the EV transition it is their responsibility to prepare the grid to handle the load for charging and to grant access to chargers which needs coordination with sub-companies. Representatives of the city’s energy company pointed to the high level of uncertainty in planning investments and that the extensive use of EV do not fulfil alone the decarbonization goals for the transport sector, since the energy provider is responsible to guarantee clean electricity sources. A high EV share would thus require substantial investments and new business models. In the short term, decisions are needed on the granularity of charging services, i.e., whether they should be provided on the household level or as a common/shared neighbourhood facility.

Regarding building stocks, interviews with energy experts focused on whether supply by district cooling and heating based on waste-heat recovery should be prioritized over electrified solutions (heat pumps, decentralized cooling systems). Unfortunately, regulatory frameworks and energy performance assessments do not indicate a clear selection path for building owners. Thus, in consolidated urban areas where the infrastructure already exists, there is a risk that the diffusion of heat pump installations might force the provider to suspend or interrupt the district cooling or heating service. Similarly, in new urban developments, if heat and cooling demands would be predominantly met by electric systems, it will not be appropriate for the energy provider to serve the area with district systems. Interviewees pointed out that the risks of a comprehensive transition to electric heating and cooling are the further increase of peak demand during extreme winter and summer periods, and consequently the raised vulnerability of the city system. Thus, a fast transition of building heating and cooling to electric sources seems to be a potential bottleneck for decarbonization (energy security). In terms of investments, this would result in costs for the improvement of the electricity grid and the phasing out of the existing power plants and the dismantling of the network. Additionally, among the GEPs measures, workshop participants jointly highlighted the relevance of installing smart meters to reduce electricity consumption in apartments and buildings. Smart meters can help to manage loads more efficiently and to reduce peak demand, and at the same time provide data to better understand user behaviours and develop more accurate predictions. However, t was also pointed out technological and organizational challenges regarding their deployment. From a technological perspective, critical decisions regard the type of equipment, software and components, data management platforms, and cybersecurity. From a governance perspective, responsibilities need to be defined to allow a fast implementation. Especially, for a new complex system which involves different institutions and private actors, it is essential to develop clear roles in management and implementation. Decisions might be further influenced by decisions on other scales and models of decentralization. This implies that future new models might emerge to produce and consume energy locally at the neighbourhood level, using smart meters at a unit of aggregation rather than at the single building/ household scale.

4.4. Communication and tools

Fragmentation in expertise and task division between municipality and energy companies results in discontinuity of knowledge and can delay decision-making processes. This lack of knowledge integration is also a potential bottleneck internally in the companies where expertise is spread out in different departments. Improving communication and increasing the level of understanding among departments is vital to facilitating agile decision processes. Furthermore, cooperation between the private and the public sector seems to be one of the major challenges in implementing decarbonization strategies and measures. New business models and guiding instruments are needed to align private and public investments toward coherent and integrated energy strategies. From the energy provider perspective, communication with building owners is essential to avoid suboptimization and facilitate systemic thinking to benefit the community rather than single owners. The development of coherent planning strategies also relies on knowledge and data sharing among experts, authorities, and owners. Visualization of results of energy computational models with spatial representations could support the communication and coordination between different stakeholders and authorities (road, water company, public transport) to discuss existing energy systems (production capacity, local waste flows) and their effects on it when development plans or energy measures are discussed. From a management perspective, more efficient planning on underground infrastructures would require further information on the subsoil and tools to coordinate interventions to minimize secondary effects on road traffic and disruptions of the service.

5. Conclusions

The GEP defines challenges that need to be addressed to achieve decarbonization goals for 2030 on a national and city level and it frames a set of actions and measures. Interviews and a workshop with local stakeholders have highlighted additional key challenges for achieving the goals and assuring successful implementation of the GEP. The identified challenges regard i) the coordination between energy and urban planning, ii) the future stability of district heating and cooling, iii) the balance in electrification of the buildings and transport, and iv) instruments and tools for decision-makers. The GEP should also promote additional measures to guarantee the development of instruments and deep analysis to face the identified challenges. This study suggests that new measures should be allocated to:

- investigate the influence of the densification development model on urban warming phenomena and future energy security during extreme climate events;
- develop frameworks and planning workflows to align energy and urban planning decisions to efficiently manage scarce available space in high-density conditions and facilitate symbiosis among buildings for exploiting local potentials (such as local waste heat);
- start envisioning alternatives to ensure a reliable provision of district cooling and heating based on sources different from the refinery's waste heat;
- develop models and frameworks that can facilitate decisions of building owners on centralized or decentralized heating and cooling supply systems to avoid suboptimizations;
- understand how to meet the potential cooling demand of multifamily houses and what technical and economic measures should be advanced;
- support the increased electricity supply needed for the transition towards a fully decarbonized private mobility, models of service and investments to upgrade the supply infrastructure
- investigate management models for smart systems implementation
- encourage the development of decision-making instruments to facilitate communication between private and public actors and to support knowledge and data exchange.

This study, by employing a participatory approach, indicates a direction for measures that might be warranted in the continued work with the plan. In combination with the challenges already mentioned in the plan, the specific ones identified in this study may provide a rather complete set of challenges related to a sustainability transition of Gothenburg's energy system. As Gothenburg shares several key characteristics with numerous other cities around the world, the study, thus, provides important lessons for other similar contexts aiming toward transforming their energy system. Additionally, it shows the benefits of engaging local actors in qualitative collaborative assessments along with the development of energy planning instruments. Still, further steps are necessary in the case of GEP to include more stakeholders in the discussion towards the energy plan improvement.

Acknowledgements
This work is funded by Göteborg Energi ABs Foundation for Research and Development under project number 20-11 and it is part of the Digital Twin Cities Centre supported by Sweden's Innovation Agency Vinnova under Grant No. 2019-00041. The authors especially would like to thank the participants at the stakeholder workshop and the interviewees for sharing their knowledge.

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