3.4: Energy infrastructure for City districts and transport.

Towards the low carbon society.

HYBES

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1 Abstract

This report presents experiences and learning points from energy district planning in the HYBES project, with a particular focus on the transition from hybrid renewable energy systems at building level to integrated solutions at district and city scale, including transportation infrastructure. The purpose is to support municipalities in planning and implementing flexible, low-carbon energy systems that enable electrification while managing grid constraints and system-level impacts.

The report is based on case studies from Bodø (Norway) and Umeå (Sweden), two northern cities with different energy system characteristics but shared ambitions for climate neutrality. In Bodø, the analysis focuses on energy planning in two major urban transformation projects: the development of Bodø Harbour as an energy hub for maritime electrification, and the planning of a new city district linked to the relocation of the airport. These cases illustrate how grid capacity constraints, peak power challenges and sector coupling require a shift from isolated solutions towards coordinated, district-level energy planning. Particular emphasis is placed on the role of thermal energy, district heating, energy flexibility, business models and the use of zoning plans as municipal tools to influence energy outcomes.

In Umeå, the report draws on strategic energy and climate planning processes, supported by modelling using LEAP and CEA, and on concrete district-level analyses in Ålidhem. The Umeå case highlights how scenario-based energy system analysis can inform long-term climate strategies, evaluate trade-offs between district heating, heat pumps and electrification, and identify system-wide effects of efficiency measures, local energy production and transport electrification.

Across both cases, the report demonstrates that successful energy district planning depends not only on technical solutions, but on understanding local energy system conditions, regulatory frameworks, timing of investments and collaboration between actors. HYBES has contributed by linking pilot-level insights with system-level planning, providing municipalities with practical knowledge on how hybrid and flexible energy solutions can support the transition towards low-emission, resilient urban districts in northern climates.

2 Introduction

The purpose of this activity is to transform insights from Hybes pilots on hybrid renewable energy systems from single buildings towards RES systems on city districts level including transportation infrastructure. This report presents some of the steps needed to evolve to the stages of hybrid RES energy systems at district level. To organize and implement town planning processes thoroughly is vital, and we have discovered both processes and factors that promote and diminish the chances of implementing hybrid RES systems to district level.

Furthermore, we also discuss technical aspects and construction of business models that are in favor of succeeding with hybrid energy systems at district level.

3 Planning for efficient energy districts in Bodø

3.1 Energy district planning in Bodø

Bodø is the largest city in Nordland County in Norway, housing 53 700 (2025) inhabitants. It is located at 67 degrees North, just above the arctic circle. The city's population has been steadily increasing the last decades, except a low growth in 2025, and is a city with ambitions of growth and attractiveness, with large transformation projects in the planning.

The energy situation in Bodø and the surrounding areas of Northern Norway is recognized by high energy production from hydro power plants, low population density and bottlenecks in the transmission lines to southern Norway where the power consumption is higher. This leads to high energy availability of energy with low climate footprint and low electricity prices in the price zone of Bodø, called NO4.

Due to this, Bodø, and Norway, has a high degree of electrification, especially in buildings. Overall, 54 % of Bodø's total energy use is from electricity (842 GWh), 40 % from oil products – by far mostly consumed by the transportation sector, and 7 % from bioenergy and district heating. In buildings (households and businesses) 76 % of the energy is from electricity – mostly for heating, while 13 % is from district heating, 7.5 % from Bioenergy and 3,5 % from oil products[1].

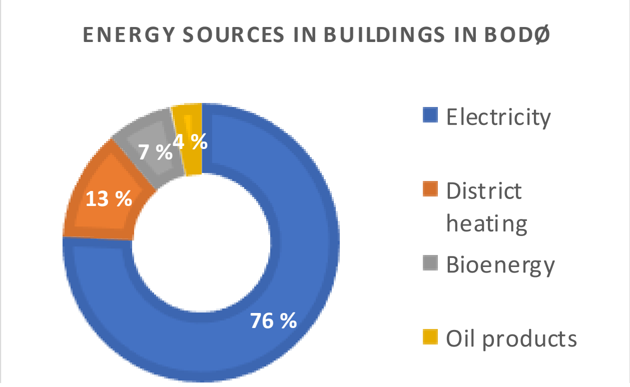

Figure 1 Energy source in buildings in Bodø

Small energy production in households is not very common today. Some public and private buildings are producing energy with solar panels or energy (thermal) wells – mostly for own consumption and not for export. Because of low energy prices it has not been much economical interest for energy production installations, but there are national funding incentives to help with investment for certain projects.

Electricity availability is with this not an apparent issue today, but the consumption in the region is expected to increase in the coming years, potentially leading to need for more energy production in the close future. The grid capacity in Norway and Bodø is however not dimensioned for significant increase in consumption. As the heating is so dependent on

[1] Energy Dashboard for Norwegian Municipalities, Bodø: Microsoft Power BI

electricity this also lead to high differences in peak consumption on cold winter days compared to normal days, and especially summer days.

With ambitious plans for development and business growth and electrification of the transportation sector, the energy situation in Bodø is important to optimize in the coming years. This report will give insights from Bodø about the energy situation of the city, and learning points and insight from Bodø's energy planning in some of the large development projects in Bodø, namely energy transformation of Bodø Harbor and energy planning in the planning of a new city district in Bodø. The HYBES project has contributed with some important learning points in the cases, as well as contributing with the constellation and coordination of knowledge and findings.

3.2 Transforming Bodø Harbor to an Energy Hub

Maritime transportation is by far the largest source of climate gas emissions in Bodø, contributing to 40 % of the climate gas emissions[2], as shown in Figure 2. The harbor has a key role in facilitation for a green transition in the maritime transport sector. Transformation of Bodø Harbour to enable electrification is therefore one of the most important measures for decarbonization in Bodø.

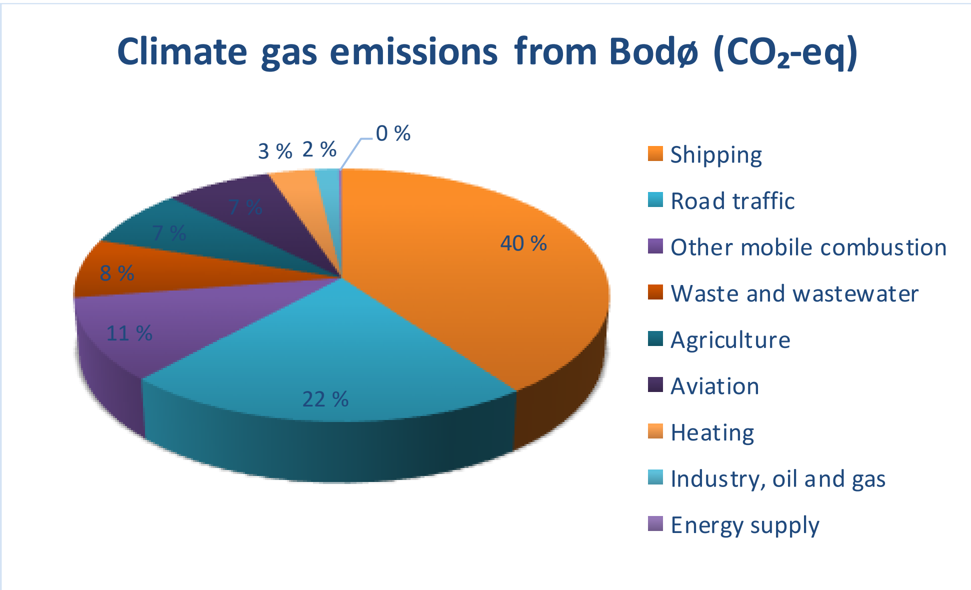

Figure 2 Overview of direct climate gas emissions in Bodø in 2023

Electrification of larger ships and the maritime sector require significant electricity and rapid charging of large batteries art certain times. This sets new requirements for the infrastructure and needs to fit into the economic models of the energy and power grid systems. To identify barriers and find solutions for the transformation, Bodø Harbor has

[2] Norwegian Environmental Agency overview of climate gas emissions from Norwegian Municipalies: Utslipp av klimagasser i Norges kommuner og fylker - miljodirektoratet.no

conducted a thorough masterplan study of how the transition to an energy hub can be realized[3].

Figure 3 Overview of Bodø Harbour and illustration of how it can serve as an energy hub[3]

The masterplan outlines a plan for transforming one of Northern Norway's most harbors into an energy hub for sustainable energy and efficient logistics, with ambitions to drive economic growth while substantially reducing environmental impact. The harbor is also envisioned to be an integral part of Bodø's future energy infrastructure, supporting the city's transition toward a low-emission society.

Bodø Harbour has together with the Municipally owned energy company Bodø Energy established a new company to work on the energy system of the harbor, called Fjuel Bodø. Fjuel Bodø is the owner of the masterplan and will be responsible for the follow-up and implementation of the plan.

3.2.1 Grid Capacity and Infrastructure Challenges

To transfer into an energy hub, it is required to have sufficient transmission of grid capacity for the area. However, the limited transmission capacity in grid system is a bottleneck the Bodø port and the whole Bodø region. So, it is crucial for all the actors to think about the grid capacity.

The existing grid infrastructure limits the realization of new power-intensive projects by traditional utilization of the grid. The traditional model is that an actor needs to reserve their needed peak energy capacity in the grid. This reservation has a price and gives the actor access to this capacity at any time of the year. In the case of the harbor, the electricity is however needed at shorter periods of time while larger ships are in port with need for

[3] Masterplan Bodø harbour energy hub: Masterplan EnergiHUB Bodø Havn

charging and/or shore connection. To serve these high intensive demands – new and expensive infrastructure also needs to be built.

New and innovative solutions and models must be explored and established to find economically and physically realistic ways to utilize the grid capacity efficiently – to enable decarbonization without larger impacts than necessary.

The harbor area is also populated by multiple other industry actors as well as land based logistics hubs and close neighbor with Bodø's railways station. The masterplan looks at ways to look at the needs of all the actors together – to be able to optimize the whole harbor energy system as one.

3.2.2 Managing Power Peaks and Grid Stability

Maximizing the utilization of existing capacity will be crucial, along with facilitating coordinated solutions that can effectively handle varying energy demands. Influx of tourists during the summer, cruise ships and other large vessels will be needed to charge which will lead to soaring the power demand in its peak. To maintain this peak load, battery storage system along with the solar production will help to manage these peak loads and maintain grid stability and capacity.

Furthermore, Bodø Port will be transformed from the traditional to smart energy management. This will involve renewable energy sources, energy storage technologies, smart grid systems, energy sharing, and the electrification of transport. The approach will enable collaboration and the exchange of energy resources across sectors and industries, prioritizing mixed solutions rather than reliance on a single energy carrier. These are the primary suggestions to meet the extra demand of power without pressurizing the grid in the broader picture.

3.2.3 Business Cases and Local Renewable Initiatives

Finding economic models for realization of the investments and the costs has been a main priority in the masterplan. To do this the masterplan uses a useful methodology that can be efficiently transferred to other cases and cities, based on identifying concrete business cases. Each business case is described with detailed expected energy need, showing how much energy is needed at what time of the day and year, economic implications of costs and income and other relevant factors. Many relevant cases are identified and categorized in timeline of realistic implementation. When combining the business cases it is possible to explore alternatives for development and how different cases can be combined to make a reasonable and wholistic development. Some examples of business cases are: electrification and charging of some of the publicly owned transportation ships, providing shore power to cruise ships in Bodø, charging of large road trucks in the harbor area (connected to the logistics hubs), use of flexibility markets, and installation of solar or thermal energy production and batteries. More information about the business cases can be seen in the

Masterplan for Bodø Harbor. Seeing this in combination makes it possible to plan and reorganize the logistics in the harbor to realize electrification without stressing the grid.

One interesting example that has arose as a consequence is a controversial discussion in Bodø, seeing that increasing the cruise traffic in Bodø for some years will make it economically feasible to make necessary infrastructure investments that will enable electrification of other parts of the maritime sector. Increased cruise traffic will however drastically increase the CO2 emissions from that sector in the period – thereby having an initial negative carbon footprint.

Figure 4 Example of business case in the Bodø Harbor Engy Hub Masterplan

Together, the business cases represent a comprehensive transition of Bodø Harbor into a smart, sustainable, and low-emission energy hub. The projects collectively reduce around 50,000 tons of CO_2 annually, integrate renewable energy production from hydrogen, solar, and geothermal sources, and optimize grid capacity through flexible and innovative solutions. By combining electrification, energy sharing, and circular use of resources, Bodø Harbor can become an example of how ports can drive green transformation and energy efficiency in a realistic way. The learning points are also taken into Bodøs next large urban development project – namely the development of a new city district close to Bodø city center.

Figure 5 Bodø Harbor business cases organized by energy need andtime

3.3 The New City - New Airport project

Bodø airport is located just outside of Bodø city center, as one of very few international airports with walking distance between airport and city. The infrastructure of the airport is old, with need for renovation, and it has been decided to move the airport a bit further out on the Bodø peninsula, just besides the current airport. This frees up an attractive urban development area of close to 3 km^2 very close to the city center – enabling the further urban growth of the city for the coming 100 years. The municipality has been working on urban planning strategies and ambitions since the plans were started around 2015, making it a new urban area with high ambitions in terms of sustainability, attractivity and social inclusion, that will shall be carried out based on all three dimensions of sustainability — environmental, social, and economic. The figure below illustrates the plans for how the Bodø peninsula will develop – with movement of the airport south and west, opening for urban transformation in the current airport area.

Figure 6 Illustration of how the airport will be moved south on the peninsula and the current airport transformed to urban area

The new airport is under construction, with plans to open in 2029/2030, which is the starting point for when the physical development of the new city district can start. Before that there are however much planning and administrative work to be done. The property will be owned by a real estate company publicly owned by Bodø municipality and Nordland County. The company will develop the area based on municipal zoning plans, ambitions set by the owners and economic interests.

The new district is planned with a 100-year development horizon and includes several ambitious goals, such as establishing a zero-emission neighborhood, achieving high energy efficiency, and ensuring long-term sustainability and resilience.

To begin with the development will centralized in two parts of the larger airport area with: one industrial area at the outermost part of the Bodø peninsula and a urban district that combine residential area with urban businesses next to the industrial area, where the terminal building of the airport is located today.

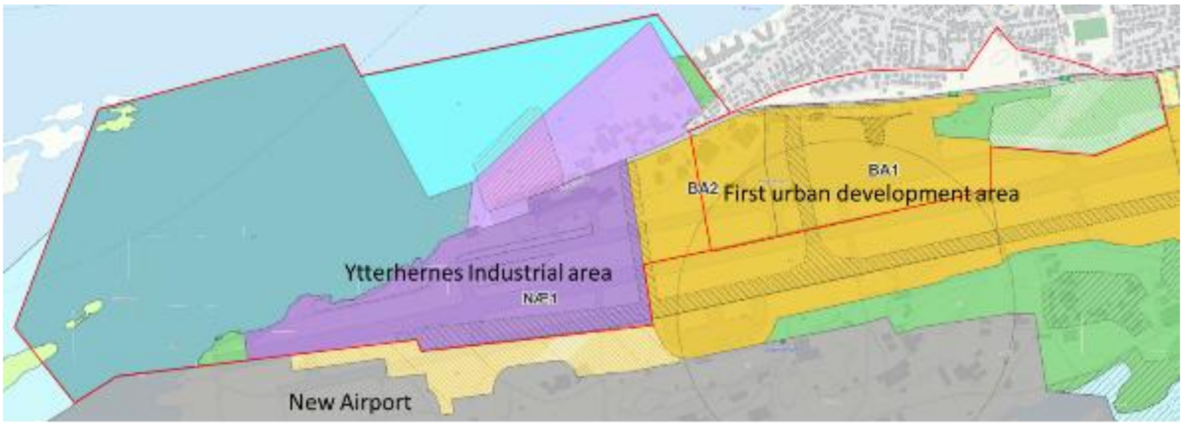

Figure 7 Map showing the first areas of development in the new city district

In the following section relevant planning processes in the municipality will be presented, with potential for learning in similar development projects. In 2022 the overarching zoning plan for the whole city district was adopted, setting goals and plans for the whole area. In 2024-2026 the municipality is finalizing more detailed zoning plans for the first two development areas. Principles and background for energy measures and ambitions will be presented in the following.

Figure 8 Illustration of the new city district concept[4]

3.3.1 Energy and sustainability goals in the New City District

Planning large new areas for development can be controversial in a time where resources consumption is too high and climate gas emissions are one of the key threats to the society. Bodø municipality has the ambitions to grow as an attractive place to work and live in the north, and when the new city district started planning, Bodø set the ambitions to develop with as low negative impact as possible and to be a part of developing methods for sustainable urban development of the future. The zoning plan for the whole[5] area therefore set clear ambitions to be a sustainable and environmentally friendly city district with zero emission neighborhoods, energy efficient district, high degree of circularity in buildings and lifestyle, sustainable transportation options, healthy lifestyle and developed with high value for nature and biodiversity[6]

The overall ambitions linked to energy and climate was formalized in an Overarching Environmental Program[7] that was adapted together with the zoning plan for the whole area.

The Overarching Environmental Program defines overall objectives within the following focus areas: energy, circularity, material management and waste, soil handling, biodiversity, and climate adaptation. For each of these topics, the program outlines specific objectives and recommended measures, providing good examples of how the goals can be achieved. The objectives and recommended measures apply to all development activities within the urban development area.

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[4] Masterplan study for the first development areas: mulighetsstudie-hernesmyra-og-ytterhernes.pdf

[5] Overall area zoning plan fo the new city district: Hernes – kommunedelplan - Bodø kommune

[6] Goals and guidelines for the new city district: mal-og-retningslinjer-for-planlegging-av-ny-bydel.pdf

[7] Overarching Environmental Program: overordnet-miljoprogram.pdf

The goals and ambitions of the Overarching Environmental Program are intended to remain consistent throughout the long-term development horizon of the city district. Therefore, the objectives are strategic and overarching, and to a lesser extent define specific technical solutions or measures. The goals presented in this document are largely formulated to address the challenges and needs identified by Bodø municipality in the case of the new city district.

The objectives and recommended measures in the Overarching Environmental Program can be adjusted as planning and development progress, and as knowledge about the effects of various measures related to climate, energy, and environment increases. In the following some of the objectives in the program are listed.

Objectives

- The new city district will be developed with the environment, nature, and people at the center, within the framework of the planet’s carrying capacity. The district’s identity will be based on the interaction between the dimensions of sustainability, and it will be an attractive area for residents and businesses to establish themselves in.
- The principles of circular economy and the waste hierarchy will form the basis for how resources, materials, and energy are managed and used during the development and operation.
- The district will be developed as a low-emission community, and zero-emission solutions will be established from the first construction phase within neighborhoods, buildings, and mobility.
- It will be a test and innovation area for testing and implementation of new solutions within mobility, energy systems, circularity, reuse, etc. Knowledge from research, development, and innovation projects will form the basis for the solutions chosen in the development.
- The district will consist of zero-emission areas, based on life-cycle principles — including the planning, development, operation, and post-use phases.
- It will have efficient, integrated, and flexible energy systems based on renewable energy sources, with the possibility for energy sharing between buildings and actors in the area. Energy security will be a key foundation.
- The development will include energy- and space-efficient pilot projects that are ahead of current technical standards and guidelines.
- Construction and building sites will be zero-emission.

3.3.2 Area zoning plans for the first development areas

The work with the zoning plan for the whole area and the following processes have led to development of multiple technical and architectural masterplans for the area and Bodø municipality's participation in different research projects related to energy, such as the HYBES project. This has given valuable insight to the more concrete and detailed planning of the areas. The work has been leading to more detailed zoning plans for the two first development areas of the new city district.

In these zoning plans the municipality set the ambitions and the overall requirements for the developers that will buy and develop properties in the specific area. More specifically it set the requirements for what developers need to include and consider in the detailed zoning plan of the development. There are limitations to what municipalities are allowed to require and include in the zoning plans, and Bodø municipality has worked to find good ways to make the area attractive for establishment while also meeting high energy, climate and sustainability standards.

Neither of the two area zoning plans are adopted by the end of the HYBES project. The plan for the industrial area is in the last phase for adaption, while the plan for the first urban area is in the making, and it is expected to be adopted by early 2027. The plan for the industrial area released for public hearing (and close to the final version) is available online[8]

The following section will go through some of the important energy related topics identified in the planning, and describe how the plans are designed to adapt the topics.

3.3.2.1 Grid load and energy consumption

The energy system in Bodø can described as highly electrified, with good availability of clean hydropower electricity with low climate gas emissions, but with constrained availability in the grid. Establishment of new industry with low climate gas emissions, which is one of the priority areas in the new industrial district, can be a challenge because they require significant power from the electricity grid. To increase grid capacity, it is required to physically develop the infrastructure, which is connected to high climate gas emissions.

Because of this Bodø municipality treat the need for energy efficient development not as a measure for decreasing the carbon footprint, but for enabling electrification and establishment of new clean businesses. The energy system is therefore still high priority in the planning of the future development but has some consequences for the approach.

The high grid load is closely connected to the fact that most of Bodø's heating is from electric heating (including heat pumps). This means that the grid is close to full capacity on cold days with high heating consumption, while high capacity the rest of the year. The grid has to be dimensioned for the hour of the year with highest consumption to avoid power failures, and this set important restrictions for new grid reservations. Finding ways to decrease the peak power on cold days is therefore high priority to utilize the grid

[8] Version for public hearing of the area zoning plan for the industrial area: Områdereguleringsplan for Ytterhernes - Bodø kommune

infrastructure efficiently. This can be done by energy-flexible solutions, the use of thermal energy, smart energy solution and wholistic planning. It is especially important for developments with power needs, and the plans therefore has high expectations from actors with high energy consumption, such as industrial actors. Some of the measures in the plans are:

- Developments needs to describe their expected energy consumption, including what times they expect high loads, how it fits into the rest of the energy system and possible measures to lower the stress on the grid.
- Description of measures to decrease load and consumption, shift consumption in time and possibilities for reasonable energy collaboration with others.
- Infrastructure with heating (such as roads) shall be energy efficient with possibility to use district heating and enabled for smart energy controlling – making it possible to turn off in times of high grid loads.

3.3.2.2 Use of thermal energy

Shifting energy sources from electricity to clean and efficient thermal energy sources for heating is one of the most important measures for normal buildings and infrastructure with heat demand – meeting the need to decrease load at the coldest days very efficiently. The heating of each individual building does not contribute much to the total load, but because there are so many such buildings it is important to ensure that the mass of new buildings choose thermal solutions.

District heating and energy wells with heat pumps for each building are looked upon as the most relevant sources for thermal energy. Bodø municipality has been part of two project that have contributed with insight in how the two solutions compare to each other: HYBES, which analyses the energy use on building level, and the research project IntoZero[9], which models the energy use in the new city district on a district level.

Looking at the energy consumption in the two HYBES pilot buildings for a year (2024) in the figure below we can see that Mørkvedbukta School and kindergarten has an energy well providing an important share of the needed heat (some exceptions early in the year due to a system failure), while about 70 % of the total energy consumption come from electricity. Looking at the Rehabilitation building at Gamle Riksveg 18, it uses district heating, leading to a notably more stable electricity consumption, and getting close to 50 % of the total energy consumption from district heating. This is just two pilot buildings, and thereby not enough to draw large conclusions, but it seems to be relevant for energy consumption on building level. This makes sense because there is need for electricity to run the heat pump for the energy well.

[9] Into-Zero web tool for early phase energy analysis for Bodø New City New Airport: Ny by - Ny flyplass

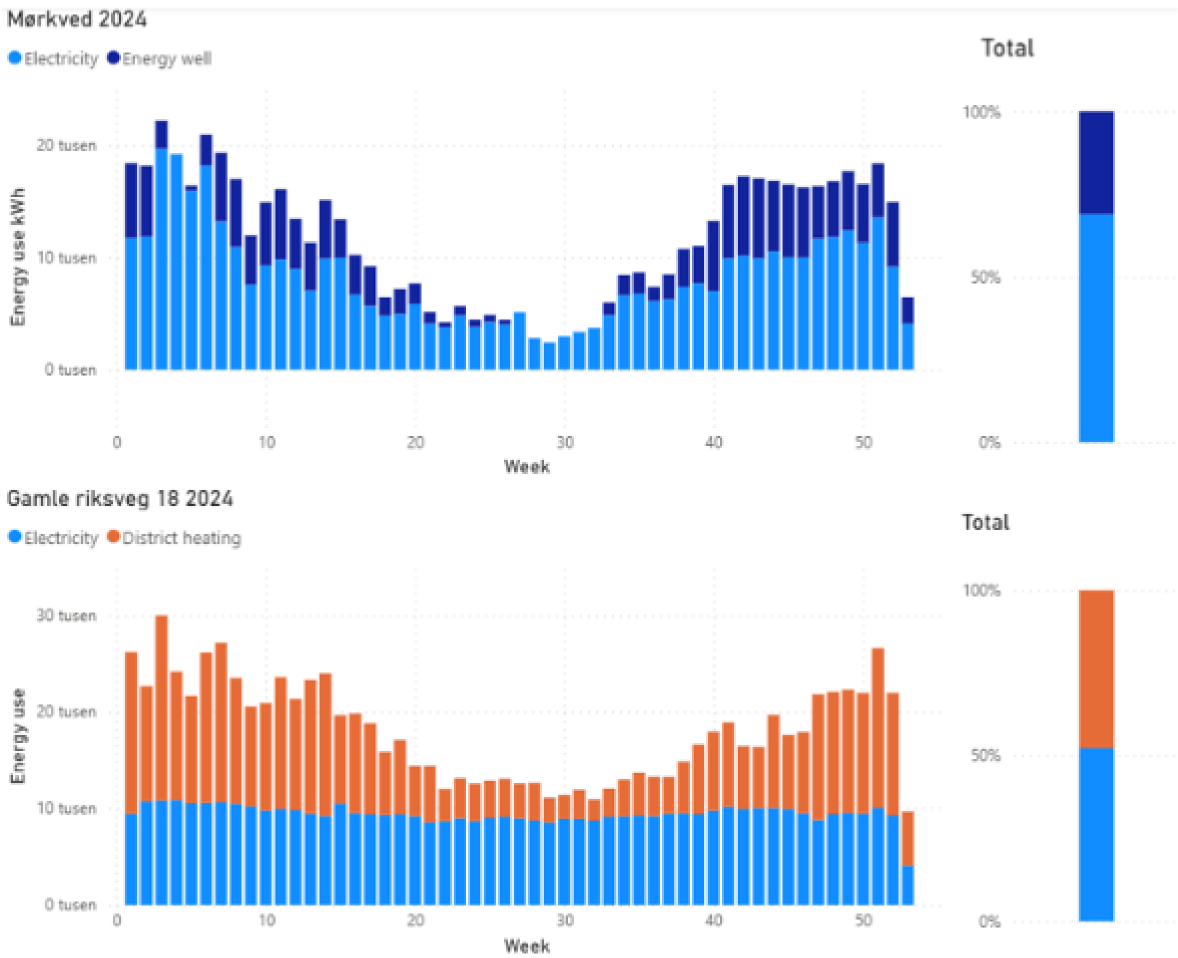

Figure 9 Energy consumption by source in the two HYBES pilots in Bodø 2024

The same tendency has been seen on district level in the IntoZero-project, finding that energy well solutions with heat pump leads to a peak electricity consumption of 75 % of pure electric heating, compared to 34 % for district heating. This shows a significantly lower grid load for district heating. The analysis does not include electricity use for the district heating, as this is connected to a different part of the grid. In the case of the new city district it is important to reduce the load in that specific part of the grid, and is therefore reasonable to prioritize this solution for that area. Based on these findings the zoning plans has set a clear priority on the use of district heating.

Looking at a city level, the LEAP analysis in HYBES however finds that district heating has a higher load on the grid than heat pumps. This looks at the energy system for the city at large. The result is interesting and can likely be explained with the use of electric boiler for peak heating and energy loss. This shows the importance of defining the relevant system boundaries in each project and to take the electricity use of district heating into account when relevant.

In the industrial area of the new city district, it is also likely to establish industry with surplus heat. This heat has high potential for utilization, and ways to utilize this must be explored and evaluated. To make the district heating more flexible to include excess heat from companies and from other sources of heat with lower temperatures, the requirements are specified to install district heating infrastructure suitable for low temperature district heating. Another benefit from this is the possibility for cooling from the same system.

In terms of heating the zoning plans require:

- Connection to the district heating network.
- Buildings above 500 sqm. and infrastructure with installed heating are required to install the necessary infrastructure to use low temperature district heating.
- Actors need to describe if they have excess heat, how much and the specifications. Actors with excess heat need to evaluate measures to utilize the heat.

3.3.2.3 Energy Production

It has been a clear ambition for the new city district to be as energy self sufficient as possible. In the planning there have been investigations into what energy production systems can be relevant and how it can be implemented. Different alternatives for energy production have been considered, where solar and thermal energy have been identified as the only realistic options to include in a zoning plan that will be used by smaller developers. Thermal energy production is as described not as desired in the form of energy wells, but there exist other options that can be of great interest, but not possible to require or suggest in a zoning plan.

The analysis of the solar installations on the two pilot buildings in HYBES have been of great interest and value in the considerations of how to approach the energy production question. These are among the largest solar installations in Bodø with statistical data available for analysis. The solar installations show reasonable production, but mostly in the summer when there is less need in the grid and energy system. The data from the solar installation at the Mørkved pilot has been used as a base for analysis of how solar energy can contribute to the energy situation in Bodø. To do this it was made a rough estimate of the roof area of all buildings in Bodø, then the solar production data from Mørkved was added to 100 % of the available roof area. This gave the figure below, showing the actual electricity consumption in all of Bodø in 2023 (light blue) and the solar production from all of the roofs (dark blue). The solar energy can contribute with a significant share of the energy consumption between April and October, and even cover all the electricity need in parts of the summer, but it does not help on the days when the consumption and grid load is the highest. The scenario is not realistic or exact but is created to give an indication of an extreme situation, for the purpose of seeing what a largely upscaled system may look like.

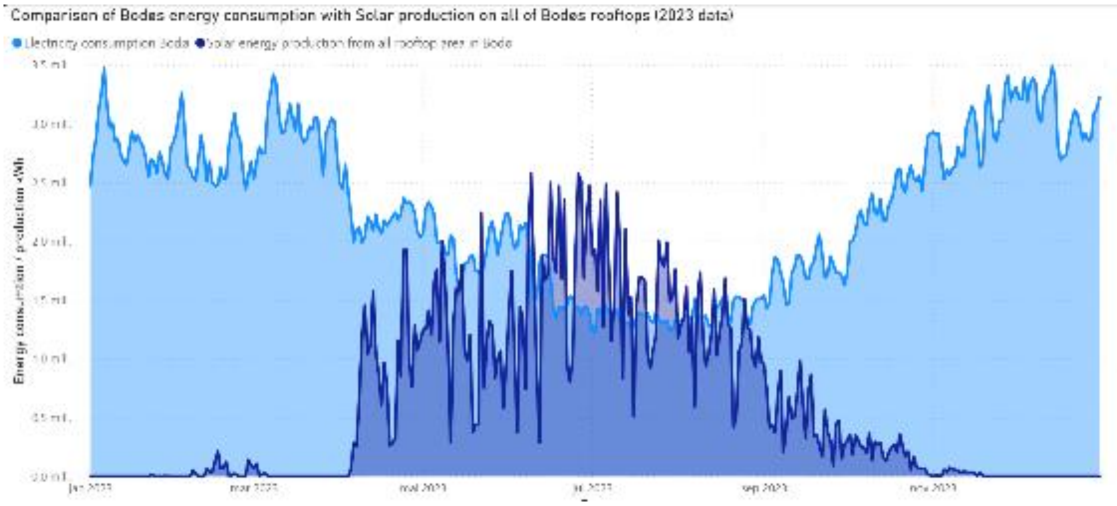

Figure 10 Comparing the total electricity consumption in Bodø with an estimation of solar production from all existing rooftops in Bodø, based on solar data from Mørkvedmarka school and kindergarten (HYBES pilot)

With basis in a system view it has been concluded that Bodø municipality do not wish to require solar installations in the new city district, as it does not serve the purpose for the area. It is however encouraged to install energy production and seek collaboration for energy production. Even though solar installations are not significant on a energy system level, each actor can have good benefit of the solution, and it is expected to be seen on much of the development. In combination with long term heat storage, it is also identified as a solution with high interest for the energy system.

A third energy production method that has been explored is the utilization of urban wind energy. In this case there is a high correlation between wind energy and energy consumption, as illustrated from consumption and wind data in the figure below. The technology for utilization of the wind is not yet developed enough to be practically and economically feasible for implementation, due to factors such as low efficiency in small scale, poor quality for high wind gusts, noise and risks from being integrated in highly populated areas. This is therefore a solution that can hopefully be of good use in the future.

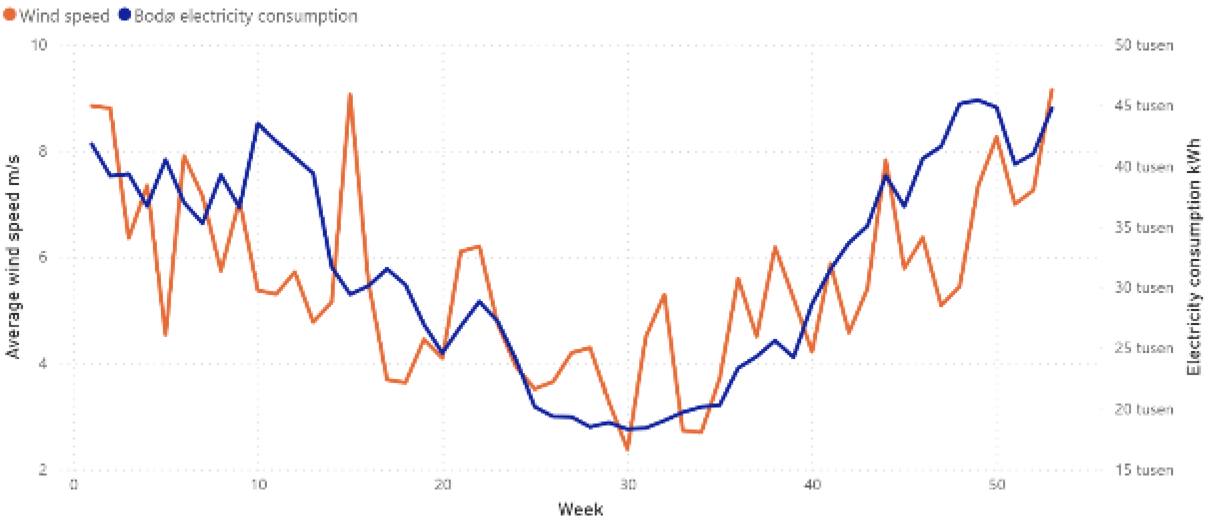

Figure 11 Wind speed compared to electricity consumption over the year in Bodø. Data from public dataases for wind statistics (seklima.no) and electricity consumption (elhub.no)

Based on this the zoning plans require the developers to:

- Include an evaluation of possibilities for energy production in early phase of the detailed zoning plan.

3.4 Learning points from the LEAP analysis of Bodø

In the HYBES project Umeå university conducted an analysis of the energy system in Bodø and Umeå using the LEAP tool, as described in HYBES report 2.1. The analysis gives some interesting take-aways for energy district planning. As it is thoroughly covered in the other report, this chapter will not go into the details, but refers to the 2.1 report and will reflect upon some of the findings. The analysis models the energy system in Bodø's buildings and car fleet at present time and consider scenarios in 2050. This shows a highly electrified society where fossil fuels are only used for transportation purposes.

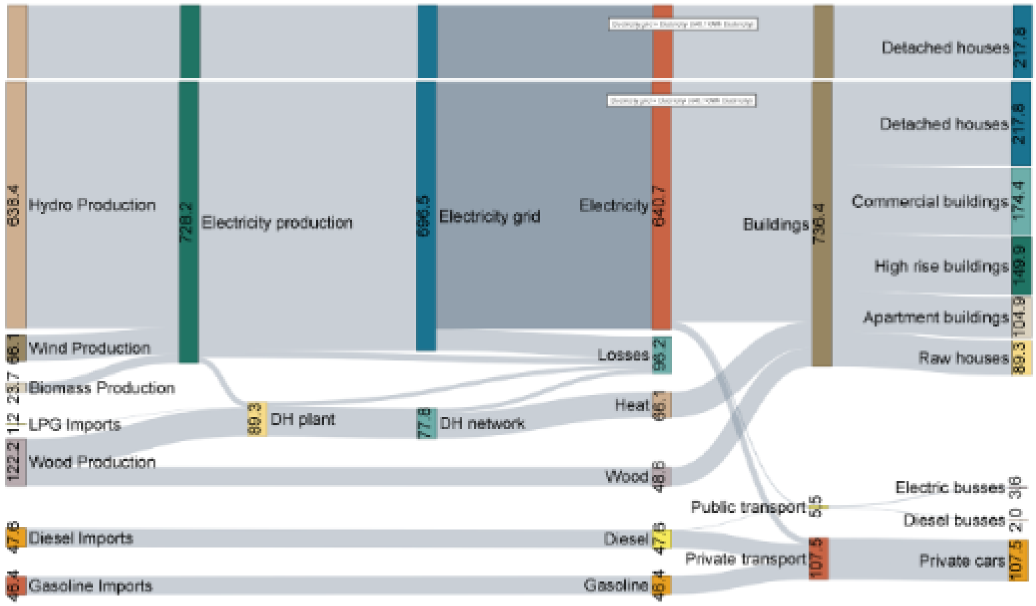

Figure 12 Sankey diagram from HYBES report 2.1, showing the energy flow (2024) from energy resources (left side) to final energy services (right side) in Bodø.

The analysis calculates the expected climate gas emissions from the energy system and the change in electricity demand for different scenarios of heating sources and electrification of the car fleet. When using CO2-emission factors from the Norwegian electricity system (mainly hydro- and wind power) there is little difference in the carbon footprint from district heating and electricity. The analysis does however show a fairly significant decrease in CO2-emissions by basing all of the heating system on heat pumps, rather than resistant heaters and district heating (Figure 13a). This scenario also gives the lowest result on the grid load (Figure 13b), making it the preferred scenario for both carbon footprint and grid load in the analysis.

Using more district heating instead of resistant heaters or heat pumps gives the same result- or slightly higher than the business-as-usual scenario for carbon footprint. In terms of grid load the replacement of resistant heaters with district heating gives a significantly lower grid load, but not as much reduction as the use of heat pumps.

These findings are interesting as they show a different result than what has been used as approach in the urban development, based on indications of substantially lower grid load from the use of district heating in Bodø, as discussed in section 3.3.2.2.

Electrification of the car fleet contributes to lower emissions and higher grid low, as would be expected.

The analysis also look at the carbon footprint using a marginal fuel approach (Figure 13c), where carbon footprint of European electricity based on coal or natural gas instead of the Norwegian electricity footprint. This also scores heat pumps as the by far best options, with district heating at second. This approach assumes that the electricity in Northern Norway could have been used in Europe instead if not used in Bodø, which is relevant to look at, even though it is at the present time not realistic, as the grid connection from Northern Norway to Europe is not strong enough for the substitution of European electricity. This may however change and is an important perspective to keep in mind.

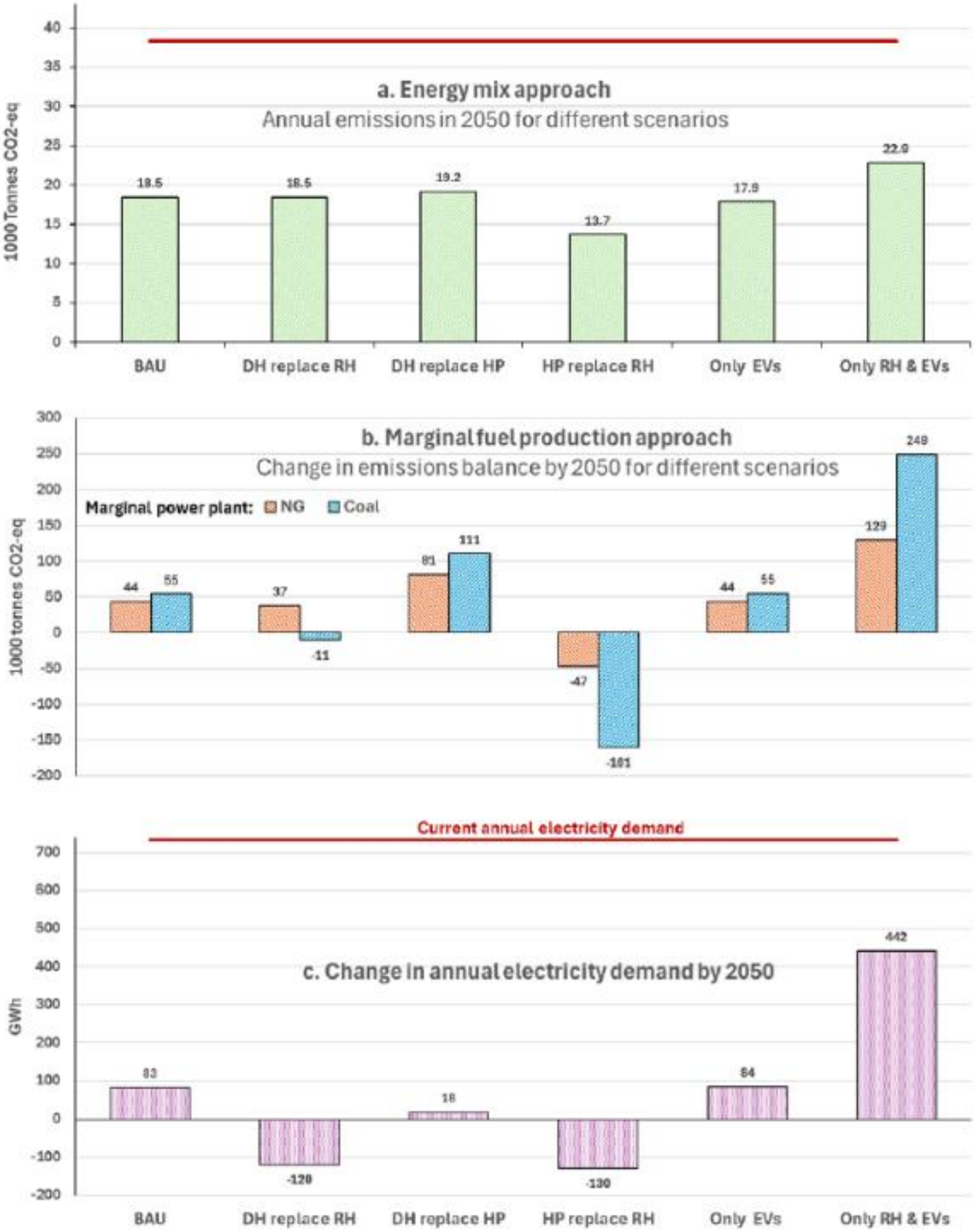

Figure 13 Result of LEAP analysis of the Bodø energy system for 2050.

4 Experience with energy district planning. The Umeå case.

4.1 Umeå municipality and the climate ambitions

Umeå municipality has been working with the climate-related project for several years, and the latest project called *Climate neutral Umeå 2030* started in the end of 2024, connecting to the EU mission label that the municipality received on the 8th of October 2024. This label is received due to the ambition of being one of the leading cities in Europe in the pursuit of becoming climate neutral to 2030. As a part of the work within the mission label, the local climate goals of Umeå municipality will be thoroughly reviewed and updated during 2025. Along with the climate roadmap, the climate portfolio and thus the energy plan are important parts to use in the transformation into a more sustainable municipality.

4.2 Strategic Mapping of Emissions and Measures

To create a long-term and carefully designed strategy for mapping emissions, measurements has an important role and a lot of effort has gone into that work. Both through internal municipality work, collaboration within municipality owned businesses and by external consultant works. ClimateView tool, as described in HYBES WP 2.2, is one important tool that has been used in this activity. Through systematic analysis, this tool has provided an extensive understanding of emission patterns and possible measures needed to achieve the climate goals set at the highest political level in Umeå municipality, and the goals that must be met on both national and EU level.

4.3 Background and Methodology

When shaping a municipal strategy for climate work, the politically adopted energy program has been one of the key factors, creating a clear connection between energy measures and climate goals. Sankey diagrams showing the energy balance of today, and the desirable future energy balance have played a central role in visualizing energy flows and identifying areas where interventions can have the greatest impact (Figure 14 and Figure 15). These diagrams have facilitated the mapping of energy consumption, production, and redistribution across various sectors.

The work with the ClimateView tool, the energy program has together with the municipality's other climate work has been adopted into the Umeå municipality's climate portfolio (Figure 16). This portfolio functions as a dynamic plan, where the final targets are surrounded by actions which are assessed and adjusted based on the data collected over time.

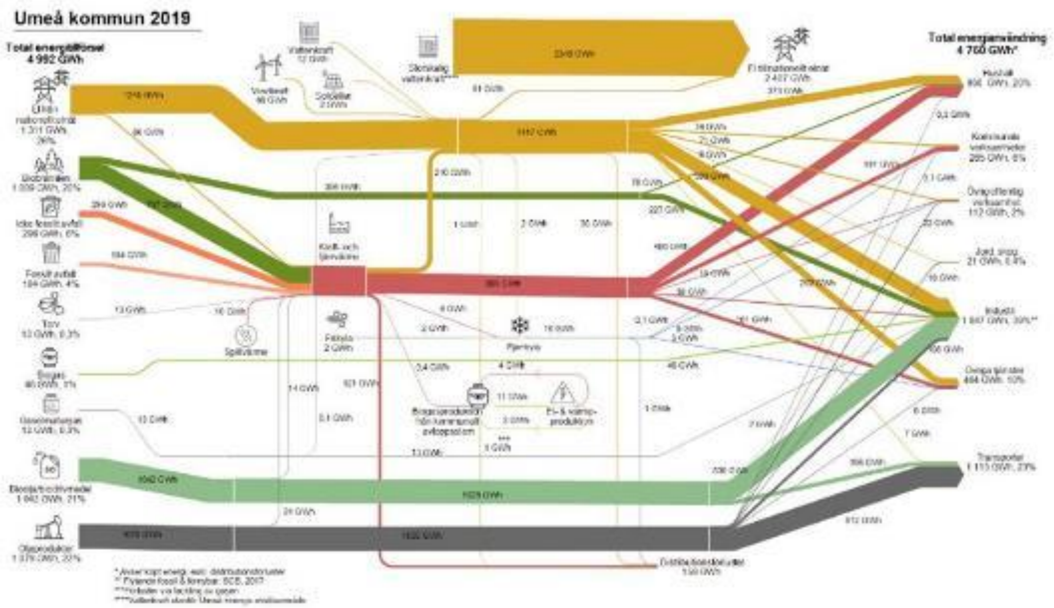

Figure 14 Current energy flows-Umeå

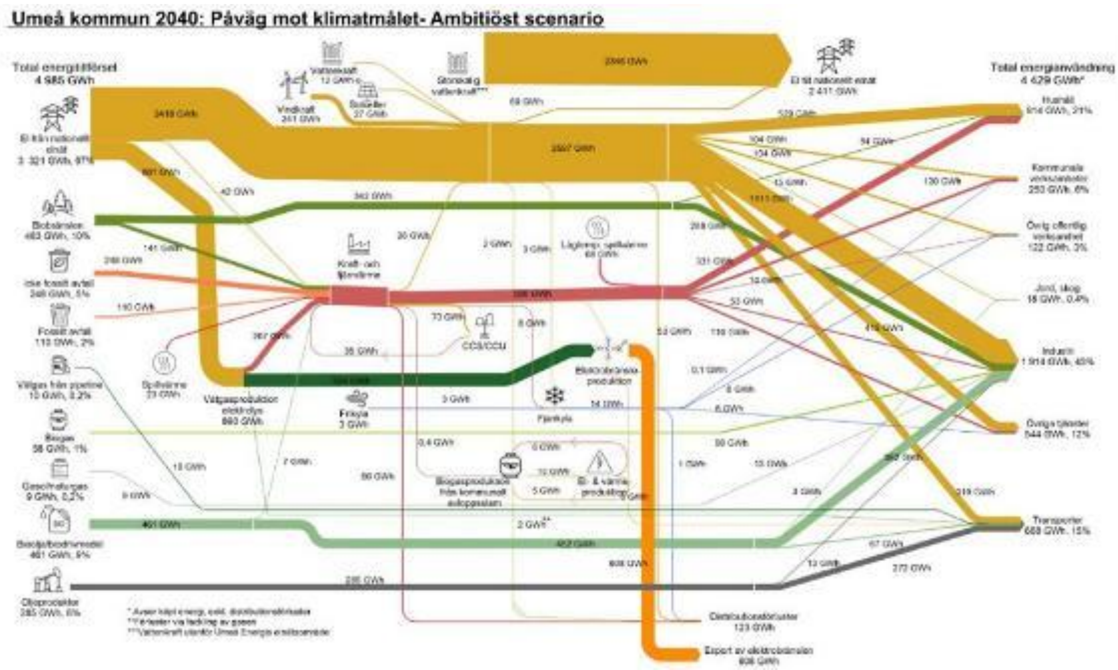

Figure 15 Future energy flows-Umeå, ambitious scenario 2040

4.4 Local initiatives

Positive energy districts and energy communities are among the identified actions to reach carbon neutrality. In order to find the best ways to establish these types of actions, projects such as Hybes plays an important role in supporting Umeå's goals of becoming climate neutral through research, analysis, pilots and so forth. To exemplify how Hybes has supported the municipal one can look at the contribution of the student research project on energy communities that was conducted within the project. This study has led to better insight into the conditions for energy communities here in the north, which in turn led to more mapping work in another project on how energy communities can possibly be supported through the municipality's preparedness work in the form of a consultancy report from Ramboll. But to have a better understanding of projects being done in Umeå by different actors which also can help utilizing RES, reliving the grid and provide sufficient of flexible solution we will also mention since exchange of knowledge between Hybes consortium partners in order to enhance the possibility of successfull outcome, improved energy infrastructure in city planning. Theese are ground source heat pumps in Norrland University Hospital, Ersboda area transportation and grid development and Blue Supply Chains in Umeå.

By fostering cooperation among various stakeholders, such as property owners, energy companies, and residents, projects like Hybes can help municipality not only to succeed with carrying out actions but also identify and establish new ones that are necessary in order to achieve climate neutrality. A key partner for achieving success is a research institute and in Umeå's case that partner is usually Umeå University. In Hybes with a focus on the Ålidhem area.

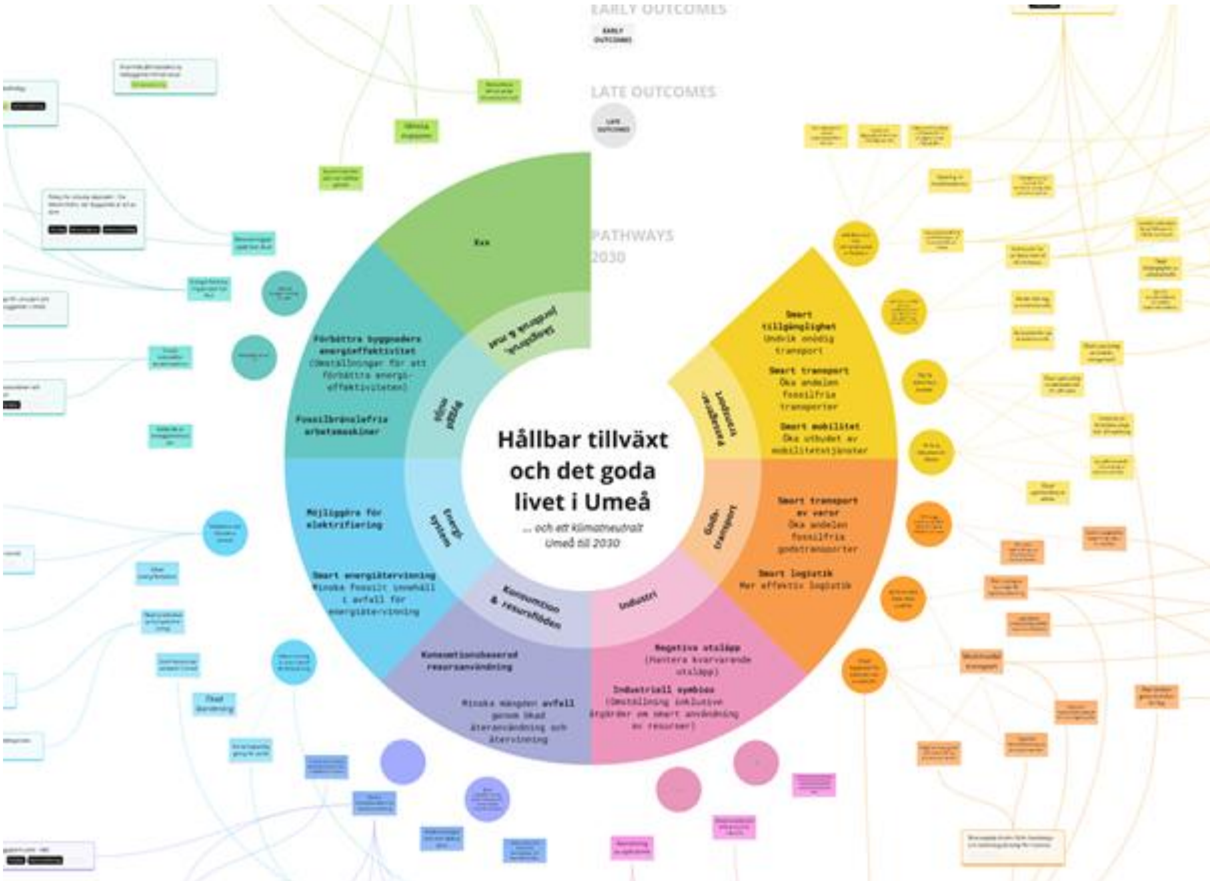

Figure 16 Climate portfolio of Umeå

4.5 Positive Energy Districts and Local Initiatives

Positive energy districts, which could contribute Umeå municipality's climate goals, has been investigated within the area of Ålidhem and addressed at workshops together with both the local energy company and Umeå University. Ålidhem is an area close to the University and can be seen as a melting pot of creative and forward focusing collaboration and processes within the municipality. By bringing together different stakeholders and engaging the local community, it has been possible to identify innovative solutions and implement concrete measures to improve energy efficiency and reduce climate impact.

Workshops have been an essential tool for both spreading knowledge and collecting practical ideas from residents and experts. Discussions have covered various topics such as smart energy systems and behavioral changes that can contribute to reduced energy consumption. These efforts have laid the foundation for continued development and collaboration within the climate and energy sector.

4.6 Ålidhem-district a case example in Umeå

Ålidhem district is a neighborhood in Umeå, in northern Sweden. The district includes 161 residential buildings (Figure 17) with land area of 0.95 km^2. The district includes apartment buildings with 2-5 floors with a total of 425,503 m^2 of heated floor area. They were built in 1970-71 as part of the Swedish national Million Programme.

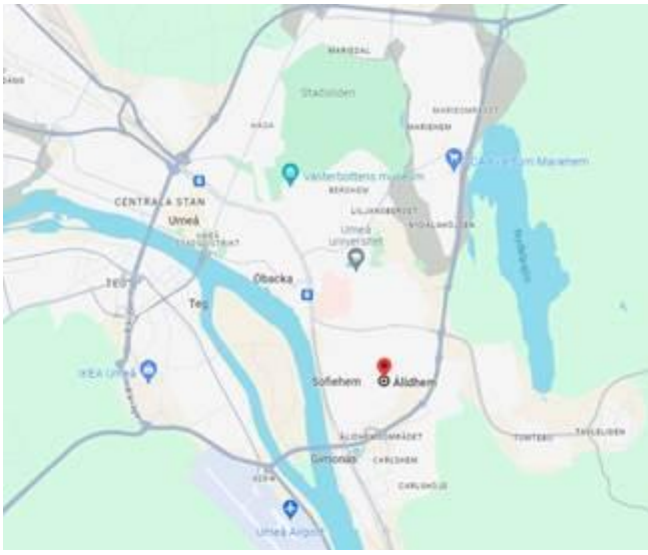

Figure 17 Map of Umeå city with the case site in Ålidhem marked. Source: google maps

4.6.1 Energy Scenario simulation of the district

Two simulation tools are used to create to develop scenarios for Ålidhem: City Energy Analyst (CEA) and Low Emissions Analysis Platform (LEAP). These simulation tools use a bottom-up approach and end-use accounting techniques to model energy demand based on building characteristics and usage patterns. The CEA is an urban building energy modeling platform for design of low-carbon and highly efficient cities. LEAP is an energy planning software for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. Energy performance of the buildings and energy reduction potential due to energy efficiency measures in Ålidhem will be used in LEAP model. Several future scenarios with net-zero emissions are being developed using LEAP that include the potential changes in energy demand, technology adoption.

4.6.2 Simulation of buildings using CEA

Modelling in the simulation tool CEA required information regarding weather and irradiation in the area and building properties and characteristics for the district. Building properties such as height, number of floors and U-values for construction components were gathered from construction drawings. Information regarding the heating, water and ventilation system were gathered from published articles. Other inputs were collected from Swedish and international standards. An EPW-file for the weather in Umeå was gathered from the Swedish Meteorological and Hydrological Institute (SMHI) from Umeå airport, which is nearby the district.

Since the buildings were built in the same period they have very similar physical properties, scaling up approach of energy use from one building to the entire district was chosen. In CEA, a single building model was created, which is the pilot building from the previous district. This model was created and calibrated with energy data before and after refurbishment, thus creating two archetypes for the building. Then the archetype that represents the building after refurbishment was applied to all other buildings in the area, and the district-model (Figure 18) could be calibrated with energy data available from the utility.

Figure 18 The chosen cluster of 21 buildings in the district are marked red, and the pilot building is shown in circle

A combination of energy measures that include reduction in electricity use for appliances, DHW, indoor temperature, wall- and attic insulation improvement, and installation of low-energy windows could result in energy savings of approximately 36%, which is a reduction of about 2200 MWh or 40kWh/m^2 GFA per year (Figure 19).

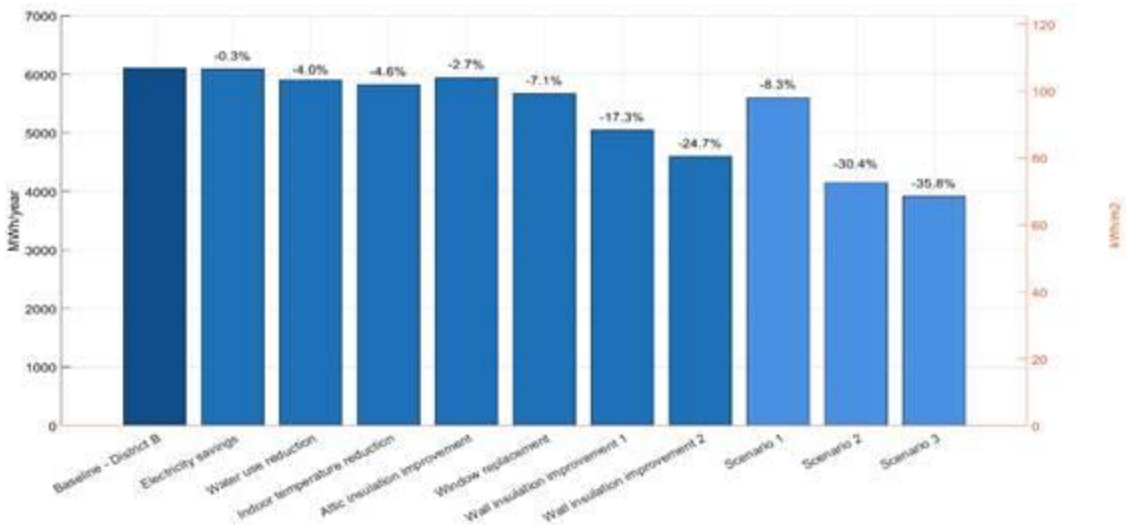

Figure 19 Energy performance of the 21 buildings for various energy efficiency scenarios, with the potential energy saving as percentage compared to District B, baseline scenario

4.6.3 LEAP – preliminary simulation results

The Sankey diagram created using LEAP illustrates the current energy flow in Ålidhem from natural resources to final energy services in the district (Figure 20). The final energy demand is highest for heating, followed by electricity, and transport.

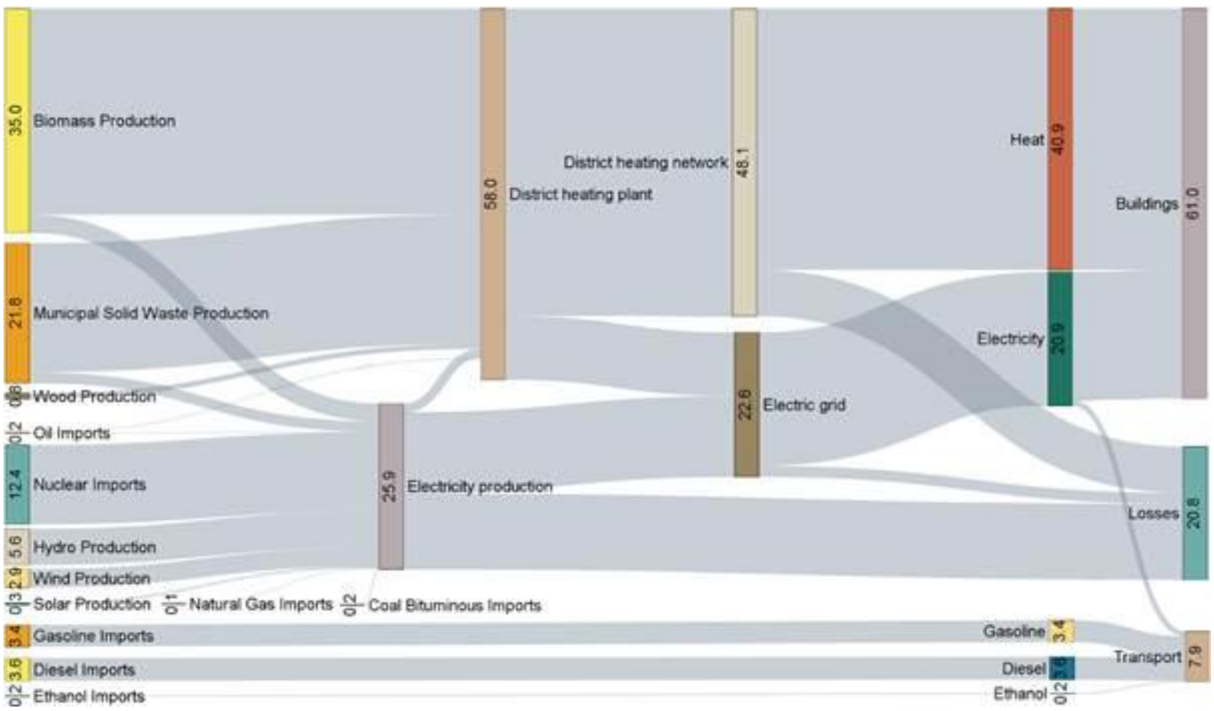

Figure 20 Current Energy flow in Ålidhem

4.6.4 Emissions Analysis

Figure 21 illustrates the current emissions from Ålidhem district. The largest cause of emissions is the burning waste in the district power plant. Gasoline and diesel for transport are the other important cause of emissions.

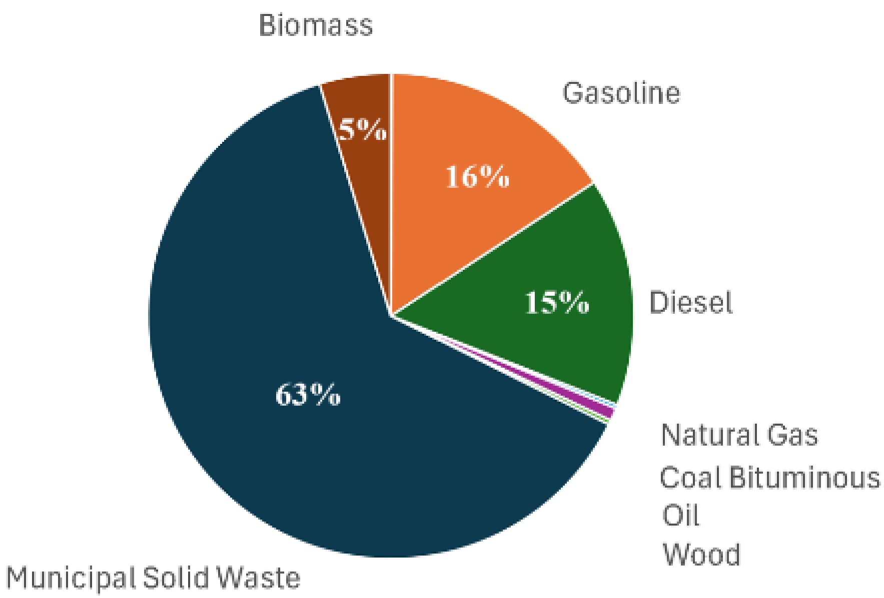

Figure 21 CO2eq emissions from Ålidhem, Umeå

The study will analyze the *CO2eq* emission reduction potential in Ålidhem by incorporating various measures such as energy efficiency improvement in buildings, installation of photovoltaic, phasing out plastics and fossil fuel-based cars.

4.6.5 Energy demand and Emissions Analysis

Energy demand and emissions of Ålidhem were analysed using two approaches: Marginal and national fuel mix approaches. Figure 22a presents a comparative analysis of current emissions and projected emissions in 2040 under different scenarios: the Business-As-Usual (BAU) trajectory and scenarios incorporating heating systems and transport. The findings indicate that standard practice of building maintenance may lead to 11% lower emissions in 2040 (BAU). When these systems are combined with national average increase in electric vehicle (EVs) fleet, the overall emissions are projected to reduce by 23% in comparison to current level. PVs installation has no effect on emission reduction as they replace already low emission electricity production. Applying additional insulation to the buildings (Intensive renovation) in addition to standard practice of building maintenance reduces the heating demand by 25%, but only 8% in comparison to the emission in the BAU scenario.

Figure 22b illustrates a marginal approach with both natural gas (NG) and coal as the marginal energy production. The results show that emissions reduction is higher if coal is the marginal production technology. Standard maintenance measures in the BAU scenario already show high emission reduction, but to reach zero emissions in 2050 additional insulation is needed in the building (Intensive renovation). Intensive renovation includes added insulation in all the buildings' façade, which is a costly measure. Installation of PVs could also provide the emission reduction necessary to counteract the current emission from the district (5961 tonnes CO_2-eq) if coal is the marginal production technology.

In Ålidhem, the marginal approach reveals that building maintenance and PV installations can together offset nearly all current emissions, but only if coal is assumed to be the marginal technology. If natural gas is the marginal source, the emission reduction is more modest, and even combining all measures—including intensive retrofitting and full transport electrification—does not achieve net-zero.

The marginal approach highlights the strategic value of reducing electricity demand and prioritizing efficiency, as these actions can have system-wide benefits beyond the local context.

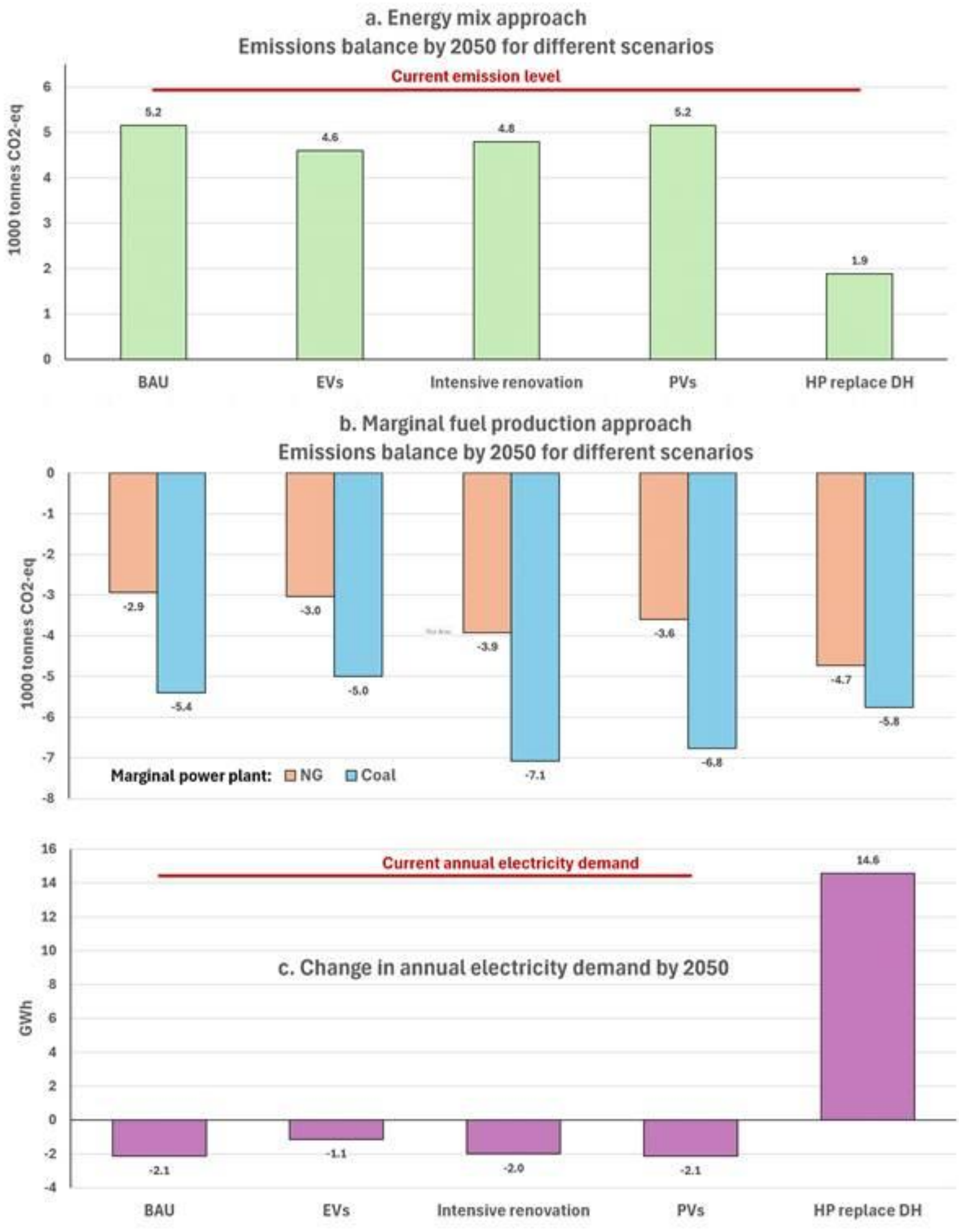

Figure 22 Change in emissions calculated by the fuel mix approach (a), by the marginal fuel production approach (b) and change in electricity demand (c) for different scenarios for Ålidhem district in 2040.

4.7 Tavelsjö area – Energy community and Safety and security point

In the rural area of Tavelsjö, located 20-30 kilometers outside the centre of Umeå, Hybes and a local group of energy advisors have conducted a study in collaboration with the consulting firm Ramboll with the aim of mapping and reviewing the possibilities for a future pilot project in the form of a local energy community and service and security centre for the area. This could then be achieved through a hybrid solution for renewable energy solutions in the area.

The work involved four different buildings: a grocery store (+ petrol station and post office), fire station, school, and nursing and care home. The basic ambition was to operate the grocery store with a full range of products, with a nearby fuel facility and backup power. The addition of the remaining buildings in the order mentioned represented a gradually increasing level of ambition.

There were several possibilities for the production of RES and backup power for an energy community, with the most obvious proposals being batteries and solar cells, hydrogen production and various renewable, low-emission backup power solutions. In the following Figure 23 a number of solutions were given depending on the level of ambition for the areas development.

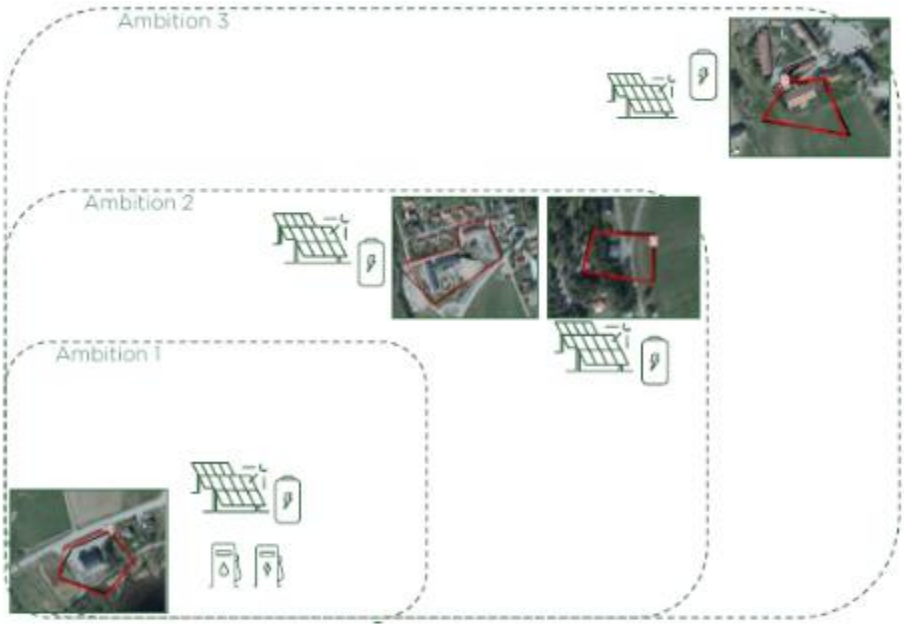

Figure 23 Different ambition levels for a possible combined energy community with a safety center.

4.8 Ground Source Heat Pumps in Norrland University Hospital, Umeå

The Norrland University Hospital [Norrlands Universitetssjukhus (NUS)] is the largest hospital in the northern Sweden. NUS has a large ground source heat pump (GSHP) which is used with the district heating and cooling network for meeting the heating and cooling demand of the hospital buildings. GSHP system that consists of 3 heat pumps (brine-to-water) was installed in 2016. The GSHP aims to meet 95% of the hospital's cooling requirement (5 GWh), and 20% of its heating requirement (7 GWh).

Two of the heat pumps are linked to boreholes for space heating and cooling, while the third uses the sub-cooler of pumps 1 and 2 to supply 60°C domestic hot water and supplementary space heating when needed. In winter, heat extracted from space cooling and the bore hole heat exchangers (BHE) feed pumps 1 and 2. In summer months, heat from the building's cooling system is discharged into the borehole thermal energy storage (BTES), primarily by running the compressors and expelling the heat from the condenser. The system consists of 8 scroll compressors and 2 reciprocal compressors. The refrigerant used are R134a and R410a. The bore hole heat exchanger consists of two borehole groups; one with 62 boreholes having a diameter of 14 cm and a depth of 200 m, while the other group consists of 63 boreholes with a diameter of 14 cm and a depth of 250 m. The annual heating load and cooling load from the GSHP are 5.1-6.2 GWh and 3.7-4.3 GWh, respectively[10]. As per a study[11] the GSHP system in the hospital could reduce the energy cost by up to 644 000 SEK/year and CO2 emissions by 92 tons.

4.9 Ersboda area – Transportation infrastructure and grid development

In terms of planning and strengthening the energy system two other activities have been carried out within the Hybes project and the municipal service of Energy advisers at Umeå municipality:

The first one is an industrial and commercial area where the energy advisory service carried out a number of energy reviews, primarily at car dealerships and garages. The initiative was targeted at this area because legal requirements for electric car charging and electrical infrastructure place increased demands on an upgraded grid and combined solutions for energy supply in different types of buildings.

In current state the area has a sufficient grid capacity but several energy efficiency actions were recommended for the venues and different buildings in terms of heating and ventilation solutions.

The review established that in light of current electric car development and charging requirements, an upgrade of the electricity grid and its substations is necessary in order to supply the area with the expected load planned for in connection with Umeå's urban development and energy planning work.

[10] Walfridson, W., 2022. Case study report for Norrlands Universitetssjukhus, Umeå, Sweden. IEA HPT Annex 52.

[11] Rao, A.P., 2021. Utilization of a GSHP System in a DHC Network: modeling and optimization. PhD Thesis., Umeå university, Umeå, Sweden, ISBN: 978-91-7855-648-9

This led to stage two follow up between the municipality with local actors, taking the matter further to the business development unit and the local energy company in order to set up a strategic plan for the current and future electricity needs in the area.

4.10 Obstacles and business models

There are several obstacles and different business models to consider depending on the level of ambition and need in the area.

Today, there is no mapping or register of energy communities in Sweden, which is complicated by the fact that there is no clear definition of what an energy community is, how it is organised and governed, and what applications should be made based on Sweden's electricity market directive and network concession regulations.

There are different ways to share energy where the infrastructure differs:

Expansion of the existing grid – means that buildings or properties keep their existing connection to the regulated grid and build their own internal, non-regulated electricity network according to the IKN regulation, which is possible under certain conditions. The electricity used within the internal grid is not taxed, and no electricity trading or grid fees need to be paid for it.

Own grid behind the connection point – means that several users are gathered behind the same connection point to the regulated grid, the metering point is thereby moved outward and the units that are connected behind the point are settled together. According to the IKN regulation, this requires that the buildings belong to the same property. The electricity used within the internal grid is not taxed, and no electricity trading or grid fees need to be paid for it.

Virtual sharing – buildings or properties have their own connection points to the regulated grid and by settling through the meter values, it is possible to determine how much electricity is fed in and out from each connection point. The electricity can then also be shared virtually between those who are part of the community. Here, both tax as well as electricity trading and grid fees are paid by the members of the energy community.

The Swedish Energy Markets Inspectorate proposed in 2020 a legislative proposal for energy communities, including a definition and surrounding regulations. An energy community must be registered, and the Act on Economic Associations is applied to energy communities to the extent specified in the legislation. An energy community can be either a citizen energy community or a renewable energy community. The Energy Markets Inspectorate's proposal is supported by the Swedish Energy Agency

As an outcome you could therefore say that it is recommended that energy communities are to be organized as economic associations.

4.11 Blue Supply Chains

Blue Supply Chains in Umeå is a strategic project that combines climate ambitions with logistics and energy production. By investing in green hydrogen and other alternative fuels, while developing port infrastructure and green transport chains, Umeå can become an important player in the future fossil-free shipping industry.

4.11.1 Background and purpose

BSC is an Interreg project for countries around the Baltic Sea, focusing on reducing the climate impact of shipping. The aim is to develop strategies for fossil-free fuels in ports, strategies for bunkering (refuelling) and green transport via ports.

The project specifically looks at green hydrogen, e-methanol and electric charging in ports as future fuel solutions.

4.11.2 Actors in Umeå

The Swedish partners in the project include: IVL Swedish Environmental Research Institute, Umeå Energi, Umeå Hamn AB, Umeå Municipality, INAB (Infrastruktur i Umeå AB) and Lindholmen Science Park.

The project is partly funded by the EU's Interreg Baltic Sea Region, with Swedish authorities and institutes (e.g. the Swedish Transport Administration and SIVL) also contributing.

4.11.3 Focus on Umeå

Umeå is a kind of 'test region' in the project: here, they will investigate how to produce, store and bunker green hydrogen and other renewable fuels at the port.

A roadmap has been developed for the Umeå region that describes how future green fuel infrastructure can be built and operated.

The roadmap highlights several strategic advantages for Umeå: recurring access to renewable electricity, biogenic carbon dioxide sources and clean water, plus the fact that by-products from fuel production can be used in the district heating system.

They are also investigating how hydrogen production can become profitable and what is required technically to be able to store hydrogen at the port.

4.11.4 Logistics and transport chains

The project is not only focused on producing fuel, but also on building 'green transport chains. This means connecting sea transport with other forms of transport (e.g. rail or road) to reduce emissions throughout the entire chain. By developing infrastructure for alternative fuels in the port, Umeå can become an important hub for sustainable freight transport in the future.

4.11.5 Environmental and climate benefits

BSC can help reduce carbon dioxide emissions from shipping, which is a major global challenge. By linking fuel production to local energy and recycling, Umeå and the region can utilise their natural resources (water, renewable electricity) efficiently and sustainably. The project is also in line with Umeå Municipality's climate goals and strategy to reduce emissions from transport.

Challenges

- Technology: The production, storage, and bunkering of green hydrogen is technically challenging and requires investment.
- Economy: Making hydrogen production economically viable is a key issue.
- Infrastructure: Electricity grids, storage solutions, and port capacity must be developed to meet future needs.
- Regulations and policy: International and national regulations for alternative marine fuels must be clear and support for the transition.

4.11.6 Significance for Umeå and the region

If the project is successful, the Port of Umeå could become a model for sustainable shipping and green logistics in Norrland and the Baltic Sea region. This could strengthen Umeå's role as a logistics hub (port + multimodal transport) and attract green investments. The project could also create new business opportunities for companies in energy technology, hydrogen, transport, and infrastructure sectors.

4.12 Summary of Umeå energy district planning

Umeå municipality has ambitious climate neural targets. In HYBES, Umeå municipality and Umeå University work closely and the project facilitate the study by university that will provide scenarios for *CO2eq* emission reduction potential in Ålidhem. The study results could feed-in the Energy Programme of Umeå to formulate necessary action plans to reduce CO2 emission. Accordingly, HYBES project is contributing to Umeå municipality’s endeavor to become climate neutral through strengthening the work on climate actions in the climate portfolio.

5 Conclusions

This report summarizes many of the most important aspects for energy planning on a district level in Bodø and Umeå, with the purpose to provide a clearer understanding of how hybrid and flexible energy solutions can support the transition toward low-carbon and resilient urban districts in northern climates. The development of efficient energy districts does not only depend on technical solutions, but need to consider the context and needs in the energy system and the availabilities of resources and regulatory possibilities. The cases highlight challenges and possible solutions in two cities and energy systems with many similarities, but also with quite different character.

The energy system in Bodø is highly decarbonized and electrified with low carbon emissions. The most important challenge is identified to be to ensure enough grid capacity to allow electrification of transportation and industry, as well as allowing for establishment of new clean industries. Climate footprint from energy use in Bodø is largely set by maritime, road and air transportation sectors, and electrification is the most efficient way for reducing carbon footprint. District heating has been identified as an efficient solution to reduce grid load in Bodø, while insights from the HYBES analysis in 2.1 has shown that the use of heat pumps may be a more efficient way to reduce grid load and carbon emissions in the energy system.

To make it possible to increase electricity consumption for electrification or new business establishment, Bodø is working to develop possible models and business models that can make it financially and practically possible to do within the current energy system. It is however challenging and require good planning and collaboration between energy consumers. The municipality is also identifying ways to influence the development in the energy system with the use of classic municipal tools. Municipalities are restricted in what they can require and does in reality have a constrained toolbox for change. The HYBES project has contributed to finding ways to facilitate for the desired change with the use of area zoning plans, giving useful tools for energy planning in urban districts.

Umeå has many of the similar challenges and have strategically painted the desired energy system for Umeå in 2040, making it possible to target change in the energy system of today, and have created a framework with goals and concretized action points to transform and decarbonize the energy system towards the desired system. There are however also important differences between the two energy systems, where Umeå has a less decarbonized system than Bodø with a much higher integration with district heating, which makes up the largest share of the energy use today. The district heating in Umeå come largely from waste incineration, which in turn is connected to higher climate footprint. Some of the important actions Umeå target to reach the desired energy system are: to decrease energy consumption by rehabilitation and energy efficiency measures, to reduce the carbon footprint of the district heat production, amongst other by utilizing the waste resources more efficiently and production of e-fuels, and lastly they open for increased use of heat pumps for heating. By doing these steps they can reach an energy system with much lower emissions, but also with more use of electricity.

Through the LEAP model analysis it is found that changing the heat source from district heating to heat pumps will lead to a large reduction in carbon footprint. It will however also increase the load on the electricity grid drastically, which ias also an important issue, both in Umeå and in Bodø.

Based on the differences in the energy system, Bodø has set a high focus on practical and detailed planning measures in the two most important districts of the city, namely the harbor and the new city district, with more focus on freeing grid capacity to allow electrification, while Umeå has a higher focus on changing the current energy system and producing more local energy.

Local energy production is desired by both cities but is challenged by a climate where solar panels does not produce electricity when heat is most needed. Finding solutions for this will be important in the decarbonization of the societies, and the HYBES pilots have contributed with important and valuable insights about how solar and other energy production should be used on a system level.

For energy district planning purposes HYBES has given the possibility to look at similarities and challenges between different regions in northern Europe, and to take learning points from smaller scale pilots and projects to a system thinking level. The work shows that there are different perspectives to take into account when planning the energy system for a building, compared to a larger city district, and that the state of the energy system and the challenges that are desired to be solved need to lay as the foundation for the measures to be planned. Many aspects are however common for the different energy systems, and there is much value in sharing perspectives, challenges, goals and solutions across cities and energy systems to find good paths towards the goals.