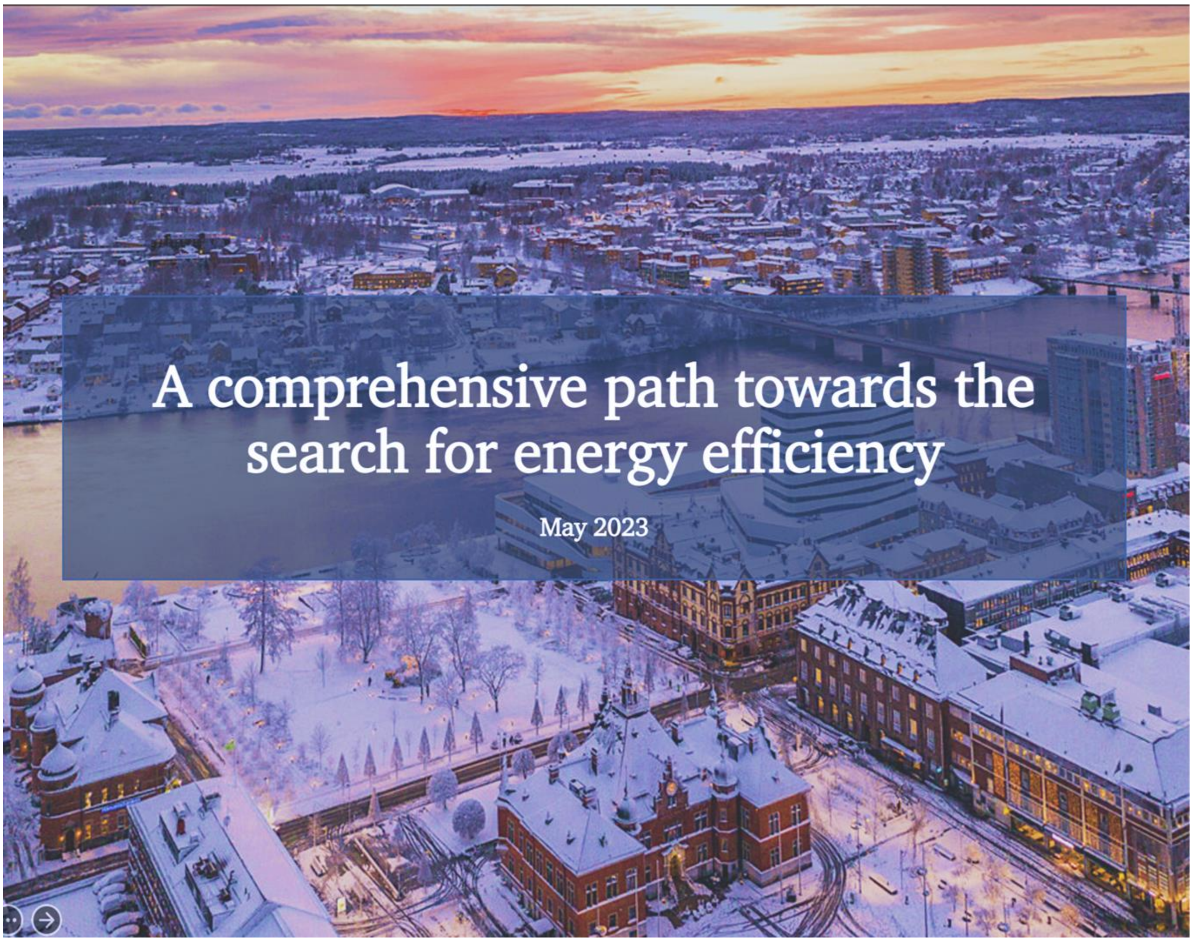
KTH 2023-1

UMEÅ UNIVERSITY

CAMPUS VISION 2050



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KTH Royal Institute of Technology
MJ2511 – Energy Management

This report was created for academic purposes at KTH, Stockholm.

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Project features

This project is developed for the course Energy Management, with the support of the private organization Akademiska Hus, to optimize the energy management in Campus Umeå, University of Umeå, Sweden. Various strategies are proposed for energy saving and production, with a focus on three KPIs: reducing energy consumption, decreasing carbon dioxide intensity, and increasing local energy supply. The project timeline spans from 2030 to 2050, during which three scenarios—Sunlight Symphony, Forest Harmony, and Nordic Breeze—have been developed to assess the impact of different plans.

In the energy-saving aspect, the project considers improving the building environment through enhanced insulation for walls, roofs, and floors. Additionally, energy-saving equipment and devices, such as smart plugs, are planned to be installed. The introduction of heat pumps is also proposed to minimize energy consumption. Regarding energy production, the project suggests incorporating solar panels, and biodigesters, which will further enhance renewable energy generation and sustainability.

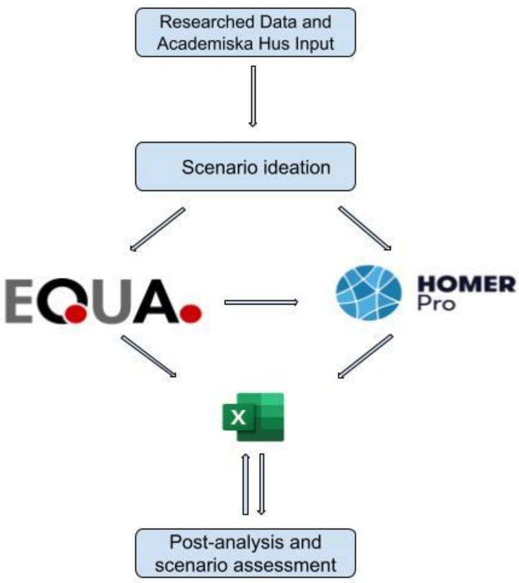
To evaluate the effectiveness of the different plans, three Key Performance Indicators (KPIs) were established. The first KPI aims to reduce energy consumption, focusing on optimizing energy usage within the defined time period. The second KPI targets the reduction of carbon dioxide intensity, aiming to minimize the environmental impact associated with energy consumption. Lastly, the third KPI aims to increase local energy supply, emphasizing the importance of self-sufficiency and reducing dependence on external energy sources.

The Sunlight Symphony scenario represents the baseline or business-as-usual approach, incorporating solar PV panel installations, building renovations, and improvements in lighting and equipment. The Forest Harmony scenario includes additional biodigesters compared to the Sunlight Symphony scenario. Lastly, the Nordic Breeze scenario focuses on solar PV panel installations, as well as the acquisition and installation of new heat pumps.

An economic assessment was conducted to evaluate the viability of the scenarios. It was found that both the Forest Harmony and Nordic Breeze scenarios demonstrated more outstanding economic performance. However, the Nordic Breeze scenario stood out as the most popular plan due to its lower initial investment and shorter payback period. Moreover, the Nordic Breeze scenario was also found to be closest to reaching the defined KPI targets.

Project Methodology

This project's methodology can be categorised into three parts: data collection and scenario ideation, modeling, and finally assessment and post analysis. For numerous reasons, a detailed literature review was done. First and foremost, the team members needed to immerse themselves in the detailed research as it is related to campus and their goals. The processed data was used to model the energy demand on IDA ICE and the inputs were used to model the energy supply and scenario modelling on Homer Pro. Excel was used to format the IDA ICE inputs to extrapolate the data to all the buildings. Lastly, the data was used to model the different scenarios iteratively to successfully model and validate the scenarios.



Project Management Team

The team in charge of developing this project is made up of 5 master students and two exchange students from different countries.

Even though the tasks were developed mostly in joint meetings, each member of the group assumed a particular responsibility to develop the necessary material for this phase of the project.

Vrashabh Doshi - Homer Pro modeling
Paul Dupin - Data analyst
Javiera Espinoza Morales - IDA ICE modeling
Vicente Gaete Hernández - Homer Pro modeling, business model creator
Arth Jagruti Mishra - Scenario author, KPI analyst, business model creator
Yi Kuang - Economic analyst, business model creator
Fayiz Riyaz - IDA ICE modeling

Supporting Staff

The progress of this report has been supported by the Energy Management team.

Hatef Madani Associate Professor
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Jaime Arias Associate Professor

1. Introduction – Campus overview

1.1.1. Global and European panorama

The global and European energy landscape is undergoing a transformative shift towards sustainability and decarbonization. The Paris Agreement and EU targets aim to limit global warming and achieve carbon neutrality. Key objectives include increasing renewable energy share, improving energy efficiency, and integrating clean technologies. This framework guides the transition to a sustainable energy system in alignment with global and European climate goals. The objective pursued in this study, summarized as a "net-zero campus", follows this framework.

1.1.2 Umeå

1.1.2.1 Location and population

Umeå city is the capital of the province of Vasterbotten, Sweden, and is located about 638 kilometers north of the country's capital, Stockholm. The city has a population of 130997 inhabitants (2021), with an approximate annual growth rate of 1450 people. Because of this, it is expected that the city will pass 140.000 inhabitants in the year 2028. (Umeå Municipality, Population forecast 2022-2033)

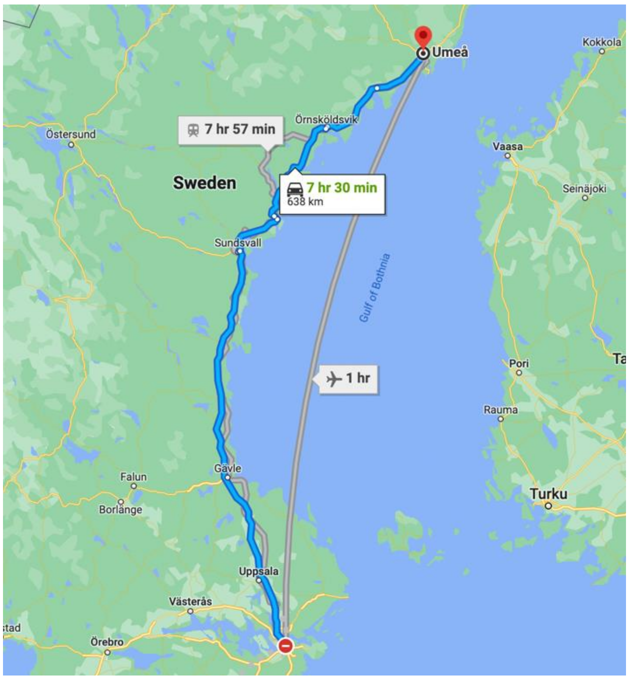


Figure 1: Distance between Stockholm and Umeå.
Source: Google Maps. Sweden. (2023).

Most of the people who move to the city are young people between the ages of 19 and 30 years old, who attend Umeå University. It is expected that the rate of young emigrants will remain the same and even increase in the next few years. (Umeå Municipality, Population forecast 2022-2033)

1.1.2.2 Energy System

Umeå city produces its own renewable energy through the company Umeå Energi AB, which belongs to the municipality. The company has the responsibility of the heat network and grid stability. It provides contracts for electricity supply, internet, heating, and cooling services to the people of Umeå. The company's energy mix is constantly updated to maintain low emissions and a circular economy while phasing out fossil fuels.

The power grid of Umeå is 100% renewable. Intermittent energies are slowly introduced in the mix while the baseload power is maintained by Hydropower and Waste/Biofuels incineration. Its enbvironmental impact is very low, with only 2 gCO2eq being emitted for 1kWh produced.

District heating in Umeå is 94% renewable. Indeed, according to the US environmtal protection agency (https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/faq.html#:~:text=Separated%20municipal%20solid%20waste%20(MSW,to%20be%20a%20renewable%20resource.) and most definitions around the globe, watse incineration is considered renewable, altough it is not a clean energy a emit a lot of carbon dioxyde for an overall intensity of 59 gCO2eq/kWh.

The detailed energy mix is provided on the company website and displayed below in figure 2 and 3.

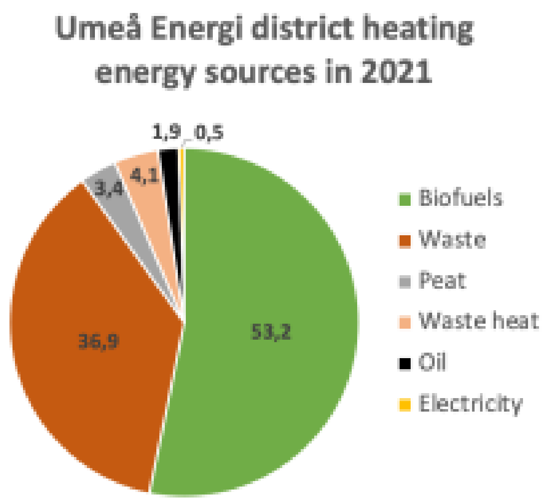


Figure 2: Umeå Energi District heating sources.
Source: Umeå energi. (2023).

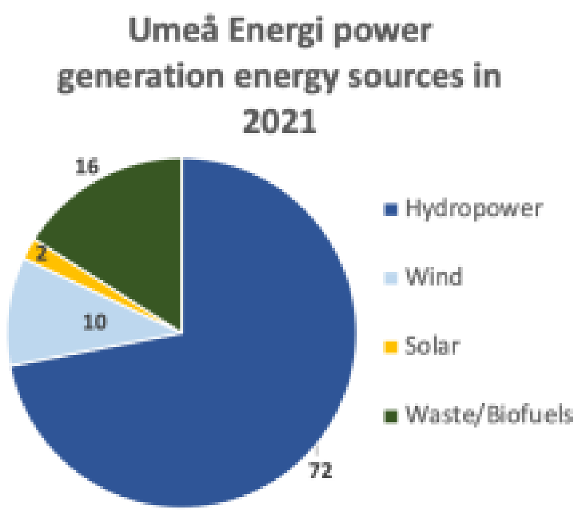


Figure 3: Umeå Energi power generation sources.
Source: Umeå energi. (2023).

District cooling in Umeå use different technique: compression, absorption and free cooling. Its environmental impact is non neglectabel with an intensity of 32 gCO2eq/kWh (source: Umeå energi).

1.1.2.3 Climate

Umeå has a humid continental climate, which is characterized by cold and rainy conditions. In the warmer months the average temperature is around 15 degrees Celsius, and in the cold months it is around -5 degrees.

Figure 4: Daylight at Umeå.
Source: Weather averages Umeå. Climate Data. (2023).

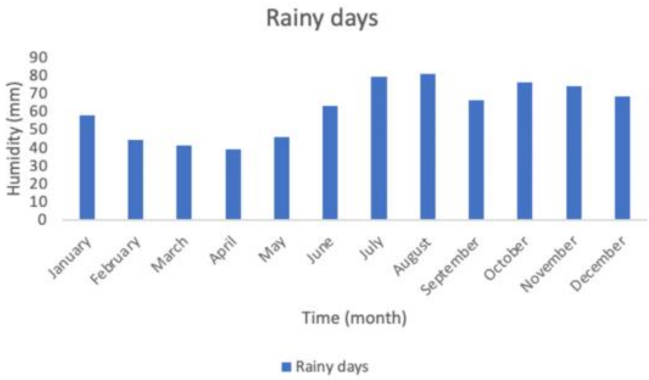


Figure 5: Rainy days at Umeå.
Source: Weather averages Umeå. Climate Data. (2023).

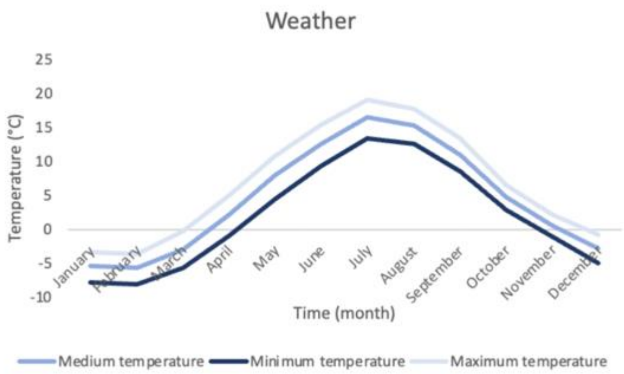


Figure 6: Averages temperatures at Umeå.
Source: Weather averages Umeå. Climate Data. (2023).

1.1.3 Umeå University

1.1.3.1 Campuses

The university has 4 campuses:

1. *Umeå Campus*, which is the main campus located almost in the center of the city. Most of the courses and programs are taught in its dependencies.
2. *Umeå Arts Campus*
3. *Campus Skellefteå*
4. *Campus Örnsköldsvik*

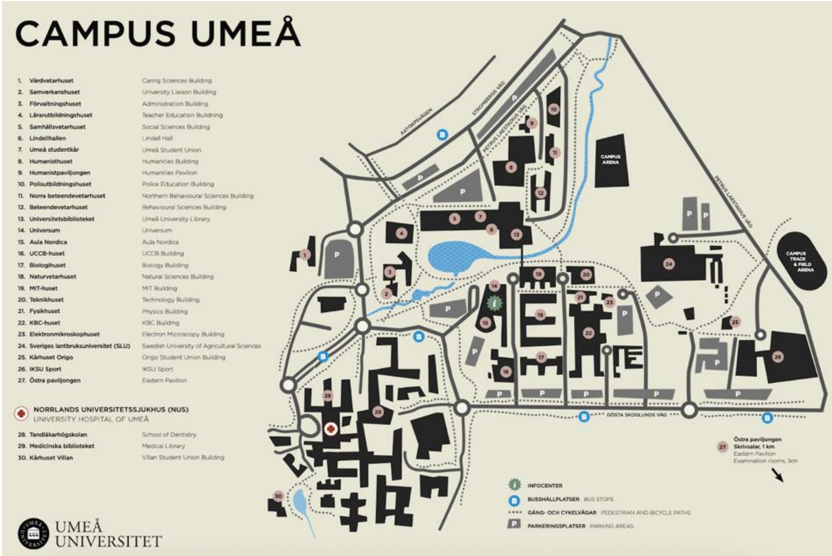


Figure 2: Campus Map.
Source: Umeå University (2023).

1.1.3.2 Buildings at campus Umeå

Umea Campus comprises a total of 33 buildings, with thirty-one located within the vicinity of Umea campus and two situated 40 kilometers away, near the sea. The ensemble of buildings aims to meet the needs of students, faculty, administrative staff, and support personnel, providing academic, recreational, and management services.

Currently, the campus has become too small for the university community, which is why the responsible body has decided to propose expansion plans. These plans take priority due to the projected population growth over the next 20 years.

1.1.3.3 Environmental policy

The University of Umeå has a plan aligned with the environmental objectives of the global agenda. To achieve this, they have developed environmental policies focused mainly on education, collaboration, and research to provide professionals with the tools to deal with the situation. At the same time, they have implemented campus policies, including recycling protocols and travel reduction measures, such as:

1. *Reduced emission from business travel:* Given the geographical location of the university of Umeå, and the academic activities that take place there, such as research, physical encounters become important. Despite this, since 2022 there is a plan to reduce travel as much as possible. For those tasks that require personal presence, an attempt is made to opt for means of transport that are more respectful of the environment, such as the train.
   Source: Action Plan for Climate and Sustainability 2021-2023. Umeå University (2023).

2. *Reduction of the impact of purchases and investments:* The university hosts various cafes, restaurants, and recreational spaces in its facilities. They seek to reduce the impact of food and its services by establishing environmental requirements for suppliers.
   Source: Action Plan for Climate and Sustainability 2021-2023. Umeå University (2023).

3. *Property and campus:* In 2020 the university consumed 28 GWh of energy. To achieve the goals of the different international organizations, the university seeks to optimize its facilities, promoting the good use and use of spaces, making environmentally friendly decisions about equipment, technology, construction materials and promoting biodiversity.
   Source: Action Plan for Climate and Sustainability 2021-2023. Umeå University (2023).

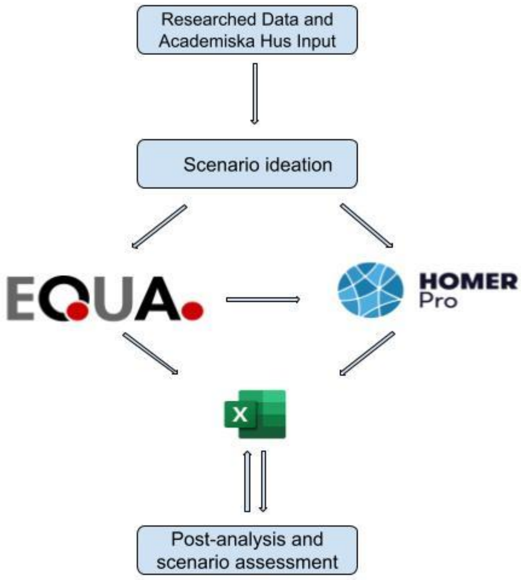
With measures like these, the university hopes to achieve the following self-proposed goals by the year 2030:

1. Sustainable development is integrated in education on all levels.
2. The knowledge and commitment of students and staff comes to use in the university's environmental sustainability work.
3. The university's research on sustainable development must increase.
4. Knowledge of researchers and staff is utilized in outreach activities and in the university's environmental sustainability work.
5. The number of procurements setting environmental and sustainability requirements must increase every year.
6. The selection of climate-friendly food and service options must increase.
7. The university's foundations and donated funds must be invested with consideration for environment and sustainability aspects.
8. Climate impact from energy use must reduce every year.
9. University premises must be used more efficiently.
10. Biodiversity on Campus Umeå must increase.
11. Climate impact from travels must decrease.
12. The use of web meetings must increase.
13. The amount of combustible waste as well as hazardous waste must be reduced.

Source: Action Plan for Climate and Sustainability 2021-2023. Umeå University (2023).

1.1.3.4 Project Methodology

This project's methodology can be categorised into three parts: data collection and scenario ideation, modeling, and finally assessment and post analysis. For numerous reasons, a detailed literature review was done. First and foremost, the team members needed to immerse themselves in the detailed research as it is related to campus and their goals. The processed data was used to model the energy demand on IDA ICE and the inputs were used to model the energy supply and scenario modelling on Homer Pro. Excel was used to format the IDA ICE inputs to extrapolate the data to all the buildings. Lastly, the data was used to model the different scenarios iteratively to successfully model and validate the scenarios.



2. System Mapping

Upon studying the given data, plans of the university and data available on the internet, we have considered 5 significant elements for our project, which are: Energy, Built Environment, Transport and Biodiversity and Waste. This qualitative model represents all significant aspects, links and flows that have been considered within the system boundary and a few outside the scope, but that are key to our project and methodology.

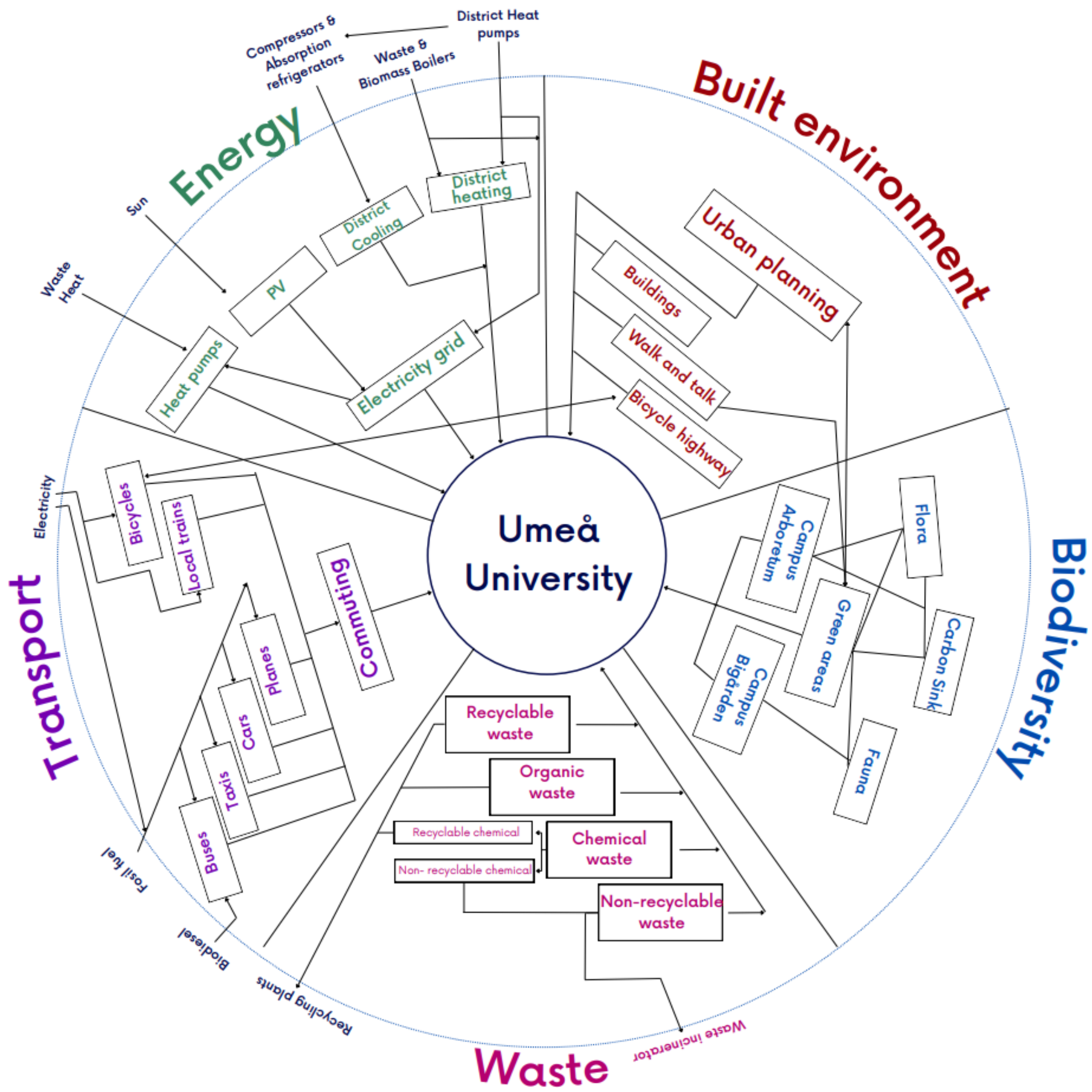


Figure XX - 1st draft of the System Map for Umeå University

2.1 Waste

At a modern campus, there are all kinds of waste produced. All waste is disposed in bins, sorted, and sent off to be either recycled or incinerated to produce heat for the city. Hence, all waste treatment has been outside the system boundaries. The transportation of all waste has also been excluded. However, organic waste has been considered for our second scenario where we use a biogas generator.

2.2 Transport

There are a lot of public transport methods available in Umeå, which include taxis, buses and more. It was considered in the boundaries to have commuting emissions from transport as an interesting idea. Since some methods use electricity and biodiesel, it would've been in the scope to help model and reduce emissions from commuting to and from campus, but it also seemed unfair to ask people to change their daily methods and mode of transportation, when there are other aspects to focus on.

The option for transport in the earlier stages was explored to model the possibility of emissions. As we passed on from phase 1 towards in-depth studies, it turned out to be too difficult to account for, and upon reviewing it with project guides and expectations from Akademiska Hus, it was decided to be out of the scope for further research.

2.3 Biodiversity

Campus Umeå has two green areas Arboretum and Bigarden. These are specialized zones dedicated to the study of trees and bees. Our major interest was brought in by the Arboretum, which creates a very high amount of biomass to be modelled. The campus layout also has a major share of green areas. All the biomass produced within the geographical boundaries of the campus has been within the system boundaries.

2.4 Energy

The electricity supplied to Umeå University is from 2 major sources, the grid and self-produced solar PV. At the same time, there is a very large share of heating required, which is fulfilled by district heating and self-produced heating through modular ground source heat pumps. There are 11 buildings that are supported by the heat produced through heat pumps and district heating. All energy supplied to the campus has been considered within the system boundaries. The assumption made here is that Akademiska Hus can control the energy used by the campus, hence, all emissions from that are within the system boundaries.

2.5 Built Environment

This section includes all buildings for which Akademiska Hus provides the data. There are also 2 laboratories that are about 40kms away from the campus but have been considered within the system boundaries since they do represent a footprint on the campus. The reason for selecting such buildings is that the organization has influence over the buildings and possible changes/recommendations can be made.

3. Data analysis and current situation

3.1 Dataset presentation and methodology

During the first phase of this project, information was gathered from the literature about Umeå University as well as a complete analysis of the data provided by Akademiska Hus.

3.1.1 Akademiska Hus data

Umeå campus is broken down into 33 buildings for which data is given regarding water consumption, electricity, and heat consumption (broken down into: purchased energy, used energy, tenant energy, building energy, self-produced energy from a heat pump or solar panels) and gas consumption.

Excel models were compiled for each of the 31 buildings that had data. Energy consumption was one point of emphasis during this project but unfortunately, most of the "used energy" dataset was empty so we had to compute it ourself in the following way:

- *Used electricity = purchased electricity + self-produced from solar (if any) – electricity used for the heat pump*
- *Used heating = purchased heat + self-produced from heat pump (if any)*
- *Used cooling = tenant cooling*

The energy consumption of each building was then computed as the sum of these 3 values divided by the surface area. Figure X shows the energy consumption of each building on the campus. The consumption of the campus is highlighted in red, and the buildings chosen to represent the campus are in grey. Universum and Aula Nordica are one and only building, as per the Energi declaration **(Boverket, n.d.)**.

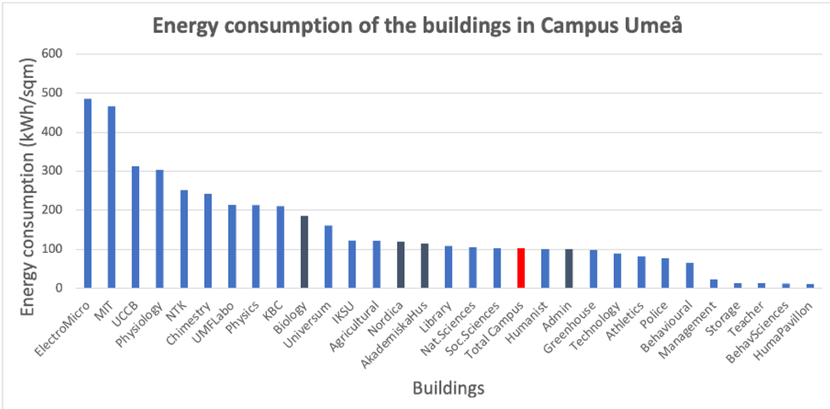


Figure X – Energy consumption of the buildings in the Umeå campus

3.1.2 Building breakdown

In order to track the energy demand of the campus and its evolution, 3 buildings were modeled on IDA DICE and their consumptions would then be extrapolated to the entirety of the campus. The 33 buildings of our campus were broken down into 3 groups, depending on their usage, displayed on the Energi declaration (Boverket, n.d.). Table X+1 shows these groups with modeled buildings displayed in yellow.

Umeå Campus		
Group 1 **Academics**	Group 2 **Student Life/Athletics**	Group 3 **Administration**
Biology	**Universum**	Soc.Sciences
Nat.Sciences	**Nordica**	Greenhouse
Chimestry	Library	**AkademiskaHus**
Physiology	IKSU	Admin
Humanist	NTK	ElectroMicro
Physics	Athletics	Storage
MIT	UMFLabo	Behavioural
Technology		HumaPavillon
KBC		Management
Teacher		
BehavSciences		
Police		
UCCB		
Agricultural		

Table X+1 – Breaking down of campus Umeå

Ratios were then calculated for each group between the overall heating, cooling and electric consumption of the group and the modeled building. With these ratios and the simulations from IDA ICE, energy consumption of our three models would be extrapolated to the group they represent, and the overall demand of the campus is then obtained.

3.2 Renewable potential

Since one of the early points of interest was the potential implementation of renewable capacity on campus, the potential for solar, wind and biomass was investigated. Akademiska Hus provided some weather data to look into the irradiance and the wind speed on campus. We will compare these data to a city in Spain, in the area of Madrid, which presents great renewable resources.

3.2.1 Solar

The city of Umeå is situated very far North, almost at the polar circle. Therefore, the days are very long during the summer and very short during the winter. Any solar-based energy system would have to heavily rely on different sources to substitute during the winter or very long-term energy storage. The heavy and regular precipitation conditions (snow, rain, clouds, etc.) also mess with the solar radiation.

Figure X+2 displays the monthly solar radiation of Umeå in comparison with Madrid in Spain.

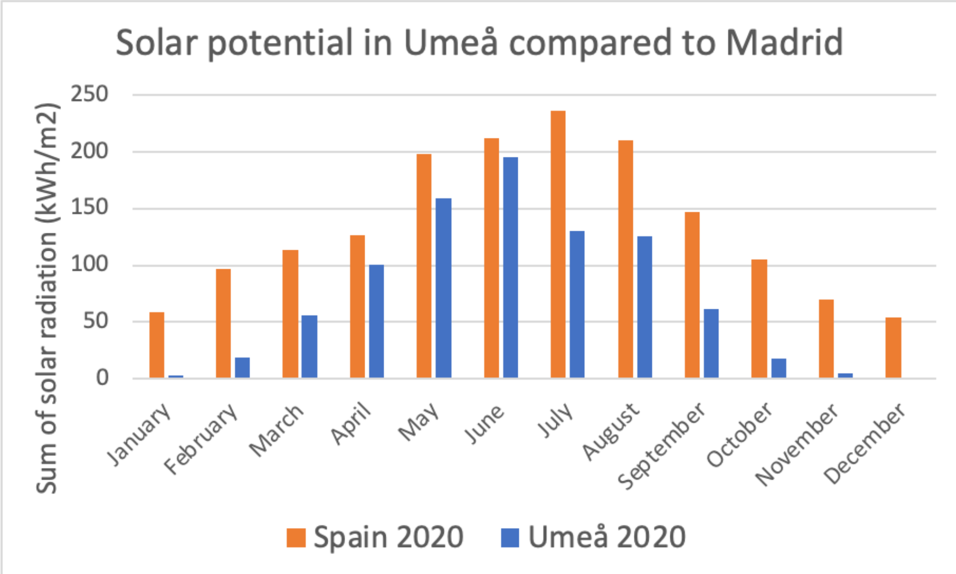


Figure X+2 – Solar potential in Umeå compared to Madrid)
(Madrid data recovered from EU photovoltaic geographical system **(European Commission, 2016)**)

The city presents very decent radiation conditions during the summer so, if the right capacity of solar is installed, the campus could have a big share of its electric supply self-produced. A rapid research about the potential offered by the rooftop surface on campus showed that only around 1MW could be installed on campus, for a current installation of around 300kW (number estimated from the production on campus). For further capacity installation, the parking slots could be looked into.

3.2.2 Wind

More surprisingly, figure X+3 shows that the wind resources on campus are also limited. The proximity with the sea could be used, as an offshore wind parks could supply the campus with renewable power throughout the year, but the capital costs involved provide Umeå University or Akademiska Hus to start such a project alone. Maybe a consensus of shareholders, Umea University, Akademiska Hus, Umeå Energi AB, could partner up and build enough demand and revenues to sign a PPA (Power Purchase Agreement) with a renewable producer.

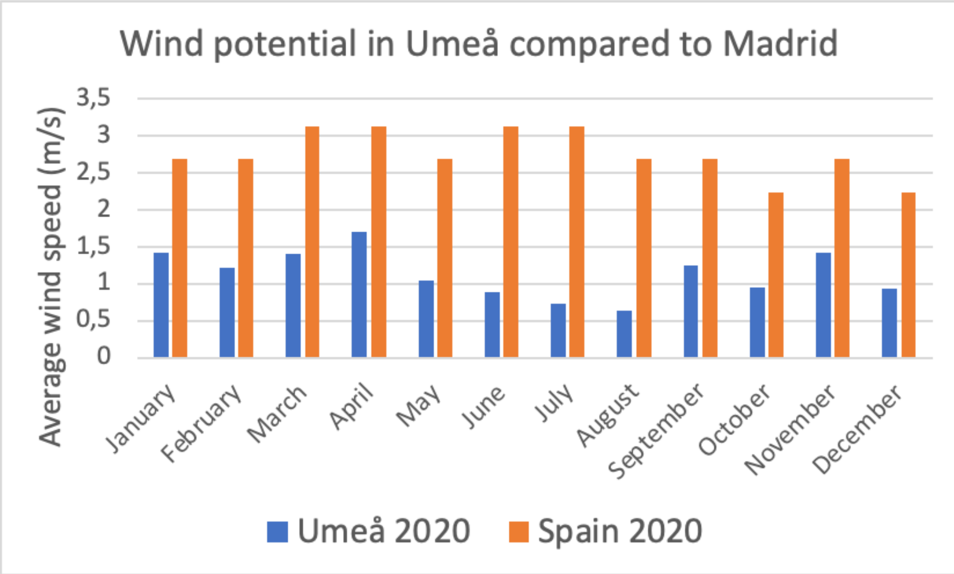


Figure X+3 – Wind potential in Umeå compared to Madrid.
(Madrid data recovered from **(weatherspark.com, 2022)**)

3.2.3 Biomass

Campus Umeå presents a promising opportunity for biomass utilization. With plans to double the number of students by 2050, the campus generates substantial biowaste, including food waste, paper, cardboard, and laboratory waste. Additionally, the campus's 18 hectares of green areas, particularly the Arboretum, provide a diverse range of biomass resources such as lawn clippings, fallen leaves, and tree branches from regular pruning activities. By efficiently managing biowaste and harnessing biowaste from green areas, Umeå Campus can make significant strides towards its sustainability goals and foster innovative biomass utilization practices.

We will explore the usage we can make out of these resources by installing a biomass burner on campus. The modeling of biomass resources can be found on the appendix.

3.3 Energy demand and supply of the campus

3.3.1 Energy demand

The energy demand of the campus can be broken down into three streams of energy: electricity, heating and cooling. The electricity used on campus is provided by Umeå Energi AB through the grid for the most part, and the rest is locally produced by newly installed solar panels. The heating demand is covered by the district heating system of Umeå Energi AB and the heat pumps installed on campus since 2015. Uncertainties remain for the cooling part, as Akademiska Hus datasets present values for "purchased cooling", interpreted as district cooling, but some heat pumps on campus also provide cooling. Energy demand on campus is displayed in figure X+4.

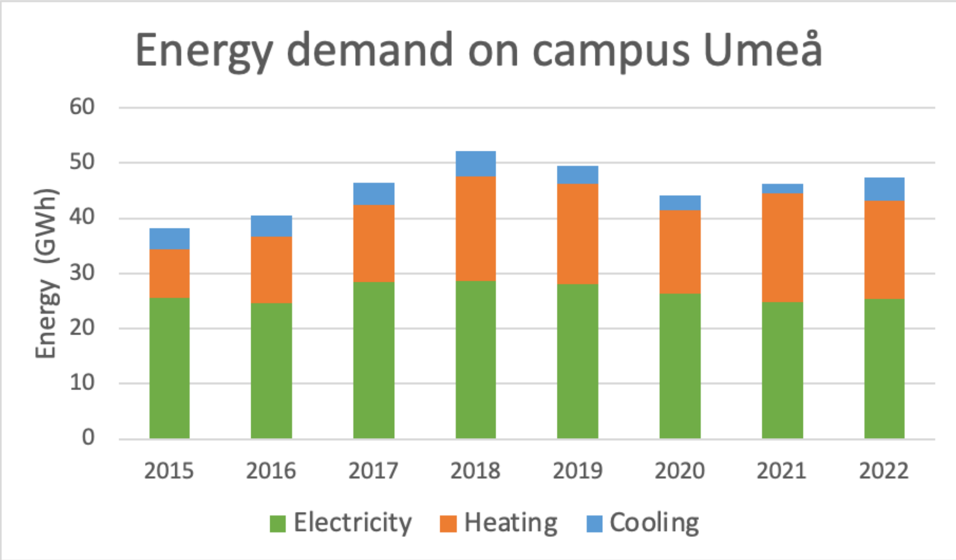


Figure X+4 – Energy consumption on campus Umeå per stream of energy
Source: Akademiska Hus data, own production

All energy demand is aggregated in this graph: the electricity value is the sum of the purchased and self-produced, the heating is the sum of district heating and heat pump but the cooling is only purchased as no data have been provided for self-produced. The electricity fueling the heat pump has not been disregarded in this graph, causing a "double counting" of the energy, since the purpose was to represent the total energy supply on campus.

The targets set in the Umeå plan for Sustainability [5] have been met for now: from 2018 to 2022, there has been a constant decrease in the energy demand on campus. The year 2020 can be disregarded as the pandemic itself is responsible for such a low consumption. Continuing this drop of consumption, if not enhancing it, would be one of the points of emphasis of this project. Electricity is tackled as efficiency of the equipment and optimization of building usage is addressed. For heating and cooling, we explored renovations and improved energy system.

3.3.2 Heating supply

Figure X+5 shows the heat supply on campus from 2015 to 2022. Even though district heating remains in the majority, the past years have seen a dramatic increase of the heat pump supply on campus. 11 buildings are provided with heat from the heat pumps on campus and the total capacity has been estimated at roughly 1800kW from the production profile, by assessing the peak supply.

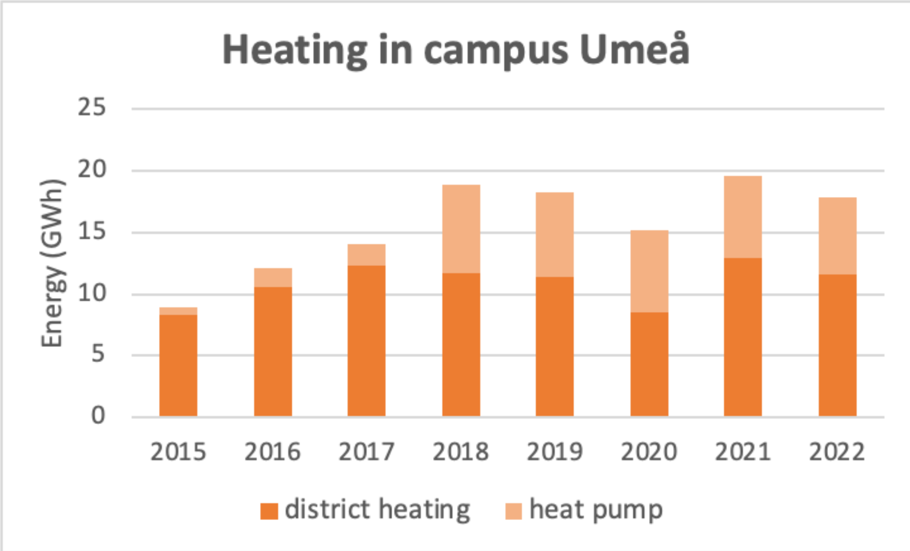


Figure X+5 – Heating supply on campus Umeå
Source: Akademiska Hus data, own production

As far as our data goes (2015), heat pumps have been installed and provided heat to the campus. But as can be seen on figure X+5, 2015 marked the start of a massive implementation of heat pumps on campus, today covering up to one third of the heat demand.

Between 2019 and 2022, heat pumps concentrated roughly 6% of the electricity demand, around 1.6 GWh, to cover roughly 38% of the heating demand, around 6.5 GWh. These values would yield a coefficient of performance of 4.1. This number seems high, even for state-of-the-art heat pumps installed in the last 5 years. The value for the heating demand covered by the heat pump may have been overrated. It may actually represent the total heat produced by the heat pump, including cooling, but the discussion will remain here, as the dataset does not allow to differentiate cooling from district cooling and from the heat pump.

3.3.3 Electricity supply

Figure X+6 shows the progress electricity supply of the campus and how it is split between purchase from the grid and self-production from the solar cells. 7 buildings are being supplied with solar power and we estimated the current capacity at 300kW from the production profile, by assessing the peak supply.

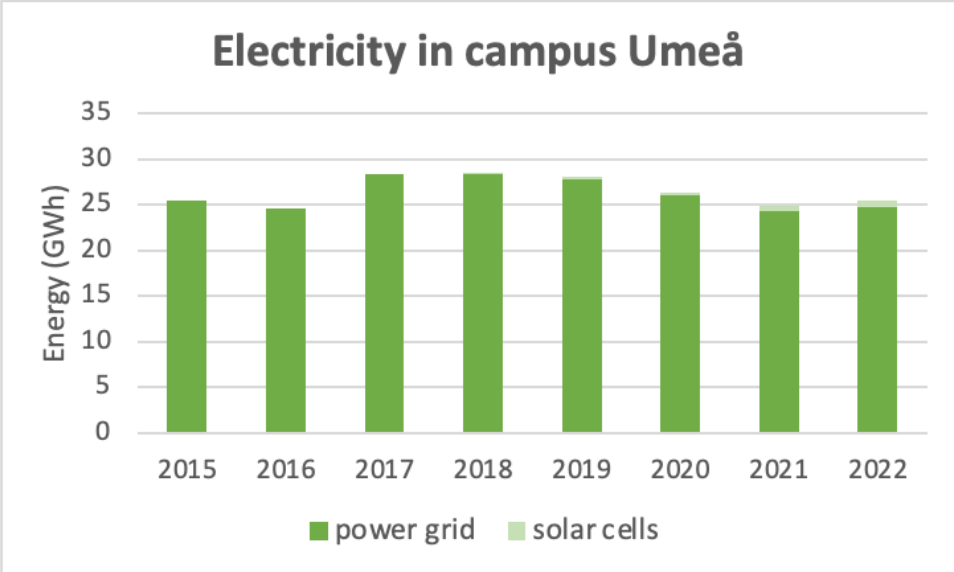


Figure X+6 – Heating supply on campus Umeå
Source: Akademiska Hus data, own production

Production of the solar cells remains low, as only 3% of the yearly electric demand of the campus is covered by the solar production. In the estimation for the solar potential of the campus, the maximum capacity has been determined at 1 MW after study of the rooftop area. Knowing that between 300 and 400kW have already been installed, it seems like rooftop capacity will not be enough for solar to have a significant share in electricity production on the Umeå campus.

3.3.4 Scope 2 emissions

According to the climate targets of Sweden, following the Paris Agreeement, Umeå University is looking to reduce its environmental footprint. Emission induced by the energy supply of the campus are estimated based on the carbon intensities values displayed by the supplier Umeå Energi AB, shown in Table Y. It is shown here than, despite a high renewable share, 94% **(Umea Energi, n.d.)**, Umeå's district heating is not "clean" and waste incineration produce a great deal of emissions.

	Carbon intensity (gCO_2eq/kWh)
Power grid	2
District heating	59
District cooling	32

Table Y – Carbon intensity of the sources of energy supply external to campus **(Umea Energi, n.d.)**

With these values, combined with the energy supply data provided from Akademiska Hus, the scope 2 emissions of the campus have been calculated and displayed in figure X+7. Are only shown here the emissions form purchased energy because solar production and heat conversion from electricity by the heat pump are approximated to be non-emissive. The share of district heating in the total emissions has been highlighted.

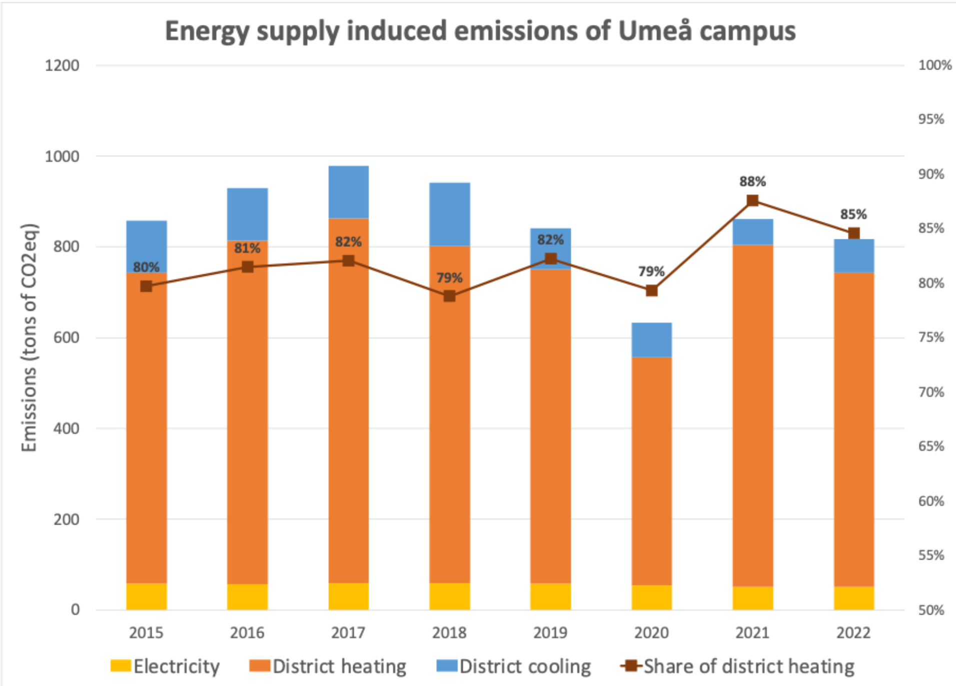


Figure X+7 – Heating supply on campus Umeå
Source: Akademiska Hus data, own production

The emissions follow the trend of the energy demand, as we can see a global decrease since 2017. Reducing the demand will therefore have a great impact on reducing the carbon footprint of the campus. But the choice of the energy supply is also very important. In 2022, despite representing 49% of the energy demand of the campus, electricity purchase is responsible for only 9% of the emissions. District heating is by far the biggest source of scope 2 emissions from the Umeå campus, concentrating roughly 85% of them since the wide implementation of heat pumps.

3.4 Pain point and opportunities

After analyzing all the data and documents, we find several pain points and opportunities for Umea Campus.

Opportunities

- The Umeå campus benefits from a supply of almost 100% renewable energy: 100% REN power grid and 94% REN district heating. Relying on this supply allows the campus to focus its effort on emissions instead of share of renewable.

- Umeå University has set the reducing of the energy consumption as one of its targets for its climate and sustainability plan [5]. As can be seen in figure X+4, the demand side is already well tackled. The administration is therefore willing to put in the effort for achieving our common objective of a reduced energy demand.

- Umeå University is following the use of the university's premises through the indicators "Average use of office premises" and "Average planned use of classrooms", both applied to weekdays during regular working hours. Here are the latest follow-up:

	Average use of office premises	Average planned use of classrooms
2019	21	13
2020	18	4
2021	20	13

Table Y+1 – Use of the university's premises indicators
Source: Umeå University [6]

There is still room to increase, and this might allow the campus to avoid the construction of new buildings.

- All scope 2 emissions take place outside the campus premises. By looking for alternative to district heating and moving the heat production locally, Umeå University will be able to better control its emissions.

- The Arboretum and other green area of the campus provide interesting resources of biomass, as well as being harbor for biodiversity. They should be preserved, if not extended.

Threats

- The campus presents limited capacity for renewable production capacity implementation. Rooftop will not be enough for solar to cover a decent share of the electricity demand and heat pump implementation might be limited by the campus topology.

4. KPIs

Key performance indicators (KPIs) are numerical values determined by the group to effectively demonstrate the impact, analysis, and outcomes of significant factors pertaining to the project. By keeping an eye on these KPIs, the group got insight into the project's performance, identify areas for improvement, and make well-informed decisions to assure project success. It is critical to define relevant KPIs that measure key project performance indicators and are aligned with the project's objectives. The group produced three important performance metrics based on these characteristic

4.1 Energy Demand Reduction

The first KPI was identified based on utilizing the campus premises in a better and efficient way. It was also a part of the project description and an important step towards net-zero campus. With increase in population with time until 2050, this KPI aims at accommodating the increase in population on the campus in the existing premises. This KPI was identified based on the observation of the campus data that highlighted that only about 17% of the campus premises are used to its capacity.

UNIT- kWh/m2

4.2 Carbon intensity of the energy

This KPI was identified based on the carbon intensity of the supply on campus. It was further observed that 100% of the grid electricity that the campus uses from Umea Energi, the local electricity company, was renewable (www.umeaenergi.se, 2022). As for the district heating, it was about 94%. Thus, the group identified this KPI to reduce the carbon intensity per kWh of the electricity used, instead of renewable share of the energy supply.

UNIT- gCO2(eq)/kWh

4.3 Local Energy Production

This KPI was identified by the group based on the high heating demand that was set to increase with the increase in population. The aim behind choosing this as one of our KPIs was to increase the share of locally produced energy to meet the heating requirement. This would reduce the dependence on grid for district heating.

UNIT- kWh (Heat Produced)/kWh(Heat Used)

Scenarios ideation

The scenarios were created based on multiple situations that would be simulated to obtain results. Based on current campus plans and numerous technologies that we wished to deploy, three scenarios were developed.

For the scenario ideation the group took into consideration various assumptions which helped to simulate the results based on the changes that were made for each scenario. This was mainly regarding the increase in population. As of 2022, the campus had about 30,000 people in population using the campus premises (www.umu.se, 2022). It was also observed that the campus had expansion plans and to enroll more students. This was taken into consideration as the results for the campus for each scenario were calculated until 2050. The group interpolated the historical data of the population increase with the expansion plans and projected that the campus will have a population of 36,000 by 2030, 45,000 by 2040 and 60,000 by 2050. However, as it was observed that the campus was not used to its capacity, we propose to accommodate the increase in population in the existing buildings and no new construction plans are proposed for the project.

The campus had an existing solar capacity of 400kW and had plans to increase the existing solar capacity by investments (Plan Vice-Chancellor, 2021). However, considering the low solar potential of Umea, especially during the winters when there was maximum demand, we chose to increase the solar capacity to same levels for all three scenarios. The capacity was set to increase from 400kW to 1000kW by 2050 in all scenarios.

Considering these factors, the group ideated three scenarios.

1. SUNLIGHT SYMPHONY

This scenario is the normalized case or the business-as-usual scenario which shows what will the case if the current situation prevails. However, we take into consideration the increase in demand based on the population and revamped solar capacity of 1000kW.

For this scenario we also propose to renovate the existing buildings with better insulation to decrease the heating demand. This would give better thermal insulation and need renovation which would incur significant costs.

2. FOREST HARMONY

This scenario also considers the assumptions for the demand increase along with the population along with revamped solar capacity. We also consider the renovation of buildings along with upgrade in the equipment like we did for the business as usual.

Umea University has immense biomass resources from the green areas which the group wanted to use for this scenario. It has high value of biowaste generated from the students and staff which keeps increasing with the increase in population. Thus, we chose to install a biodigester with a biogenerator of capacity 100kW to meet the heating and electricity demand. However, this would mean that there should be a concrete system for management of the biomass of the campus.

3. NORDIC BREEZE

The third and final scenario developed by the group also takes into consideration the demand increase with population and installation of 1000kW of solar like the other two scenarios.

It was observed that the Umea Energi has 100% renewable electricity production and about 94% renewable district heating. The group saw potential to increase the heat pump capacity on campus from 1827kW to 2577kW. This would mean an installation of new heat pumps with capacities equivalent to 750kW. It is important to note that we propose that the heat pump capacity may also be linked with cooling and heating of water to further increase the overall efficiency of the campus.

5. Quantitative modelling

5.1IDA ICE

The Umea campus was modeled using IDA ICE software to represent the existing environment and forecast the future energy landscape with the help of current predictions of baseline values. To accomplish this, three buildings were selected to represent the entire campus. These buildings were chosen according to the following criteria:

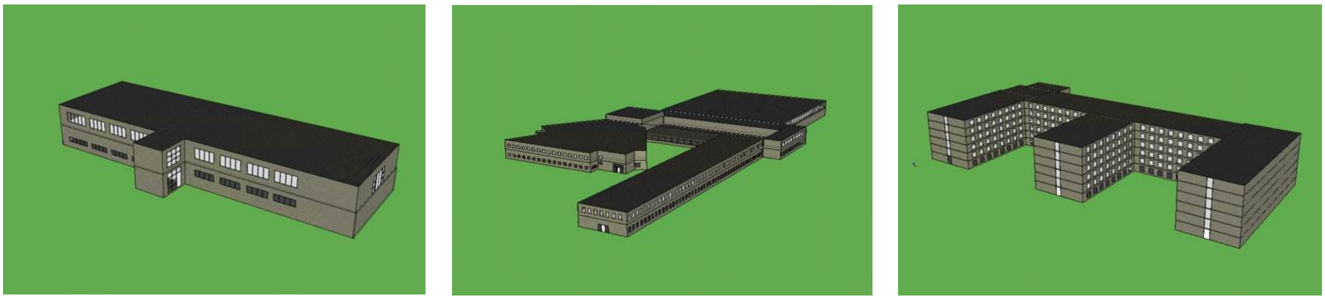
1. Usage: Buildings with different purposes were chosen to cover student facilities, offices, and recreational spaces. Residential buildings were not considered since, although they are part of the university, they are not within the geographical limits of the campus.

2. Energy system: Systems with different energy sources, such as district heating, electricity, heat pumps, etc., were chosen to cover all the campus's energy needs.

In this way, the chosen buildings are presented in the following table.

Building Name	Building purposes	Heating system
The biology house	100% academic purposes	Ground source heat pump and district heating
Universum	35% restaurants, 20% shops, 30% entertainment rooms, 15% offices	district heating and electricity
Academic house office	100% office purposes	Ground source heat pump and district heating
Aula Nordica	35% restaurants, 15% office and administration, 20% shops and warehouses for other trade, 30% theatre, concert cinema rooms and meetings rooms	district heating and electricity

Table 1. General parameters of the chosen buildings



(a) Academic House Office (b) Aula Nordica and Universum (c) The Biology House

The initial values required to initiate the modeling process include material specifications, heat transfer coefficients, insulation, occupancy, electricity and equipment consumption, heating and cooling systems, water consumption, efficiency, performance coefficients, and more.

3.1 Homer Pro

Homer Pro (Hybrid Optimization Model for Multiple Energy Resources) is a robust software tool widely recognized for its energy system analysis capabilities. It provides an extensive range of simulation capabilities, allowing for the modeling of energy consumption and the evaluation of various system configurations. By leveraging data obtained from IDA ICE, a reputable energy analysis platform, Homer Pro enables accurate and reliable simulations.

In the analysis conducted for Campus Umea, northern Sweden, Homer Pro was employed to model the electrical and thermal consumption of the campus. The objective was to explore three potential future scenarios: Sunlight symphony, Forest harmony with the integration of a biogenerator to harness biomass from the campus (including the expansion of green areas), and Nordic breeze with an increase in the number of heat pumps. Each scenario encompassed multiple factors such as electrical and thermal demands over the years, PV capacity expansion, biomass utilization, heat pump deployment, emissions reduction, and economic considerations. Multiple simulations were conducted for different years, including 2030, 2040, and 2050, to assess energy demands and the effectiveness of each scenario in achieving the goal of a "nearly" zero energy campus.

Homer pro methodology

It is important to mention that by not having heat pumps as a default component in the software, in each scenario the energy demands and supplies of the campus and the heat pumps were modeled separately. With the data provided by IDA ICE, the following loads were obtained:

Scenarios	Year	Campus		HP	
		Elec. Load (kWh)	Therm. Load (kWh)	Elec. Load (kWh)	Therm. Load (kWh)
	2030	63255	31683	4354	16909

Sunlight symphony	2040	63251	31342	4307	16727
	2050	63243	30291	4163	16166
Forest harmony	2030	61108	31798	4370	16971
	2040	59182	31744	4362	16942
	2050	57570	31261	4296	16684
Nordic breeze	2030	61866	23418	4934	19160
	2040	60006	12727	4915	19090
	2050	58605	5755	5927	23019

Table – Projection of the electrical and thermal demand of the campus

The results obtained in each modeling were carefully compiled in post processing.

Base components: Across all three scenarios, certain components were incorporated for consistent evaluation. These include the existing heat pumps already incorporated into the campus in 2018 to achieve the sustainable aims for the 2030 agenda. Additionally, solar panels were integrated to harness renewable energy and contribute to the electricity generation of the campus. The PV capacity expansion was uniformly applied to each scenario to reflect the university's future plans accurately. Also, as required, the grid connection was added with an emission rate of 25 gCO2/kWh and a price of 2.1 k/kWh.

Sunlight symphony: The first scenario represents the current energy consumption patterns of Campus Umea. It serves as the baseline for comparison with the alternative scenarios. HomerPro modeled the existing energy consumption based on data provided by Akademiska Hus.

Forest harmony: For the second scenario, a biogas generator was added to the campus energy system. This allowed the utilization of biomass generated within the campus considering the increase in students following the growth rates expected by the university, with additional biomass obtained from the expanded green areas. HomerPro facilitated the modeling of the bio generator, taking into account the availability and potential production of biomass. The software enabled the evaluation of the energy generation capacity, emissions reduction potential, and economic viability of this scenario.

Nordic breeze: In the third scenario, the number of heat pumps in the campus was increased to meet the thermal demands more efficiently. HomerPro played a pivotal role in simulating the performance of the additional heat pumps, considering their impact on energy consumption, emissions, and costs. The software facilitated the analysis of the campus's heating and cooling requirements, enabling informed decision-making regarding the optimal number and placement of heat pumps.

The results obtained through HomerPro enabled comprehensive insights into each scenario's energy performance, supporting the objective of transforming Campus Umea into a "nearly" zero energy campus

6. Business model innovation

This business model proposal provides a strategic approach for utilizing Umeå University's large biomass potential to develop a biochar production system. The suggested model aims to encourage sustainable agriculture practices, improve soil health, and contribute to the university's environmental goals by exploiting these large biomass resources.

Collaborations with local food service providers are incorporated into the concept, which emphasizes the use of climate-friendly food and generates a circular economy within the campus ecosystem.

1. **Biomass Resource Assessment**: Umea University's campus has a substantial biomass potential produced from a variety of sources such as food waste, paper, cardboard, laboratory waste, grass clippings, fallen leaves, tree branches, and pruning. This diversified and abundant biomass supply serves as a good foundation for biochar production.

2. **Biochar Production System:** The business plan involves establishing an advanced biochar manufacturing system on campus, complete with efficient pyrolysis technology. The biomass on campus will be converted into high-quality biochar, which will be used as a vital soil additive for sustainable agriculture.

3. **Campus Collaboration**: The strategy highlights the advantages of collaboration between members of the campus community. The effort can tap into the campus's intellectual resources and build a culture of sustainability by integrating a variety of stakeholders, including students, staff, and faculty. Members of the university community will not only help with the biochar manufacturing process, but will also promote awareness and support sustainable behaviors across disciplines.

4. **Strategic Partnerships with Food Service Providers:** The business strategy suggests strategic collaborations with local food service providers, such as restaurants, cafes, and catering services, to develop a synergistic relationship. These collaborations will be founded on common principles and a dedication to climate-friendly eating. Biochar produced on campus can be supplied at a special discounted rate to these providers, rewarding them to embrace sustainable agriculture methods and support the college's environmental aims.

5. **Marketing and Branding**: The business strategy emphasizes the biochar produced on campus's unique selling qualities, such as its environmental benefits, carbon sequestration properties, and contribution to sustainable agriculture. The approach intends to enhance consumer awareness through focused marketing initiatives, promoting partnership with food service providers and the positive impact of climate-friendly food choices.

6. **Revenue Generation:** The principal source of revenue will be the selling of biochar to local agricultural suppliers who understand the need of sustainable techniques. Additional revenue streams on biochar consumption and sustainable agriculture might be explored through instructional programs, workshops, and consultant

services. Funding opportunities might also be generated through collaborative projects and research initiatives.

This business model concept takes advantage of Umea University's large biomass resources to develop a biochar production system that promotes sustainable agriculture. The concept generates a virtuous circle that benefits the campus's environmental goals by forming ties with local food service companies and promoting climate-friendly food choices. This model's implementation necessitates careful consideration of financial factors, stakeholder participation, and operational logistics. The suggested model, with a clear focus on sustainability and collaboration, presents the campus as a leader in climate-friendly efforts and demonstrates the possibilities of utilizing biomass for biochar production.

7. Results

7.1Scenario analysis

Renovation of buildings is often undertaken with the aim of improving energy efficiency, reducing environmental impact, and enhancing overall functionality. However, it is important to acknowledge that despite the efforts and costs put into renovation projects, the actual reduction in energy consumption may not be as substantial as expected. Energy-saving measures are implemented during renovations like upgrading insulation. It has been observed that installing energy-efficient appliances, and optimizing heating and cooling systems results in better reduction in energy consumption.

Several factors contribute to this limited impact on energy consumption reduction. Firstly, the existing infrastructure and design of older buildings may pose inherent limitations in achieving optimal energy efficiency. For instance, structural constraints, outdated construction materials, or architectural elements that cannot be easily modified may hinder the full potential of energy-saving measures and significantly increase the cost. Consequently, despite the best efforts to improve energy efficiency through renovation, the inherent limitations of the original building design may limit the extent to which energy consumption can be reduced.

Additionally, the cost associated with building renovations can be substantial. Renovation projects often involve extensive planning, design, construction, and material costs. While these investments are made with the expectation of long-term energy savings, the actual return on investment may take time to materialize. Depending on the scale and complexity of the renovation, the upfront costs can be significant, and it may take several years or even decades to recoup the initial investment through energy savings. Therefore, the cost of renovation should be carefully evaluated against the expected energy efficiency improvements to ensure that the financial benefits align with the desired goals.

The Umeå campus, located in a region with relatively low solar potential, faces certain limitations that restrict the benefits derived from increased solar capacity. Solar potential refers to the availability and suitability of solar energy resources in a particular area, influenced by factors such as geographic location, climate conditions, and environmental variables. Understanding these limitations is essential to assess the feasibility and effectiveness of implementing solar energy solutions on the Umeå campus.

One of the primary factors that contribute to the low solar potential of the Umeå campus is its geographic location. Umeå, situated in northern Sweden, experiences harsh and long winters and short summers. The high latitude of the region means that the campus receives less sunlight compared to areas closer to the equator. The reduced duration and intensity of sunlight in this region limits the amount of solar energy that can be harnessed throughout the year.

Considering these constraints, it becomes important to adopt a comprehensive approach when exploring renewable energy options for the Umeå campus. While solar energy may have limitations, it does not negate the potential benefits entirely. Implementing a combination of renewable energy technologies alongside solar capacity, can help compensate for the low solar potential and maximize the overall renewable energy output.

The Umeå campus benefits from a significant availability of biomass resources, which presents a profitable opportunity for implementing bioenergy systems on campus. Leveraging this abundant biomass resource can contribute to the campus's energy self-sufficiency and reduce its reliance on grid. However, it is important to note that while bioenergy provides certain advantages, it is associated with higher emissions compared to district heating systems. However, it is crucial to consider the environmental implications associated with bioenergy. While bioenergy is renewable, the combustion or conversion of biomass releases carbon dioxide (CO2) emissions on campus.

District heating system can achieve higher energy efficiency and lower emissions due to advanced technologies. In contrast, bioenergy systems may have lower combustion efficiencies and fewer emission control options, leading to higher emissions on campus.

The Umeå campus can greatly benefit from the installation of heat pumps with high coefficients of performance (COP) for meeting its heating demands. By coupling these heat pumps with an already existing 100% renewable power grid, the campus can significantly reduce its energy demand and achieve a sustainable and environmentally friendly energy solution.

The high COP of the heat pumps implies that they can produce a large amount of usable heat energy for every unit of electricity consumed. This high efficiency enables the Umeå campus to minimize its energy consumption while still meeting its heating requirements. By utilizing renewable power from the grid to power the heat pumps, the campus can ensure that the energy used for heating is entirely sourced from clean and sustainable resources.

Implementing the Nordic breeze scenario, which involves the installation of heat pumps and utilizing a 100% renewable power grid, offers numerous advantages. Firstly, it reduces the overall energy demand on the campus. The high efficiency of the heat pumps means that less energy is required to generate the necessary heat, resulting in lower energy consumption and reduced environmental impact. This helps the campus move towards energy self-sufficiency and reduces its reliance on external energy sources which is also a part of our key performance indicators.

7.2KPI evaluations

Depending on the action implemented, the three scenarios yielded different results. In this part, the three key indicators identified earlier will be used as a way to compare the effectiveness of the suggested plan of actions.

7.2.1 Energy consumption

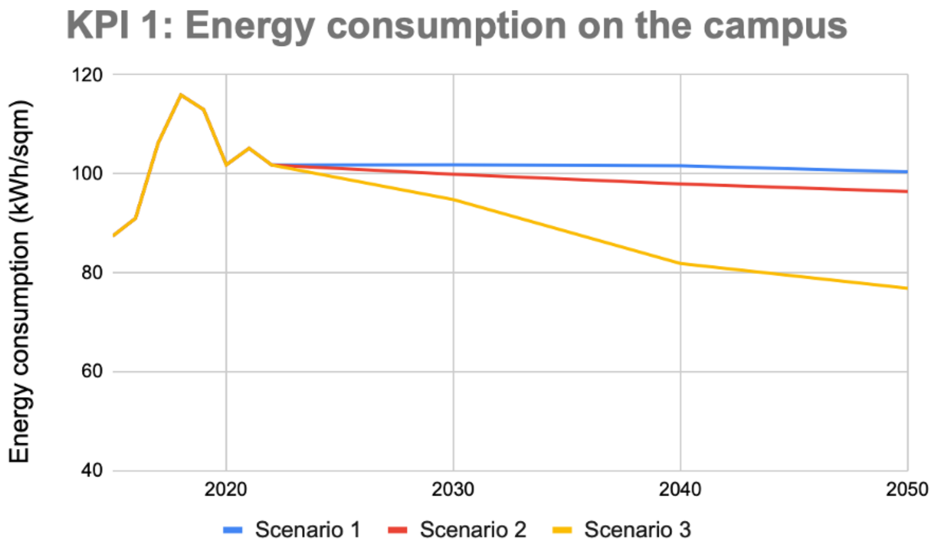


Figure Z – Comparison of the evolution of the first KPI on the three scenarios

Source: data from Akademiska Hus (historical) and own model

Reducing the energy demand of the campus was one of the points of emphasis for this study. Since the population of the campus is expected to double by 2050, managing for a constant energy demand is already an achievement. It was reached because the construction of new buildings was avoided thanks to a better use of the campus's premises.

Now comparing the different curves of figure Z, it appears as the implementation of the heat pumps is, by far, the best option. The reason for this is that installing these systems (or upgrading the existing one by combining heating and cooling for instance) shift the energy load from heat to electricity with a factor of 4 in our case: it is the coefficient of performance of the heat pump. Despite renovating all our buildings in the first scenario, the energy consumption is not greatly affected. One of the reason for this is that the build environment in Sweden is already well adapted to cold, therefore the insulation is already good. Improving the efficiency of the lights and equipment on the other hand have a measure effect on the demand for moderate costs.

7.2.2 Carbon intensity of the supply

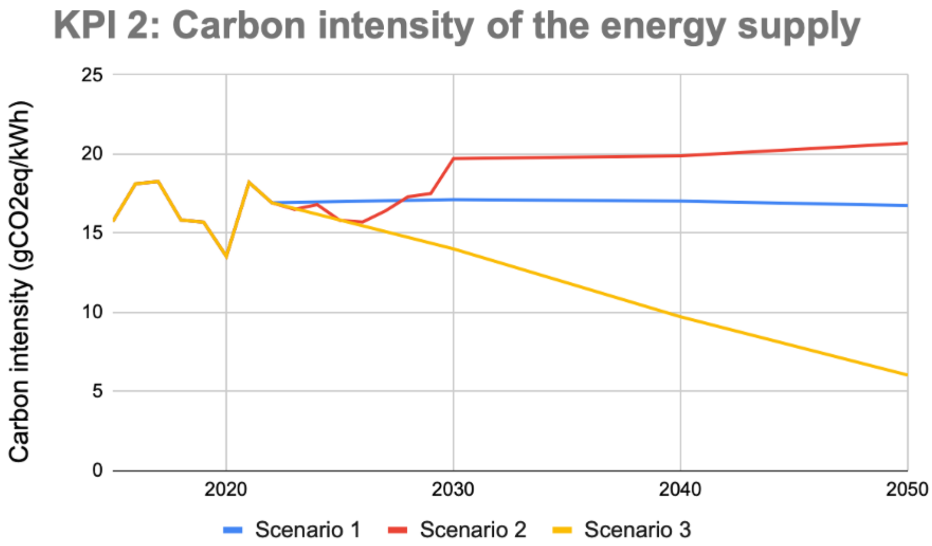


Figure Z+1 – Comparison of the evolution of the second KPI on the three scenarios

Source: data from Akademiska Hus (historical) and own model

Since we have decided to consider the carbon intensity of our supply instead of share of renewable, shifting the heat supply away from district heating, which had the higher carbon footprint, was our priority regarding this KPI. Solar implementation has no real effect on the carbon footprint of the campus supply because it shifts the load from a already almost non-emissive source: Umeå power grid.

Regarding the alternative of district heating, the implementation of a biodigester in the second scenario make use of the local resources of biomass but also increase dramatically emissions on campus, as can be seen on figure Z+1. Despite a small proportion in our heat supply (around 10%), the high energy intensity of this technology leads to a big environmental impact. That being said, one could argue about these emissions. Indeed, burning biomass is emitting CO_2 already present in the carbon cycle, therefore not really participating to climate change, in opposition to burning household waste, which often contains fossil-based materials, such as plastic. Again, the implementation and upgrading of heat pumps yield great results because of the shift from district heating (intensity of 59 gCO2eq/kWh) to the power grid (intensity of 2 gCO2eq/kWh).

7.2.3 Local share of production

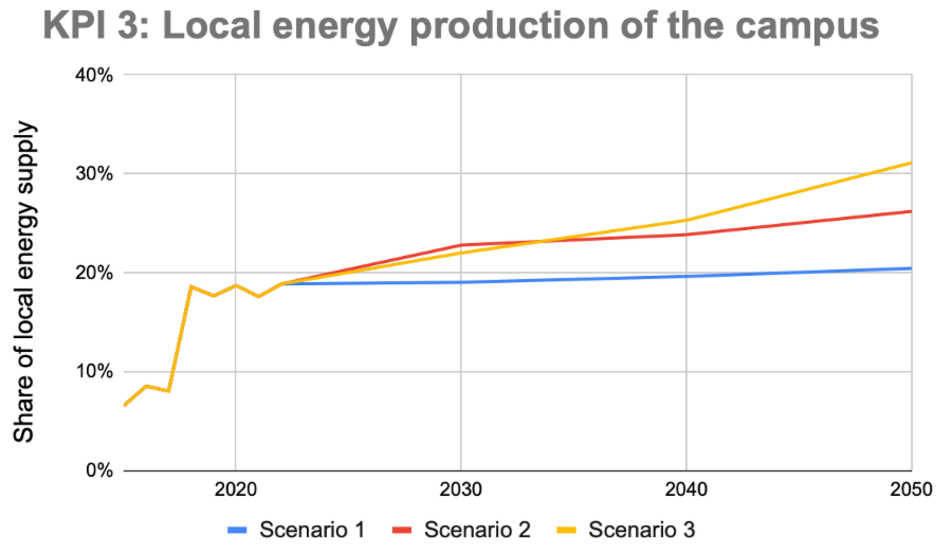


Figure Z+3 – Comparison of the evolution of the first KPI on the three scenarios

Source: data from Akademiska Hus (historical) and own model

This KPI has been followed for two main reasons: the relocation of energy production (especially heat) would enable the campus to have a better control of its energy related emissions and, in a context where energy supply becomes more and more uncertain (notably in terms of prices), energy self-sufficiency is a clear advantage.

For the first scenario, solar implementation alone gives the curve a slight increase, as shown in figure Z+3. Scenario 1 and 2 yield better results by relying on alternative sources of heating than district heating. A discussion must be brought here on the local aspect of heat pump energy generation. If the heat is produced locally, the electricity used to fuel the heat pump comes for roughly 95% from the power gris, therefore heat pump cannot really be considered as self-produced energy. In this study, the electricity used to fuel the heat pump is considered as external source of energy (at 97% in 2022) while the heat produced is considered local.

7.3Sensitivity analysis

7.3.1 IDA ICE

The stock buildings in the EU are relatively old, and older buildings typically use more energy than new buildings (Directorate General for Internal Policies, 2016). By implementing energy efficiency measures, the energy performance of buildings can be significantly improved (La Fleur, Rohdin & Moshfegh, 2019). The renovation of the buildings is one of the ways to improve the energy efficiency of the old buildings.

Among the 3 buildings selected to extrapolate the data to represent all buildings on the campus, the Biology House has the highest energy intensity and the oldest construction (1963), this building is thus selected and various renovation strategies are applied iteratively and modelled on IDA ICE. The renovation of Inner Walls, Inner Floor and the Roof are considered. The current descriptions of the building parameters assumed for the modelling is given in table X, based on the Tabula Webtool ("Building Typology," 2023). The main goal is to identify the economical and optimal renovations for the selected building, adding value and considering the reduction in the energy intensity.

Building Segment	Area	Original Construction	U-Value (W/m^{2}K)
Floor	9360.5 m^2	Concrete 0.1m Light insulation 0.13m	0.2604
Wall	4967.25 m^2	L/W concrete 0.1m Light insulation 0.06m	0.4
Roof	2686 m^2	Concrete, 0.2 m Light insulation 0.15m	0.2245

The renovations were carried out to reduce the U-value in line with the usual refurbishment or advanced refurbishment values given in ("Building Typology," 2023), to accommodate within the stipulated budget of $400,000. No structural renovations were considered, improvement of U-Values is based on calculated assumptions by adding relevant layers of insulation.

Expanded Polystyrene and extruded polystyrene are common insulation materials used in thermal insulation systems (Lv & Wang, 2010), which corresponds to the light insulation on the IDA ICE. While renovating the inner walls, the insulation was increased by adding an extra layer of wood and light insulation.

For the floor renovations, increasing the thickness of concrete, adding a layer of light insulation (EPS) and floor coating was considered. Including a layer of Mineral Wool for the roof was found to be the most efficient and comparatively the most cost efficient among the rest.

The cost of materials was estimated for the renovation for all the cases excluding the labour charges. It was found that the roof renovation was the most economical at lowering the heating demand and lowering the energy intensity comparitvely.

	Area	Improved U-Value	Renovated construction	Cost per Square Meter	Total Cost

Walls	4967.25 m^2	0.2731	Wood 0.1m Layer extruded polystyrene 0.1m	$65	$323035
Floor	9360.5 m^2	0.2367	Light insulation 0.12m, Floor coating 0.01m	$40.8	$381652
Roof	2686 m^2	0.0537	Light insulation- Mineral Wool 0.51m	$60	$161160

7.3.2 Homer Pro

In this section, we will discuss how the scenario simulations and sensitivities led to changes in the outcome over the years in terms of electric and thermal energy. All scenarios have been modelled in different files and the results from Campus and Heat Pump have been complied for Pareto sensitivity analysis. Since the project lifetime in HomerPro has been set to be 20 years, an analysis based on costs has to be starting from 2030. Hence, based on the data set from that year, used the software to run the levelized cost of energy versus net renewable fraction and self-sufficiency.

Sunlight Symphony

In this scenario, there aren't as many significant changes made, but we just model the future scope of the campus and how it will change. The pointers marked over here refer to the Solar PV capacity increasing from 500kW in 2030, 700kW in 2040 and 1000kW in 2050.

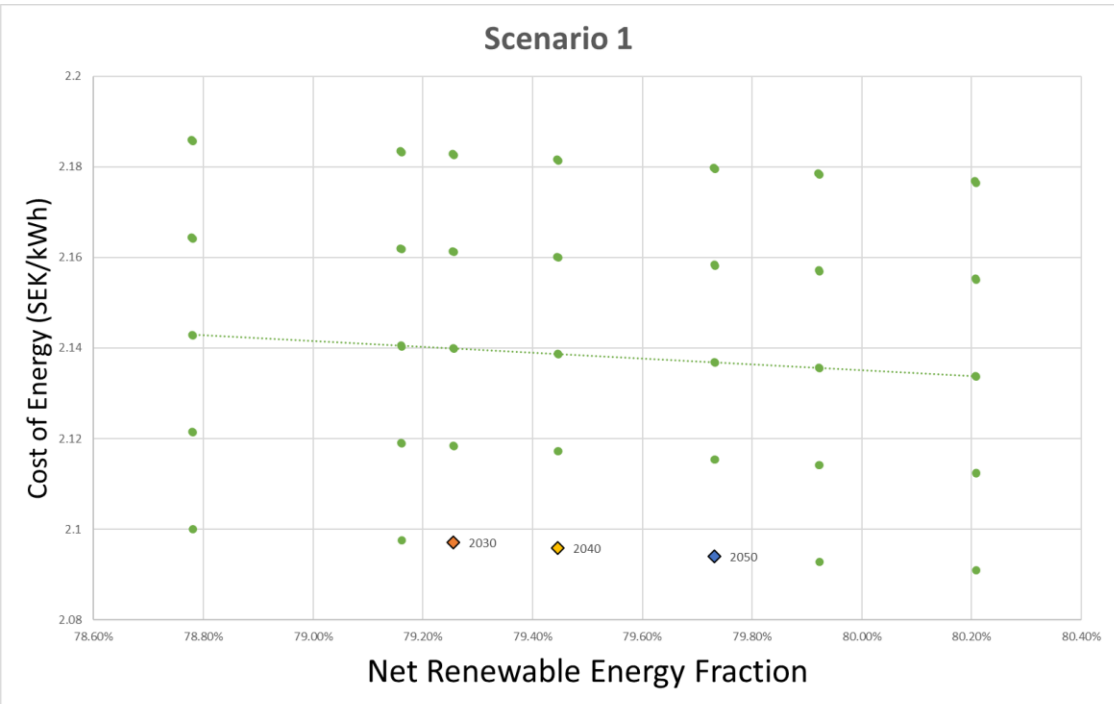


Figure XX: COE vs NRF for Scenario 1.

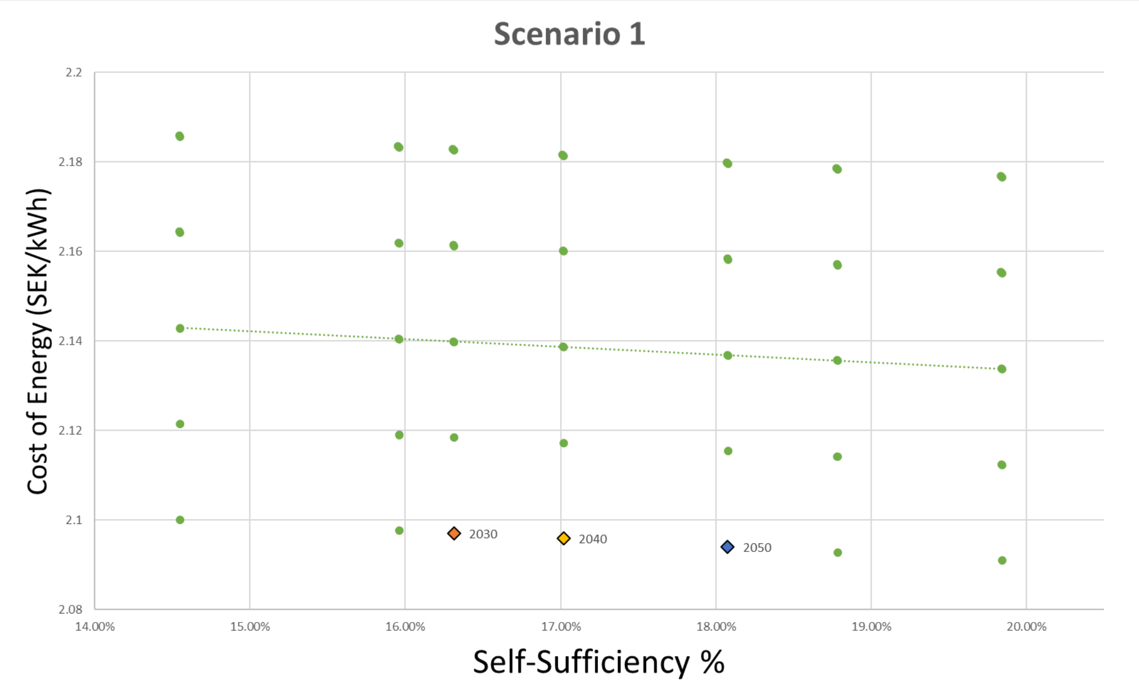


Figure XX: COE vs SS for Scenario 1.

Forest Harmony

For this scenario, a different approach was used, since it has many more variables due to the sensitivities as of the Biogas Genset. Here in the chart, all the data can be viewed, but we selected a constant capacity of 100kW biogas generator, this helps us shorten down the variables and the results are as shown below.

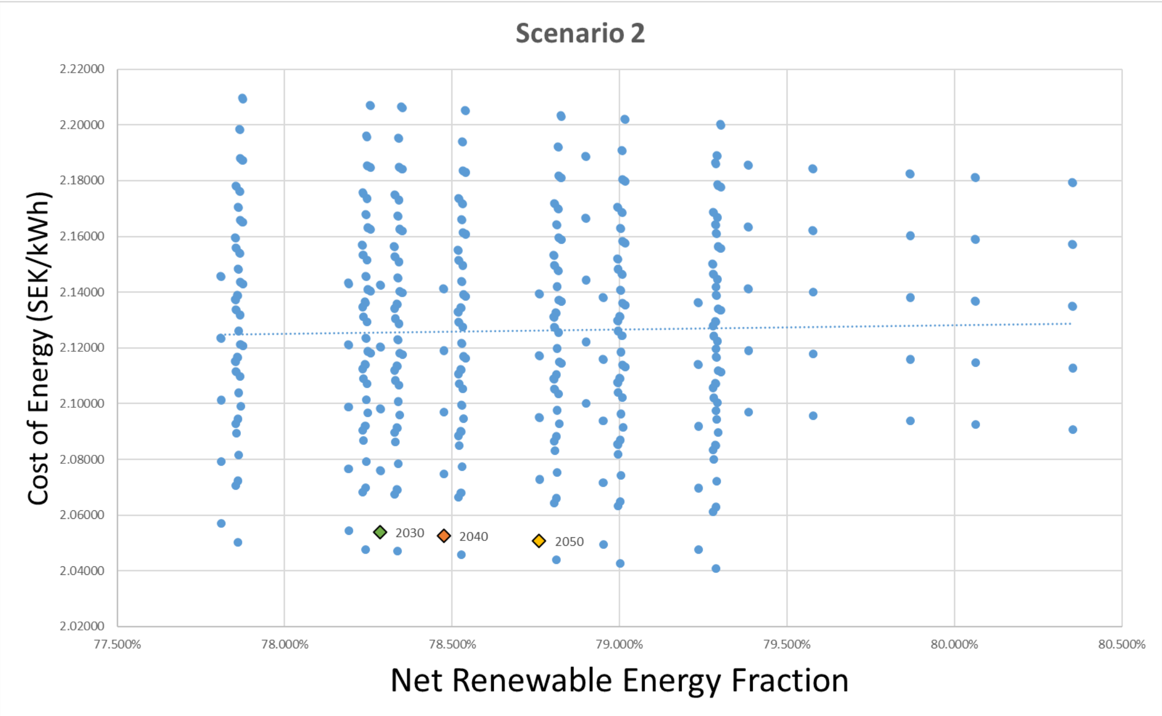


Figure XX: COE vs NRF for Scenario 2.

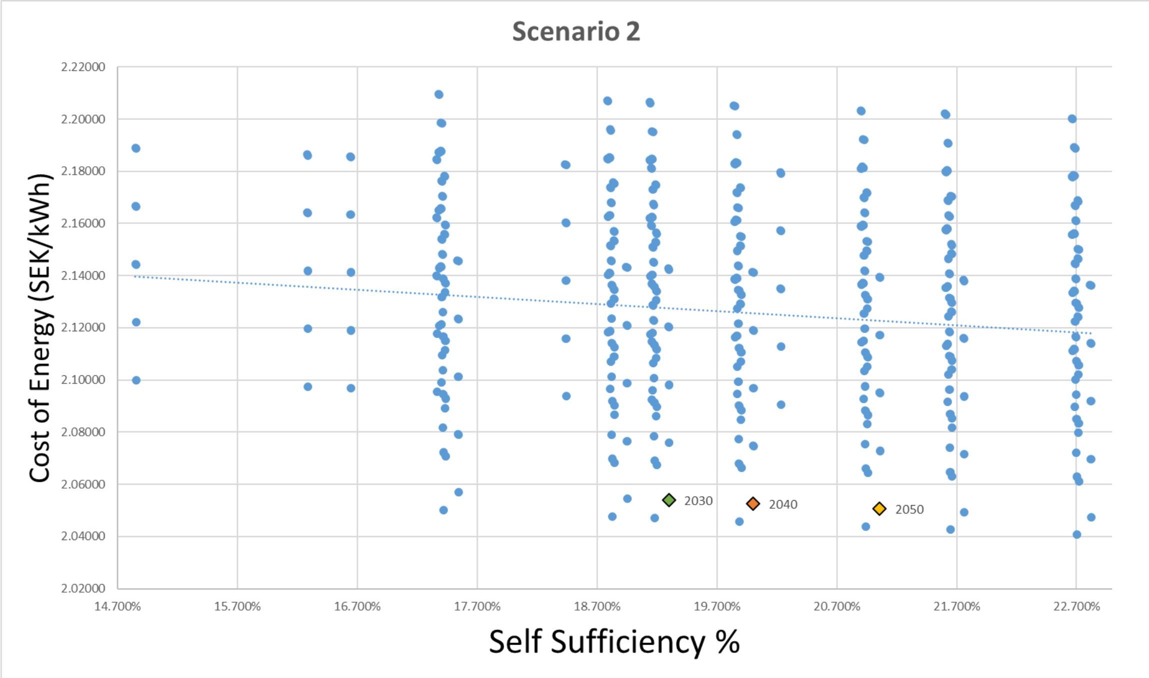


Figure XX: COE vs SS for Scenario 2.

Nordic Breeze

Since this scenario is based on increasing the capacity of heat pumps, while the buildings are turning out to be more efficient and less in requirement of heating, over the years, even though the there are significant changes in the capacity fulfilled by the heat pumps, there wasn't a significant change observed towards the NRF, since there is still a reduction in the total thermal and electrical demand.

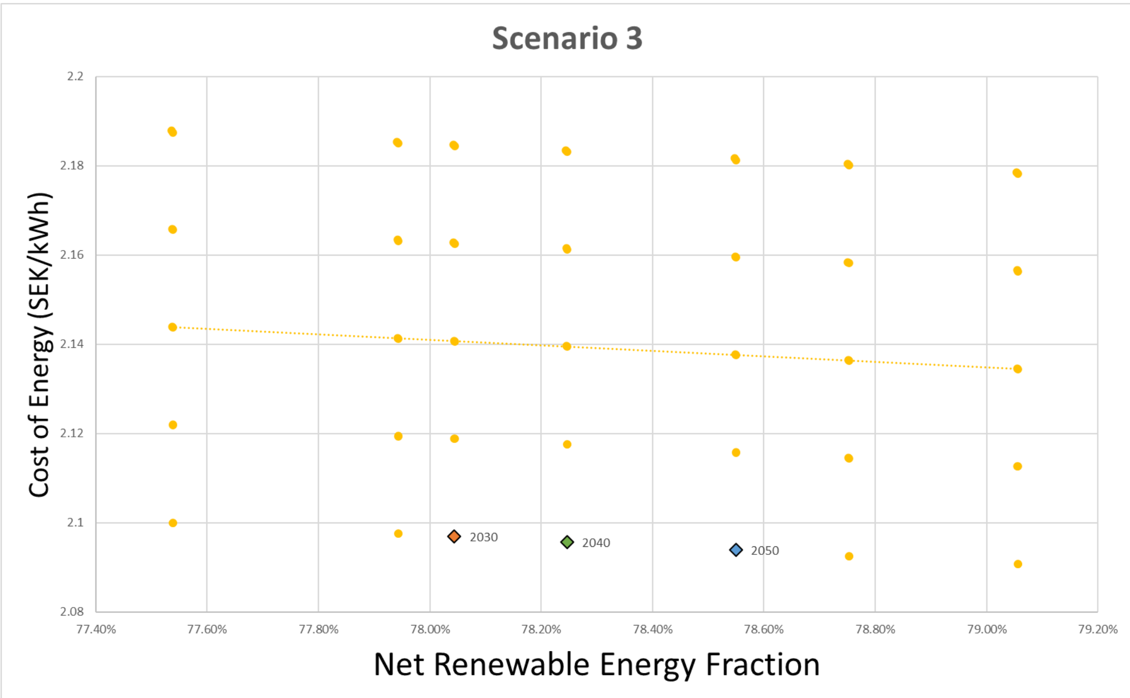


Figure XX: COE vs NRF for Scenario 3.

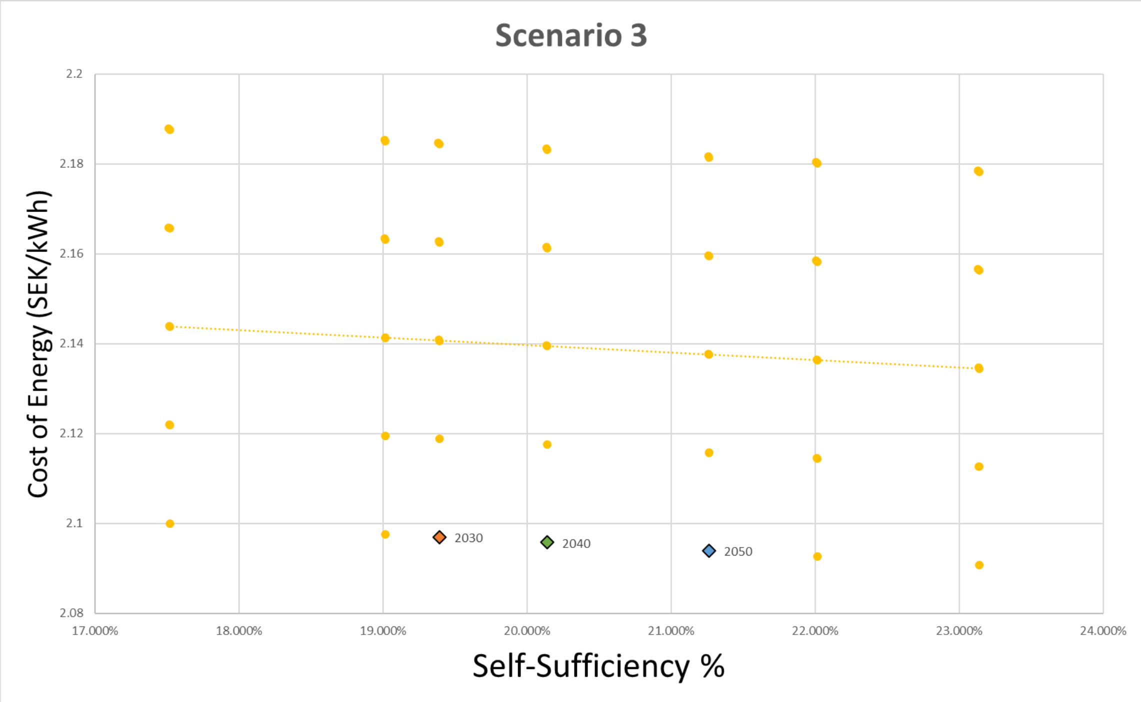


Figure XX: COE vs SS for Scenario 3.

7.4 Economic analysis

To assess the economic and financial viability of the implemented adjustments in the three scenarios, an investment and economic analysis was conducted, incorporating four key indicators:

- Net Present Value (NPV)

NPV measures the disparity between the present value of cash inflows and outflows associated with an investment or project. A positive NPV indicates that the present value of future cash inflows surpasses that of cash outflows, implying potential profitability. Conversely, a negative NPV suggests the investment may result in a loss.

- Return on Investment (ROI)

ROI enables the evaluation of an investment's profitability and financial effectiveness, providing a quantitative measure of the return generated relative to the initial cost or investment outlay.

- Internal Rate of Return (IRR)

IRR represents the discount rate at which the present value of cash inflows equals that of cash outflows, resulting in a net present value of zero. Profitable investments always exhibit an IRR higher than the discount rate.

- Discounted Payback Period (DPP)

DPP assesses the duration required for an investment or project to recover its initial cost while considering the time value of money. DPP plays a critical role in risk assessment, as investments with excessively long DPPs are considered high-risk propositions.

The calculations of the indicators incorporate the initial cost, annual cost, annual benefits, and salvage values. It should be noted that these costs and benefits vary across different scenarios due to the implementation of distinct measures.

Sunlight symphony

In the Sunlight Symphony scenario, the initial costs encompass expenses related to the purchase and installation of solar PV panels, building renovation, as well as improvements in lighting and equipment. The primary annual costs revolve around the operation and maintenance of PV panels, while the annual benefits are derived from energy savings and the generation of solar energy.

Forest Harmony

In comparison, the Forest Harmony scenario involves the installation of a biodigester, which incurs additional initial costs associated with the infrastructure required for the biodigester. The supplementary annual costs pertain to the operation and maintenance of the biodigester, while the annual incremental benefits stem from the energy generated by the biodigester.

Nordic Breeze

Moving on to the Nordic Breeze scenario, its initial costs encompass the purchase and installation of solar PV panels, as well as the acquisition and installment of new heat pumps. The annual costs encompass the operation and maintenance expenses of both the PV panels and heat pumps, while the annual benefits are attributed to energy savings and the heat generated by the heat pumps.

The nominal discount rate utilized in the analysis is set at 7%, with an inflation rate of 2%. For a succinct overview of the economic indicators related to the various scenarios, please consult Table 5. For a more detailed breakdown of the costs associated with different technologies in each scenario, please refer to the tables provided in the Appendix.

Scenario	NPV (kr)	ROI in %	IRR in %	DPP (yr)
Sunlight symphony	738,506,572.04	3.7	5.5	12.75
Forest harmony	706,230,115.49	9	12	9.7
Nordic breeze	691,187,546.25	9.9	8.4	6.5

Table 1: Summary of economic indicators for all scenarios

Results Analysis

Based on all indicators presented in the table, we find out that both the Forest Harmony scenario and the Nordic Breeze scenario exhibit superior economic feasibility. In contrast, the Sunlight Symphony scenario, while yielding positive NPV values across all scenarios, possesses an IRR that surpasses the discount rate and entails a protracted DPP, thereby rendering it a less appealing proposition.

In terms of **Return on Investment** (ROI), the Sunlight Symphony scenario exhibits a relatively modest ROI of 3.7%, indicating that for each unit of currency invested, a return of 3.7% can be expected. Conversely, the Nordic Breeze scenario offers a higher ROI of 9.9%, suggesting a more lucrative investment opportunity.

Turning to the **Internal Rate of Return** (IRR), the Sunlight Symphony scenario demonstrates an IRR of 5.5%, which falls below the discount rate of 7%. This signifies that the expected rate of return for the project does not meet the desired level of profitability, thus potentially creating a discrepancy between the project's financial performance and the expectations of investors or stakeholders. On the other hand, the Forest Harmony scenario exhibits a slightly higher IRR of 12%, indicating a more favorable rate of return. Similarly, the Nordic Breeze scenario displays an IRR of 8.4%, signifying moderate profitability.

The **Discounted Payback Period** provides insights into the duration required to recover the initial investment. For the Sunlight Symphony scenario, the Discounted Payback Period amounts to 12.75 years, indicating a comparatively longer timeframe for the recovery of cash flows. In contrast, the Forest Harmony scenario presents a relatively shorter payback period of 9.7 years, suggesting a quicker return on investment. The Nordic Breeze scenario exhibits the shortest payback period of 6.5 years, implying a condensed timeframe for generating positive cash flows. This aspect can enhance liquidity and expedite the recovery of the initial investment.

Conclusion

Upon careful evaluation, the Nordic Breeze scenario stands out as a more advantageous selection when comparing it to the Forest Harmony scenario. Despite both scenarios exhibiting comparable Net Present Values (NPVs) of 691,187,546.25 kr and 706,230,115.49 kr respectively, the Nordic Breeze option distinguishes itself by entailing a substantially lower capital cost of 34,717,092 kr. In contrast, the Forest Harmony scenario necessitates a significantly higher initial capital investment of 106,773,437 kr. The Nordic Breeze scenario's lower capital cost provides several noteworthy advantages. Primarily, it alleviates the initial financial burden and capital requirement associated with implementation. By reducing the capital cost, the scenario necessitates fewer financial resources upfront, affording greater flexibility in budgeting and potentially mitigating the reliance on external financing. Furthermore, the lower capital cost of the Nordic Breeze scenario corresponds to a shorter payback period of 6.5 years. This expedited payback period enables a more rapid recoupment of the initial investment, facilitating an accelerated return on investment and potentially mitigating financial risks linked to prolonged cash flow recovery.

8. Conclusion and recommendations

To conclude, the project has yielded results in various sectors of our boundaries. The energy demand has been shown to be reduced in economic ways by increasing the solar capacity, heat pump capacities and even adding newer sources of electricity and heat through biogas generators. Only the third scenario achieves all three KPIs, and the other two scenarios have moderate results. Based on that, some recommendations can be considered:

- Reducing the energy demand
    - Installation of further heat pumps to support more of the heating demand through the campus itself, they have great COP and provide much cleaner thermal energy than DH sources.
    - Installation of more efficient LEDs and having the computers timed to reduce electrical demands.
    - Optimization of building facility usage and further avoiding new buildings.
- Decarbonization of energy supply
    - Since heat pumps are based on electricity, and the Umea power grid as mentioned earlier, is completely renewable, thermal energy being sourced from there would increase the NRF.
    - To implement biogas generators, possibilities of exploring carbon capture techniques would be a viable option to reduce the emissions on campus, while making complete use of the biomass available on campus.

9. Appendix

Appendix A: IDA ICE

Scenario 1: Sunlight symphony

1.1 Academic house office

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,0707	0,0707	0,0707
Walls	Light insulation	0,2208	0,1988	0,1988
Floors	Floor coating	0,2104	0,2104	0,1988
Windows	3 panel glazing	2,04	2,04	2,04

Table 1: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	4	4	4
Equipment [W/m2]	4	4	4

Ocuppancy [no/m2]	0,0204	0,021	0,022
Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	1.5	1.5	1.5
Return air [L/s*m^2]	1.5	1.5	1.5
Average hot water use [kWh/m2]	5	5	5

Table 2: Operating parameters

COP	2030	2040	2050
Heating	3	3	3
Cooling	3	3	3
Hot water	1	1	1

Table 3: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	1550	1550	1550	1550
Heating	51,01	50,45	50,38	51,5
Cooling	3,975	4,011	4,035	3,9
Electricity	39,415	39,415	39,41	39,411
Consumption	***94,4***	***93,9***	***93,83***	***94,811***

Table 4: Energy consumption

1.2 Aula Nordica and Universum

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,0707	0,0707	0,0707

Walls	Light insulation	0,2208	0,1988	0,1988
Floors	Floor coating	0,2104	0,2104	0,1988
Windows	3 panel glazing	2,0400	2,0400	2,0400

Table 5: Construction parameters

Input	**2030**	**2040**	**2050**
Lighting [W/m2]	3	3	3
Equipment [W/m2]	4	3,5	3
Ocuppancy [no/m2]	0,0204	0,021	0,022
Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	1.5	1.5	1.5
Return air [L/s*m^2]	1.5	1.5	1.5
Average hot water use [kWh/m2]	5	5	5

Table 6: Operating parameters

COP	**2030**	**2040**	**2050**
Heating	3	3	3
Cooling	3	3	3
Hot water	1	1	1

Table 7: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	1550	1550	1550	1550
Heating	50,04	52,08	52,3	51,5
Cooling	5,226	3,584	3,492	3,9
Electricity	37,175	36,017	34,889	39,411
Consumption	***92,44***	***91,35***	***90,68***	***94,811***

Table 8: Energy consumption

1.3 Biology house

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,1002	0,0784	0,0707
Walls	Light insulation	0,2155	0,2103	0,2103
Floors	Floor coating	0,1871	0,1871	0,1702
Windows	3 panel glazing	1,9000	1,9000	1,9000

Table 9: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	20	19	18
Equipment [W/m2]	22	22	22
Ocuppancy [no/m2]	0,18	0,225	0,3
Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	10	10	10

Table 10: Operating parameters

COP	2030	2040	2050
Heating	1	1	1
Cooling	1	1	1
Hot water	1	1	1

Table 11: Energy system efficiency

Comparison

	2030	2040	2050	Historical
Area	12137,8	12137,8	12137,8	12137,8
Heating	175,9	147,5	166,7	173,7
Cooling	83,92	83,4	92,5	85,51
Electricity	151,29	144,32	144	158,06
Consumption	***411,11***	***375,22***	***403,2***	***417,27***

Table 12*:* Energy consumption

Scenario 2: Forest Harmony

2.1 Academic house office

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,0707	0,0707	0,0707
Walls	Light insulation	0,2208	0,1988	0,1988
Floors	Floor coating	0,2104	0,2104	0,1988
Windows	3 panel glazing	2,0400	2,0400	2,0400

Table 13*:* Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	3	3	3
Equipment [W/m2]	4	3,5	3
Ocuppancy [no/m2]	0,0204	0,021	0,022
Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	1.5	1.5	1.5
Return air [L/s*m^2]	1.5	1.5	1.5
Average hot water use [kWh/m2]	5	5	5

Table 14: Operating parameters

COP	2030	2040	2050
Heating	3	3	3
Cooling	3	3	3
Hot water	1	1	1

Table 15: Energy system efficiency

Comparison				
	2030	2040	2050	Historical
Area	1550	1550	1550	1550
Heating	50,04	52,08	52,3	51,5
Cooling	5,226	3,584	3,492	3,9
Electricity	37,175	36,017	34,889	39,411
Consumption	***92,44***	***91,35***	***90,68***	***94,811***

Table 16: Energy consumption

1.2 Aula Nordica and Universum

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,1002	0,0784	0,0707
Walls	Light insulation	0,2155	0,2103	0,2103
Floors	Floor coating	0,1871	0,1871	0,1702
Windows	3 panel glazing	1,9000	1,9000	1,9000

Table 17: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	20	19	18
Equipment [W/m2]	22	22	22
Ocuppancy [no/m2]	0,18	0,225	0,3
Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit

Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	10	10	10

Table 18*: Operating parameters*

COP	2030	2040	2050
Heating	1	1	1
Cooling	1	1	1
Hot water	1	1	1

Table 19: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	12137,8	12137,8	12137,8	12137,8
Heating	175,9	147,5	166,7	173,7
Cooling	83,92	83,4	92,5	85,51
Electricity	151,29	144,32	144	158,06
Consumption	***411,11***	***375,22***	***403,2***	***417,27***

Table 20*: Energy consumption*

1.3 Biology House

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,2245	0,2250	0,1498
Walls	Light insulation	0,3995	0,3995	0,2997
Floors	Floor coating	0,2604	0,2191	0,1931
Windows	3 panel glazing	2,2000	2,2000	2,2000

Table 21: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	9	9	8
Equipment [W/m2]	10	9	9
Ocuppancy [no/m2]	0,06	0,075	0,1

Heat Setp Temperature [°C]	21	21	21
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	5	5	5

Table 22: Construction parameters

COP	2030	2040	2050
Heating	3	3	3
Cooling	3	3	3
Hot water	1	1	1

Table 23: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	17207,7	17207,7	17207,7	17207,7
Heating	73	72,7	70,3	72,8
Cooling	3,8	3,6	3,9	3,9
Electricity	88,2	85,3	82,6	90,9
Consumption	***164,9***	***161,6***	***156,9***	***167,5***

Table 24: Energy consumption

Scenario 3: Nordic Breeze

3.1 Academic House Office

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,1002	0,0784	0,0707
Walls	Light insulation	0,2155	0,2103	0,2103

Floors	Floor coating	0,1871	0,1871	0,1702
Windows	3 panel glazing	1,9000	1,9000	1,9000

Table 25: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	20	20	20
Equipment [W/m2]	25	25	25
Ocuppancy [no/m2]	0,18	0,225	0,3
Heat Setp Temperature [°C]	21	20	20
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	10	10	10

Table 26: Construction parameters

COP	2030	2040	2050
Heating	3	3	3
Cooling	1	3	3
Hot water	1	1	3

Table 27: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	12137,8	12137,8	12137,8	12137,8
Heating	68,02	64,23	54,18	173,7
Cooling	90,06	28	31,34	85,51
Electricity	158,04	151,3	151,3	158,06
Consumption	***316,12***	***243,53***	***236,82***	***417,27***

Table 28: Energy consumption

3.2 Aula Nordica and Universum

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,1002	0,0784	0,0707
Walls	Light insulation	0,2155	0,2103	0,2103
Floors	Floor coating	0,1871	0,1871	0,1702
Windows	3 panel glazing	1,9000	1,9000	1,9000

Table 29: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	20	20	20
Equipment [W/m2]	25	25	25
Ocuppancy [no/m2]	0,18	0,225	0,3
Heat Setp Temperature [°C]	21	20	20
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	10	10	10

Table 30: Construction parameters

COP	2030	2040	2050
Heating	3	3	3
Cooling	1	3	3
Hot water	1	1	3

Table 31: Energy system efficiency

Comparison				
	2030	2040	2050	Historical
Area	12137,8	12137,8	12137,8	12137,8
Heating	68,02	64,23	54,18	173,7
Cooling	90,06	28	31,34	85,51

Electricity	158,04	151,3	151,3	158,06
Consumption	***316,12***	***243,53***	***236,82***	***417,27***

Table 32: Energy consumption

3.3 Biology House

U values [W/m2K]		2030	2040	2050
Roof	Light insulation	0,2245	0,2250	0,1498
Walls	Light insulation	0,3995	0,3995	0,2997
Floors	Floor coating	0,2604	0,2191	0,1931
Windows	3 panel glazing	2,2000	2,2000	2,2000

Table 33: Construction parameters

Input	2030	2040	2050
Lighting [W/m2]	9	9	8
Equipment [W/m2]	10	9	9
Ocuppancy [no/m2]	0,06	0,075	0,1
Heat Setp Temperature [°C]	21	20	20
Cool Setp Temperature [°C]	22	22	22
System	CAV	CAV	CAV
AHU	Sta. air handling unit	Sta. air handling unit	Sta. air handling unit
Supply air [L/s*m^2]	2	2	2
Return air [L/s*m^2]	2	2	2
Average hot water use [kWh/m2]	5	5	5

Table 34: Construction parameters

COP	2030	2040	2050

Heating	3	4	4
Cooling	3	3	4
Hot water	3	3	3

Table 35: Energy system efficiency

Comparison				
	2030	**2040**	**2050**	**Historical**
Area	17207,7	17207,7	17207,7	17207,7
Heating	69,6	48,1	46,3	72,8
Cooling	3,8	2,8	2,3	3,9
Electricity	88,2	85,3	82,7	90,9
Consumption	***161,6***	***136,2***	***131,2***	***167,5***

Table 36*:* Energy consumption

Appendix B: HomerPro Analysis

A. Biomass modelling

In order to estimate the biomass potential of the campus, calculations were conducted separately for each source.

a. Biowaste from Facilities:

To estimate the biomass generated in the facilities, we relied on the average biowaste produced per person in Europe, which is approximately 0.1 kg per day*. This value was used as a basis for projecting the biomass generation for the years 2030, 2040, and 2050, taking into account the anticipated student and staff population growth rates provided by Umea University.

Linden , Reichel (2020) Bio-waste in Europe — turning challenges into opportunities. European environment agency.

https://www.eea.europa.eu/publications/bio-waste-in-europe

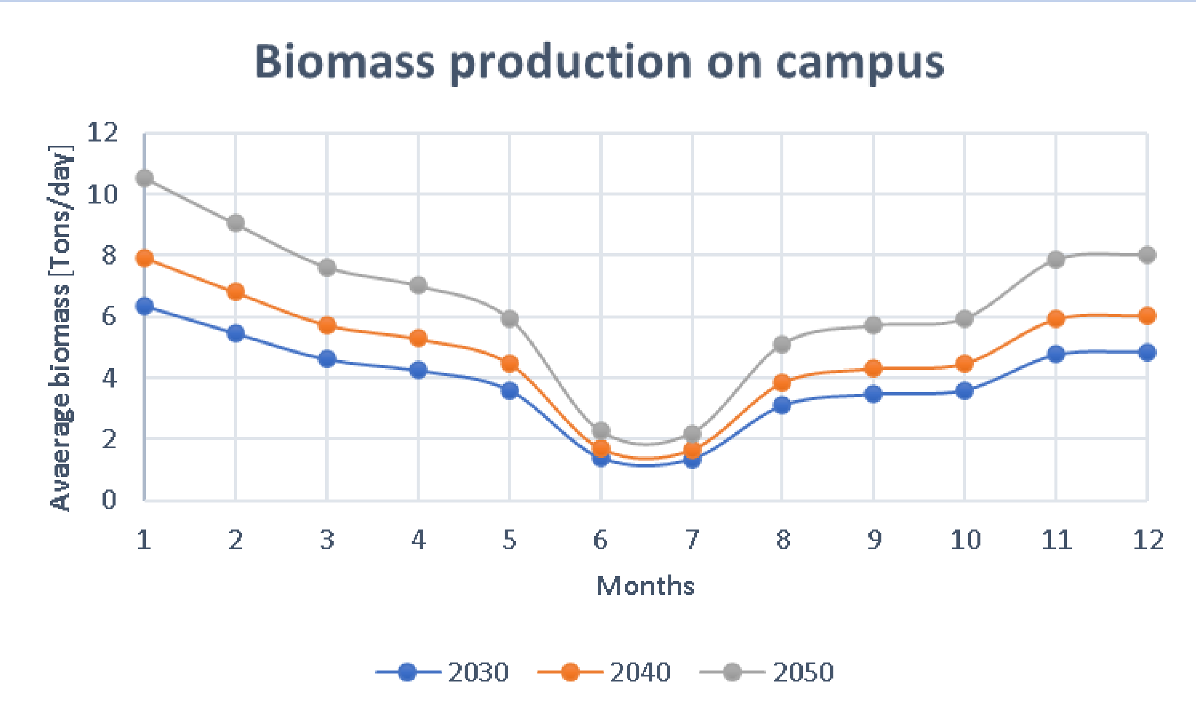
b. Biowaste from Green Areas:

The campus boasts significant potential for biomass generation from its green areas, with the Arboretum campus serving as the primary source. Through the utilization of Google Maps, we mapped the green areas on campus that contained tree populations and identified expansion possibilities. The total area of green space was estimated to be approximately 18 hectares.

Considering that each hectare of green area in Sweden generates around 10 tons of biowaste annually*, we obtained an approximate annual biomass yield of 180 tons from the green areas. However, only 20% of this biowaste was considered usable organic matter suitable for biomass conversion. Thus, the estimated annual biomass yield from the campus' green areas was approximately 36 tons, distributed evenly throughout the year to facilitate calculations.

Vogt W. (2010) Reviewing Biomass Yield. FarmProgress. https://www.farmprogress.com/commentary/reviewing-biomass-yield

Finally, in order to provide a comprehensive assessment of the biomass potential on Umeå campus, the biomass generated from both the facilities and green areas will be combined. By summing up the biomass estimates from these two sources, an approximate daily value can be obtained, representing the biomass generated on campus.



This highlights the significant biomass potential that exists at Umeå campus. In light of this potential, an evaluation will be conducted to assess the feasibility of incorporating a biogas generator to efficiently harness and utilize this biomass resource. This evaluation aims to explore the possibilities of implementing a sustainable energy solution that aligns with the campus's commitment to environmental stewardship and resource optimization

B. Detailed outcomes

This section contains detailed results from the HomerPro Simulations concerning the electrical and thermal production, as well as the costs incurred over the project's lifetime of 20 years.

The cost summaries presented below were directly provided by the software itself. It is important to note that:

- The total cost in the heat pump modeling cost summaries represent the amount saved by the campus through the avoidance of district heating expenses.
- The campus electricity production tables also incorporate the energy generated by photovoltaic (PV) systems, taking into account the specified increases set by the campus for the upcoming years.

a. Scenario 1

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	kr0.00	kr0.00	kr0.00	kr130,104,772.16	kr0.00	kr130,104,772.16
Generic flat plate PV	kr15,950,000.00	kr0.00	kr4,008,700.83	kr0.00	-kr1,102,455.51	kr18,856,245.32
Grid	kr0.00	kr0.00	kr589,545,554.57	kr0.00	kr0.00	kr589,545,554.57
System	kr15,950,000.00	kr0.00	kr593,554,255.40	kr130,104,772.16	-kr1,102,455.51	kr738,506,572.04

Table XX- Net Present Value summary for Campus model

Electrical Production		
Consumption	kWh/yr	%
Generic flat plate PV	747,830	3.24
Grid Purchases	22,340,100	96.8
Total	23,087,930	100

Table XX- Electrical Production summary from Campus model.

Thermal Production		
Consumption	kWh/yr	%
Generic Boiler	11,564,172	100
Total	11,564,172	100

Table XX- Thermal Production summaruy from Campus model

Heat Pump Modelling

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	0.00	0.00	0.00	68,433,521.98	0.00	68,433,521.98
Grid	0.00	0.00	41,938,175.6	0.00	0.00	41,938,175.67
System	0.00	0.00	41,938,175.6	68,433,521.98	0.00	110,371,697.65

Table XX- Cost summary from the Heat Pump model.

Electrical Production

Consumption	kWh/yr	%
Grid Purchases	1,589,195	100
Total	1,589,195	100

Table XX- Electrical Production summary from Heat Pump model.

Thermal Production		
Consumption	kWh/yr	%
Generic Boiler	6,171,825	100
Total	6,171,825	100

Table XX- Thermal Production summary from Heat Pump model.

b. Scenario 2

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	kr0.00	kr0.00	kr0.00	kr121,657,055.51	kr0.00	kr121,657,055.51
Generic flat plate PV	kr15,950,000.00	kr0.00	kr4,008,700.83	kr0.00	-kr1,102,455.51	kr18,856,245.32
Generic Large Genset (size-your-own)	kr2,287,500.00	kr918,280.67	kr6,537,197.97	kr0.00	-kr787,156.78	kr8,955,821.86
Grid	kr0.00	kr0.00	kr556,760,992.80	kr0.00	kr0.00	kr556,760,992.80
System	kr18,237,500	kr918,280.67	kr567,306,891.61	kr121,657,055.51	-kr1,889,612.30	kr706,230,115.49

Table XX- Cost Summary from Campus model

Electrical Production		
Consumption	kWh/yr	%
Generic flat plate PV	747,845	3.56
Generic Large Genset (size-your-own)	458,816	2.18
Grid Purchases	19,806,325	94.3
Total	21,012,986	100

Table XX – Electrical production from Campus model

Thermal Production		
Consumption	kWh/yr	%
Generic Large Genset (size-your-own)	799,215	6.88
Generic Boiler	10,813,309	93.1
Total	11,612,524	100

Table XX- Thermal Production form the Campus Model

Heat Pump modelling

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	0	0	0	68,682,093.23	0	68,682,093.23
Grid	0	0	42,090,507.92	0	0	42,090,507.92
System	0	0	42,090,507.92	68,682,093.23	0	110,772,601.15

Table XX- Cost Summary from the Heat Pump model

Electrical Production		
Consumption	kWh/yr	%
Grid Purchases	1,594,968	100
Total	1,594,968	100

Table XX – Electrical production from Heat Pump model

Thermal Production		
Consumption	kWh/yr	%
Grid Purchases	6,194,243	100
Total	6,194,243	100

Table XX – Thermal production from Heat Pump model

c. Scenario 3

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	kr0.00	kr0.00	kr0.00	kr96,164,585.32	kr0.00	kr96,164,585.32
Generic flat plate PV	kr15,950,000.00	kr0.00	kr4,008,700.83	kr0.00	-kr1,102,455.51	kr18,856,245.32
Grid	kr0.00	kr0.00	kr576,166,715.61	kr0.00	kr0.00	kr576,166,715.61
System	kr15,950,000.00	kr0.00	kr580,175,416.45	kr96,164,585.32	-kr1,102,455.51	kr691,187,546.25

Table XX – Cost Summary from Campus model

Electrical Production		
Consumption	kWh/yr	%
Generic flat plate PV	747,830	3.31
Grid Purchases	21,833,125	96.7
Total	22,580,956	100

Table XX – Electrical production from Campus model

Thermal Production		
Consumption	kWh/yr	%
Generic Boiler	8,547,448	100
Total	8,547,448	100

Table XX – Thermal production from Campus model

Heat Pump Modelling

Cost Sumary						
Component	Capital (kr)	Replecement (kr)	O&M	Fuel (kr)	Salvage (kr)	Total (kr)
Generic Boiler	kr0.00	kr0.00	kr0.00	kr77,542,818.53	kr0.00	kr77,542,818.53
Grid	kr0.00	kr0.00	kr47,520,634.09	kr0.00	kr0.00	kr47,520,634.09
System	kr0.00	kr0.00	kr47,520,634.09	kr77,542,818.53	kr0.00	kr125,063,452.62

Table XX – Cost Summary from Heat Pump model

Electrical Production		
Consumption	kWh/yr	%
Grid Purchases	1,800,736	100
Total	1,800,736	100

Table XX – Electrical production from Heat Pump model

Thermal Production		
Consumption	kWh/yr	%
Generic Boiler	6,993,366	100
Total	6,993,366	100

Table XX – Thermal production from Heat Pump model

Appendix C: Economic Analysis

Measure	Lifetime (years)	Reference	Initial cost	Reference	O & M cost	Reference
LRD light	10	LED Luminaire Lifetime, 2014	6.69 (€/m²)	Craig Gibson, 2023		
Heat pump	20	United Kingdom Department of Energy & Climate Change, 2012	265.54 (€/kw)	Fujitsu, 2019	10.62 (€/kw*year)	J Peck, 2020

Wall insulation	60	Charles john, 2012	38 (€/m²)	Ajuntament de València, 2018		
Roof insulation	60	Charles john, 2012	51 (€/m²)	Ajuntament de València, 2018		
Floor coating	60	Charles john, 2012	153 (€/m²)	Ajuntament de València, 2018		
Solar PV	25	National Renewable Energy Laboratory, 2020	857 (€/m²)	IRENA, 2022	8.6 (€/kw*year)	IRENA, 2022
Generator of Biodigester	20	Assumed	15250 (kr/kw)	Richardo G, 2008	15.94 (kr/hr)	Richardo G, 2008

Table XX: Input parameters for 3 scenarios

house insulation	roof area (m²)	wall area (m²)	floor area (m²)	roof cost (€/m²)	wall cost (€/m²)	floor cost (€/m²)	floor	Group area (m²)	Total costost 2030 (€)	Total cost 2040 (€)	Total cost 2050 (€)
biology house	2868	4967.25	17207	51	38	153	6	315885.2	2685180.243	10740252	14205416
Aula/Univers	6508.43	3026.3	12137.8	51	38	153	2	45841	7447992.852	4760440	5194760
Akademiska	990.36	849.5	1550	51	38	153	2	97474.9	5206377.153	10633150	12663207
sum								459201.1	15339550.25	26133844	32063384

Table 1: Calculation of house insulation

equipment	area (m²)	Group area (m²)	LED price (€/m²)	Number of smart plug	smart plug price (€/m²)	Group area (m²)	Total cost 2030 (€)	Total cost 2040 (€)	Total cost 2050 (€)
biology house	17207	315885.2	6.69	204	20	315885.2	2685180.243	10740252.84	14205416.37
Aula/Univers	12137.8	45841	6.69	144	20	45841	7447992.852	4760440.936	5194760.787
Akademiska	1550	97474.9	6.69	20	20	97474.9	5206377.153	10633150.71	12663207
							15339550	26133844	32063384

Table 1: Calculation of energy efficient equipment

heat pump	existing HP (kw)	new heat pump (kw)	HP cost (€/kw)	capital cost(€)	capital cost (Kr)	annual benefit (Kr)
2030	612.2	250.06	265.54	82654.8424	939000.3371	708163.2
2040	1224.47	500.12	265.54	165311.5433	1878021.788	685163.7
2050	1836.7	750.2	265.54	247972.493	2817091.507	1975764.6

Table 1: Calculation of heat pump

Kr	improvement	cost in 2030	cost in 2040	cost in 2050	benefit in 2030	benefit in 2040	benefit in 2050
Sunlight symphony	insulation+equipment	52326580.96	65849683.91	72585937.45	1379130.403	2007307.603	2949575.503
Forest harmony	insulation+equipment	52326580.96	65849683.91	72585937.45	2371781.503	3240522.103	4558179.703
Nordic breeze	new heat pump & improve	939000.3371	1878021.788	2817091.507	1306739.7	2175480.3	3493137.9

Table 1: Calculation of building environment

Kr	improvement	cost in 2030	cost in 2040	cost in 2050	annual cost 2030	annual cost in 2040	annual cost 2050
Sunlight symphony	PV installment	15950000	22330000	31900000	40087.008	120261.025	240522.05
Forest harmony	PV installment	15950000	22330000	31900000	40087.01	120261.03	240522.05
Nordic breeze	PV installment	15950000	22330000	31900000	40087.01	120261.03	240522.05

Table 1: Calculation of solar panel

Kr	Capital cost 2030	Capital cost 2040	Capital cost 2050	Annual cost 2030	Annual cost 2040	Annual cost 2050
Sunlight symphony	0	0	0	0	0	0
Forest harmony	2,287,500	2,287,500	2,287,500	326859.8985	326859.8985	334208.7645
Nordic breeze	0	0	0	0	0	0

Table 1: Calculation of biodigester

Overall	Total capital			annual cost					
Kr	cost 2030	cost 2040	cost 2050	cost 2030	cost 2040	cost 2050	benefit 2030	benefit 2040	Benefit 2050
Sunlight symphony	68276580.96	74656580.96	84226580.96	40087.008	120261.025	240522.05	1379130	2007307	2949575
Forest harmony	70564080.96	90467183.91	106773437.5	366946.9085	447120.9285	574730.8145	2371781	32405223	4558179
Nordic breeze	16889000.34	24208021.79	34717091.51	40087.01	120261.03	574730.8145	1306739.7	2175480.3	3493137.9

Table 1: Overall calculation of three scenario

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