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Internship Report

ZEnMo

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1. Project Context

1.1 Heat Networks

The project tries to accelerate the energy transition, with a focus on, but not limited to, heat networks. These networks seek to replace the heating of houses using individual systems such as boilers, electrical heaters or heat exchangers by centralised heating systems. In a neighbourhood, a pipe will be laid through which streams water that is kept at a certain temperature by a centralised heating source. Houses can then use this pipe in a heat exchange process to heat their house, and could even use the water to replace hot water (for drinking, washing or other usage) in the building.

Using heat networks would make heating more efficient while also making it less complex to switch to a green energy source. The central heating can for example be done via biomass, be solar powered, geothermic (heated by transporting it next to the earth's core) or using rest-warmth (left over heat from industry or trash process facilities). In the city of Apeldoorn, where we tested one user case, there is even one neighbourhood heated by aquathermics, which uses heat produced by sewage. [1]

Heat networks would also allow extensions that allow the storage of heat. This can be seasonal, so that in summer extra heat is stored so that it can be used in winter, or on a shorter base where any heat that is not used by the neighbourhood can be stored for moments when there is a bigger demand for heat. This allows networks to spread the production and demand of heat more evenly, while also allowing for better usage of sustainable sources which often vary highly in production throughout a day and the year.

These networks can also be implemented in parallel with a cold water network, which could allow for the cooling of buildings as well as the usage of cold water in buildings. This would especially work well with seasonal heat storage, where extra warmth during summer can relieve the cold winters, while also saving that cold to use in summer. In this case, the heating of buildings during winters would result in storing the cold, and cooling buildings in summer would result in the storage of heat.

1.2 Project Description

In this project, we are working with different parties to make the heat transition more understandable, while also generating a intuition that all parties of interest can develop by using our program as a game. The goal is to create a game that both civilians and the energy suppliers / engineers of the heating network can use to generate more understanding of the bottleneck and the costs of the heating network.

This project is meant for commercial implementation for heating networks, but also serves as a basis on which to build further implementations. This means that the program should also allow for easy adding of components.

Another subject that will be investigated by this project is the implementation of the program for neighbourhood that contain commercial buildings and industries. These instances often do not have a lot of data to share, but are of interest for the commercial sides of this project. Implementing them will also be essential as industry accounts for 45% of the energy usage in the Netherlands, while being responsible for 30% of the emissions.[2]

[1] https://www.topsectorenergie.nl/tki-urban-energy/kennisdossiers/warmtenetten
[2] https://energieinnederland.nl/wp-content/uploads/2020/02/EBN-INFOGRAPHIC-2020-Final.pdf

1.3 Project Modelling

To reach these goals, we work with an agent based modelling program called Anylogic[3]. Agent-based modelling is a technique that investigates a system by describing the behaviour and interactions of the individual agents and letting that play out. In a way, agent based models try to represent a complex system by building the interactions of lower-level subsystems[4]. For example, one could estimate how busy a traffic junction will be by describing exactly the start-time, destinations and velocities of individual cars, while also dictating when cars would stop and start again according to traffic rules and interactions with nearby cars. Doing this for the whole neighbourhood and running the program should exactly show which cars are where in this digital twin of the neighbourhood.

We could do something similar where we would create a digital twin of the neighbourhood that we want to investigate the heating network in. We could then model the individual components, like the heat network, the buildings, heat storages, the biomass heater, and more, as agents with behaviour that dictates the demand and production of heat. Now running the whole program should give us a clear idea of the bottlenecks of the network.

The program that we use to do this is called Anylogic. Anylogic is especially handy in this case because it used graphical modelling. This means functions, variables and other components of the program are objects within the visual space. This means that while one is programming the model, one is at the same time also creating the graphical interface. As we will be trying to make the program as interactive as possible, it is handy that we don't have to create a user interface within a different program.

However, as user interactions differ strongly from the interactions within the model, and because we want to create a model that can be used for different purposes, we will still model the UI as a model that is different from the behavioural model. This means that the underlying model can be more easily implemented on other problems by creating a different UI model.

1.4 ZEnMo

This project is done at ZEnMo simulations. As the energy transition is dependent on the most modern science, and often is dependent on a huge amount of factors, making models that predict the transition becomes nearly impossible to do conventionally as data is scarce and hard to come by and the models are too complex to make. Peter Hogeveen and Auke Hoekstra reacted to this by creating ZEnMo, a company focused on creating agent-based models to illustrate the energy transition in more detail. ZEnMo strives to make the transition better understandable by programming tools that policymakers can use while also staying transparent in how their science is done.

Initially, ZEnMo started out feeling the waters of the market by doing a few small projects. Now, they are working on two bigger projects, and therefore ZEnMo has also grown by a handful of people. Officially (ignoring interns and students working on thesis) ZEnMo consist of 5 people, and apart from some specific roles, the structure of the company is horizontal.

[3] https://www.anylogic.com/
[4] https://en.wikipedia.org/wiki/Agent-based_model

2. Method

In this chapter, we will discuss all components of the program that we ended with. Important decision that have been made will also be elaborated upon. My model was mainly based on the HOLON model that was already being developed by others at ZEnMo, but over time I've made a lot of changes to it and added a lot of things. This means that mostly the structure and the naming conventions are similar, and other parts of the program are further separated from the original. I've also split the program into two layers, of which one is the model and one is the User Interface, so even the structure differs.

2.1 Buildings

2.1.1 HOLON household model

In the first case, the building model was based on the household model from HOLON. This model based itself on a simple heat equation:

$$\frac{dQ}{dt} = dQ_{heating} \pm dQ_{radiation} - dQ_{transmission} - dQ_{convection}$$

$$T = \frac{\frac{dQ}{dt}\,\Delta t}{c_{building}}$$

In which different *dQ*'s describe different heat fluxes per timestep (radiation can be both an influx and an outflux, but is assumed to be zero to simplify the model). The variable $c_{building}$ is the heat capacity of the house in kWh/K, which tells us how much heat a house can absorb, and is calculated via the volume of the building.

The building heats via a heater that is activated when the temperature goes below a reference point, from when on the heater will generate 100kW heat per timestep until the temperature of the building is higher than the reference point again. Both transmission and convection are calculated as a difference between the temperature in the house and outside, but are multiplied by their own respective coefficients based on the empirical insulation Rc value and specific ventilation flow rate per floor area respectively.

This model is a purely mathematical model that incorporate past weather data to derive the heat flux, and thus the heat demand, per timestep. This means that this model is not able to predict the future heat demand, nor the peak heat demand. We want to predict how the heat network will be used all over the year, so that we can better approximate if the network has enough capacity to match the heat request all over the year, and incorporate heat buffers if necessary. As the above model calculates per timestep, it would be computationally heavy to calculate the heat request per building per timestep for a whole year. Therefore we switched our approach after a few months, such that we ended up with a simplified model that was able to estimate the heat request over the year.

2.1.2 Thermic Model from gas profiles

Another reason to work with another model, is because we want to have a good estimate of how the heat request of industries and commercial spaces look like. As these are private institutions that are very unique, there is not a lot of data present about their heat profiles. We decided that we had to sacrifice detail of individual instances such that we would get a more accurate but generic overall heat profile. For this, we started out by loading the gas profiles from NEDU.[5]

These profiles show an estimation of the how much gas is used throughout the year for certain buildings that can be put in 4 different categories[6]:

- G1: standard profile for less than 5000m3 gas used
- G2: profiles that use more than 5000m3 (assumed to be industries and commercial instances)
    - G2A: operating times below 750 hours per year
    - G2B: operating times between 750 and 1500 hours per year
    - G2C: operating times above 1500 hours per year

These generic profiles however only show the relative gas usage, meaning only what percentage of gas is used per timestep (in hours). Therefore, we can deduce the actual generic gas profiles for specific instances by taking their annual gas usage and multiply this with their profile. For this, we take 2 different approaches. For residential buildings, we can derive their annual gas consumption from average data that is dependent on the building year of the building, divided by the average floor surface.[7] For no-residential buildings, we take a look at CE Delft[8], which divides the buildings in function and building year, from which the heating per m2 floor surface can be derived (appendix table A.1).

We now can calculate the actual energy profiles per building by multiplying the relative energy profiles with the annual energy usage per m2 floor surface area and the floor surface area of that building instance. From this, we can also calculate what the peak energy usage is, as well as the energy usage per hour throughout the year. From CE Delft we can also calculate the possible ventilation demand, as well as the demand for warm tap water, cooling water and help energy (the energy needed to operate the hot and cold water within the building) based on their utility function (as seen in table A.2 and A.3). Depending on what sort of heating network is selected, this could be implemented in the calculations as well.

2.1.3 Energy Model from Electric Profile

NEDU also has information on the profiles of electricity use for different connections, explained in table 2.1. From this we can see that there are a lot of different user profiles from which we can choose, so some decisions need to be made. First of all, we decide to only work with single tariffs. We can investigate further by looking at Liander[9], from which we decide that:

- E1A: used for residential buildings without extra electrical equipment
- E2A: used for residential buildings with electric cars, solar panels or other heavy electrical equipment.
    - Also used for smaller companies, but as this is hard to define, we will not use it for this goal. We do assume Loges to operate similarly.
- E3: Companies of different operating times.

[5] https://www.nedu.nl/documenten/verbruiksprofielen/
[6] https://www.3nergie.nl/blog/verbruiksprofielen-elektra-gas /
[7] https://www.vtwonen.nl/inspiratie/duurzaam-wonen/gemiddeld-gasverbruik/
[8] CE Delft “vereffenen kosten warmtetransitie”
[9] https://www.liander.nl/consument/aansluitingen/typen

- As most Dutch companies operate for 220 days per year[10], we assume offices, stores, education and gathering to follow E3B profiles.
- The other industry types (sports, prison and healthcare) are assumed to operate throughout the year for at least 14 hours a day, and therefore follow a E3D profile.

Table 2.1: The energy profiles according to NEDU[11]. Given are the upper and lower limits of certain connections in Ampere (assumed to be for the electricity grid of 230V). Also is given if the profile is for single or double tariffs, and for which operating time.

E1A	-	< 3 x 25A	Single Tariff
E1B	-	< 3 x 25A	Double Tariff (7:00 to 23:00)
E1C	-	< 3 x 25A	Double Tariff (7:00 to 21:00)
E2A	> 3 x 25A	< 3 x 80A	Single Tariff
E2B	> 3 x 25A	< 3 x 80A	Double Tariff
E3A	> 3 x 80A	-	Operating time < 2000 hours
E3B	> 3 x 80A	-	2000 hours < Operating time < 3000 hours
E3C	> 3 x 80A	-	3000 hours < Operating time < 5000 hours
E3D	> 3 x 80A	-	Operating time < 5000 hours

For residential buildings, we can then order the energy demand depending on surface and the number of people living there[12]. Offices are divided in two categories with different energy demands[13], and we assume that one employee needs 12.5m2 to calculate the amount of employees within that office[14]. For healthcare, we can calculate per square meter[15] and the same can be done for education[16]. Stores again are classified by either food or non-food[17], so for simplification, we assume all stores above 500m2 to be food oriented. For all the other types of industry, we refer back to CE Delft and assume ventilation is the only energy factor.

2.2 Heat Network

For the heat network, I had thought out a few approaches. One of them would use information like the current-and- target temperature of the water, the volume of water in the network and the specific heat of water as a way to calculate how much the temperature of the heat network would lower per timestep as buildings would use heat exchangers to absorb the heat needed. The central heating would then calculate how much power it would need to provide to get the temperature of the network up to the target.

This method, although more accurate, would quickly become too complicated as this would also mean we needed specific details of the workings of the heat network to implement a heat flux equation that was unnecessarily complex. Especially knowing how much water was in the network to derive the capacity of the network proved to be a feature that demanded unnecessarily specific input. Heating the water while it was flowing also seemed to be unnecessarily complex as it raised

[10] https://gemiddeldgezien.nl/gemiddelde-aantal-werkdagen
[11] https://www.nedu.nl/documenten/verbruiksprofielen/
[12] https://www.cbs.nl/nl-nl/achtergrond/2018/14/energieverbruik-van-particuliere-huishoudens (Figure: “Gemiddelde Energielevering van het openbare net aan tussenwoning naar oppervlak en aantal bewoners 2016”)
[13] https://www.minder.nl/gemiddeld-energieverbruik/kantoor
[14] https://www.flexas.com/nl/blog/hoeveel-m2-kantoorruimte-heb-je-nodig
[15] https://www.omgevingsweb.nl/nieuws/duurzaamheid-in-ontwikkeling-voor-de-gezondheidszorg/
[16] https://dashboards.cbs.nl/v2/energieverbruik_vastgoed_funderend_onderwijs/
[17] https://www.minder.nl/gemiddeld-energieverbruik/winkel

questions about if the water was stored in the heater till it reached the necessary temperature, which raised questions about how the flux worked inside the heater, or if it flowed past the heater, which would mean we would not be sure the temperature was reached. For this reason I chose to use a more simplified version of the problem. I however did discover that HOLON now does implement this version.

I opted to model the whole heat network as a unlimited battery from which the whole neighbourhood could subtract hot water. The water subtracted from the network would be registered in a variable that represented the hot water shortage in kWh. Every half timestep, the district heater (in this case the biomass plant), would check the heat shortage in the network and refill it. In this model it is possible to limit how much power the biomass plant can supply, meaning the heat storage can build up over time. In this model, the only variable of interest is the amount of hot water shortage in kWh, which is added on by the buildings and subtracted from by the central heating. This greatly simplifies the amount of information needed to let the model work.

2.2.1 Heat loss

The way a pipe often loses heat is via the next heat equation[18]:

$$Q = \frac{2\pi L(T_i - T_o)}{\frac{\ln\left(\frac{r_o}{r_i}\right)}{k}}$$

In which Q is the heat loss, L the length of the pipe in meters, T_i & T_o the temperature inside and outside the pipe in kelvin respectively, k is the thermal conduction factors of the pipe in Watt per meter Kelvin respectively. The radius r_i&r_o is given for the inside and the outside of the pipe in meters respectively. Although this is the method used by HOLON, the equation ignores that often the pipe lies below the ground, and therefore heat loss happens in a different way. Therefore, we'd rather use a transfigured version of the above equation[19]:

$$Q = S\,K_m(T_i - T_o)$$

In which K_m is the average soil conductivity, which is assumed to be 0.9 W/mK. S is the shape factor defined by:

$$S = \frac{2\pi L}{\ln\left(\frac{4z}{r_o}\right)}$$

In which z is the depth at which the pipe lies in meter. This equation is valid when are applicable when L is large compare to D and z is larger than 1.5D, which is most certainly the case. If the pipe lays above ground, we should return to the previous equation.

Although it is near impossible to verify the resulting heat loss, applying this to the model will give us a heat loss that fluctuates between 10% and 40%, which is in accordance with given data[20].

2.2.2 Dimensions Heat Network

To calculate the right Heat loss, we therefore need to estimate the depth and length of the pipes, as well as the radius. I decided to split the network into three parts: from the biomass plant to the centre of the network, from the centre branching off through the streets, and the individual pipes

[18] https://www.engineeringtoolbox.com/conductive-heat-loss-cylinder-pipe-d_1487.html
[19] http://webwormcpt.blogspot.com/2009/08/estimating-heat-loss-from-buried-pipe.html
[20] https://www.topsectorenergie.nl/tki-urban-energy/kennisdossiers/warmtenetten

that connect buildings to the communal network (look at figure 2.1 for an example). Although we give the user the option to adjust all parameters involved, we also need to give a first estimate for them.

For the main pipe that goes to the centre of the network, we estimate the pipe to have been laid deep at 4 meters, and to have a big radius of 40 cm. The program automatically calculates the length by taking both locations of the biomass plant and the centre of the network and calculating the x and y distances between them. The sum of the x and y distances will be the estimate, meaning we assume the pipe will have a 90 degree angle. This choice was made mainly because the pipe will probably follow roads, as it is hard to dig beneath buildings, and roads often lie orthogonal to each other.

For the branching off of the network, we assume the pipe to lay less deep at 1.5 meters (where usually the gas network lies), and assume the radius to be 10cm. Estimating the actual length is a lot harder, and therefore we take a look at existing networks[21]. In this source, we can also use a measuring tool to draw a pipeline, and derive the length. We will use this as the main estimate.

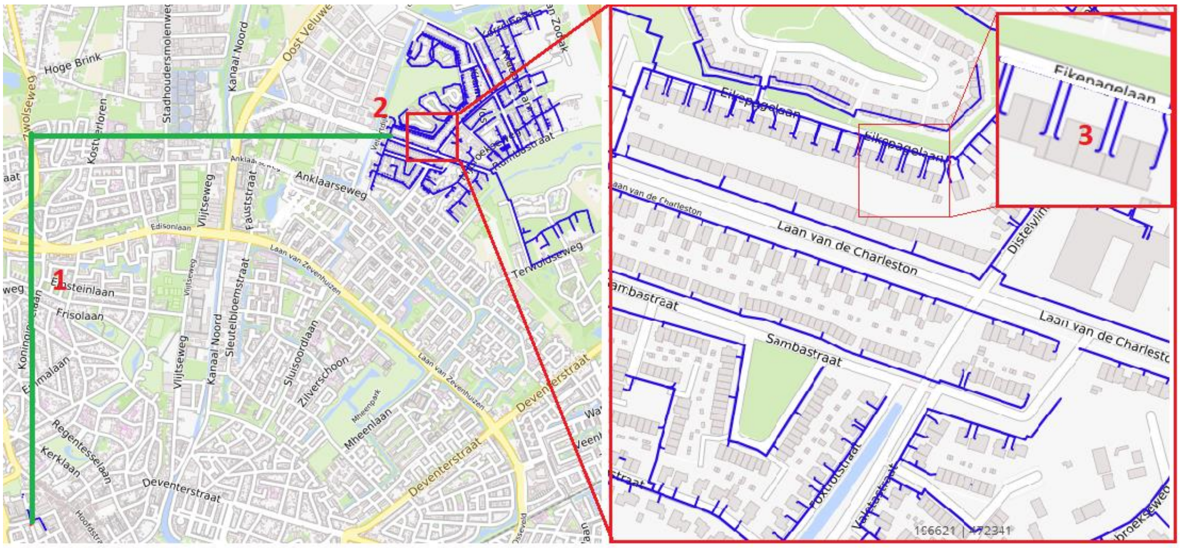


Figure 2.1: An existing heat network in Apeldoorn, with 3 zoomed in versions (left to right). The number 1 shows the part of the heat network that goes from the biomass plant to the part where the heat network branches off. The second part is where the heat network is branched off and goes through the streets. The number 3 is given to show the individual buildings being connected to the heat network that lies in the street. Made via https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart.

For calculating the individual lengths needed to connect a building to the network, we take a look at appendix table A.4[22], which shows us the lengths of pipes necessary to connect a building to the gas network. We will assume the heat network to have similar lengths, and therefore we assume every building needs 22 meters of pipes to be connected to the heat network.

Using these parameters gives us a heat loss that fluctuates between 10% and 30%, which is also the heat loss that we are expected to have.[23] This should also tell us that the dimensions of the network do not necessarily have to be exact, as long as the profile (which is dependent on the outside temperature) and the relative heat loss (in this case the 10-40%) are realistic.

[21] https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart
[22] CE Delft "Kosten van de warmtetransitie"
[23] https://www.topsectorenergie.nl/tki-urban-energy/kennisdossiers/warmtenetten

2.3 Financial Model

In this model, we would also like to give an analysis on the costs of installing the heat network for both the user and the supplier. There are some different sources of how much this would cost for both parties, so we have decided to make the costs a variable so that the user can change them during simulation so that they are more realistic (as seen in chapter 3.1 figure 3.2). Of course, we still need an initial estimate of the cost, so for this we take a look at table 2.2.

In table 2.2, the user costs are filled in according to the maximally allowed costs (ACM). These costs only have a legal maximum for users with connections under 100kW. For users with connections above the 100kW (often industries and commercial users), there is no legal roof on these costs.

The same initial costs are assumed however as we have no better way to derive this. Another limit to this calculation can be seen in how we decide on the costs per meter. The actual way that ACM quotes the roof on these costs, is that under 25 meter the costs for users with connections under 100kW, can at maximum amount to €4959.14. Above the 25 meters, each extra meter can at maximum cost €224.49-.

Table 2.2: The different costs for installing and using the heating network. The supplier costs are based on CE Delft[24] (or found in appendix table B.1). The user costs are derived from ACM[25] in which we fill them in according to the maximally allowed cost.

	User	Supplier
Instalment Costs per Building	€ 228.00	€ 12000.00
Laying Costs Network per Meter	€ 224.49	€ 270.00
Yearly Operation and Maintenance Costs	€ 235.03	€ 360.00

These costs are used together with the price per kWh for the heating network (which is also made variable) and the individual user profiles of the buildings to calculate the instalment costs and the yearly costs of the network. The breakdown of such a cost analysis can be viewed during simulation as can be seen in figure 3.5.

[24] CE Delft "Kosten van de warmtetransitie"
[25] https://www.acm.nl/nl/onderwerpen/energie/afnemers-van-energie/warmte-informatie-voor-zakelijke-afnemers/warmtetarieven

3. User Guide to Using the Program

Below we will discuss how the program works. Given is the main interface. The most important elements are pointed at, and will be discussed separately. When one runs *model_UI*, the following window opens:

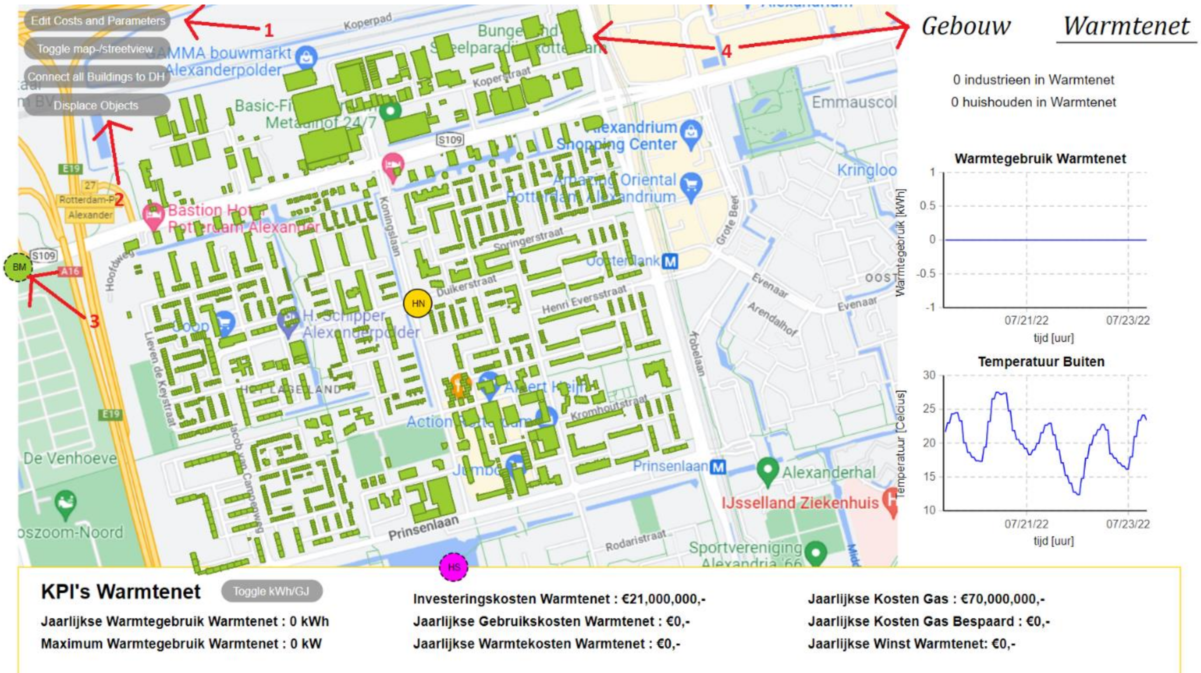


Figure 3.1: The main interface. The numbers with arrows in red point to different parts of the interface which coincide with their respective chapter numbers.

Here we see in the centre a map with drawn on it the buildings we have loaded in green. Below are given the KPI's of the heat network, such as the amount of heat used in a year, and the costs of installing and operating the network. These costs can further be analysed by clicking on *Edit Costs and Parameters* in the top left, which will show the financial model input parameters in a separate window that can be found in chapter 3.1.

On the right, one can see information such as the amount of buildings that are connected to the heat network, the heat produced by the network, and the temperature outside. One could also select a building by clicking on it in the centre and click on *Gebouw* in the top right to go to the building interface in chapter 3.2. This interface gives information of the building, but it also gives us the option to connect the selected building to the heat network. Once a building is connected, it turns from green to red and vice versa.

This means one can play around connecting different building to the heat network to investigate the impact this has on the heat usage in the network, as well as on the costs found at the KPI's.

Also shown in the centre are the three circle icons BM, HN and HS, which stand for biomass plant heat network and heat storage respectively. One can click on the specific icon to open up a window that shows us information about this object found in chapter 3.3. One can also click on *Displace Objects* to change the location of specific objects via the displacement window in chapter 3.4. In this case the heating network icon indicates the part of the network where the main pipe from the biomass plant branches off to the individual buildings.

3.1 The Financial Interface

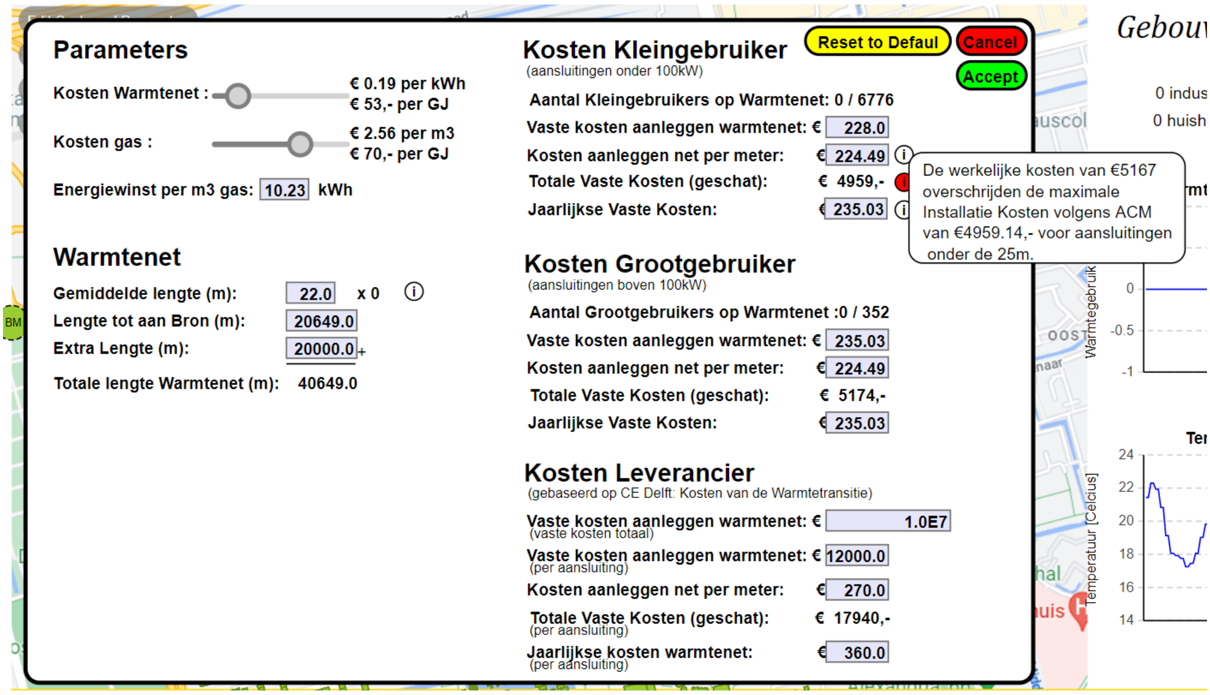


Figure 3.2: The financial interface. One can investigate the financial model, and make changes to certain numbers. It will also give information based on what is allowed in the financial model.

The Financial interface is focussed on the distributor and allows one to change the parameters which are used in calculation of the costs. The exact parts on the right of this interface are more clearly discussed in chapter 2.3. The left contains parameters like the costs per kWh of operating the biomass plant, and the costs per m3 of gas, which are parameters that fluctuate constantly. Also given are the parameters that calculate the total length of the network from which the heat loss and costs are calculated. The average length is derived from CE Delft "vereffen kosten warmtetransitie", and is based on what kind of neighbourhood this is. The length to source is calculated by taking the orthogonal distance between the biomass plant and the heat network object. The extra length is optional to indicate the distances from the heat network object to the individual buildings, and can be calculated via https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart.

3.2 Object Interface

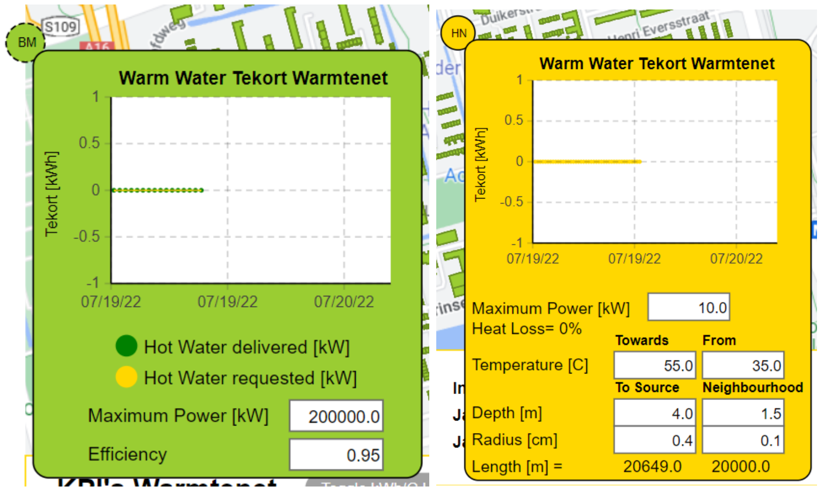
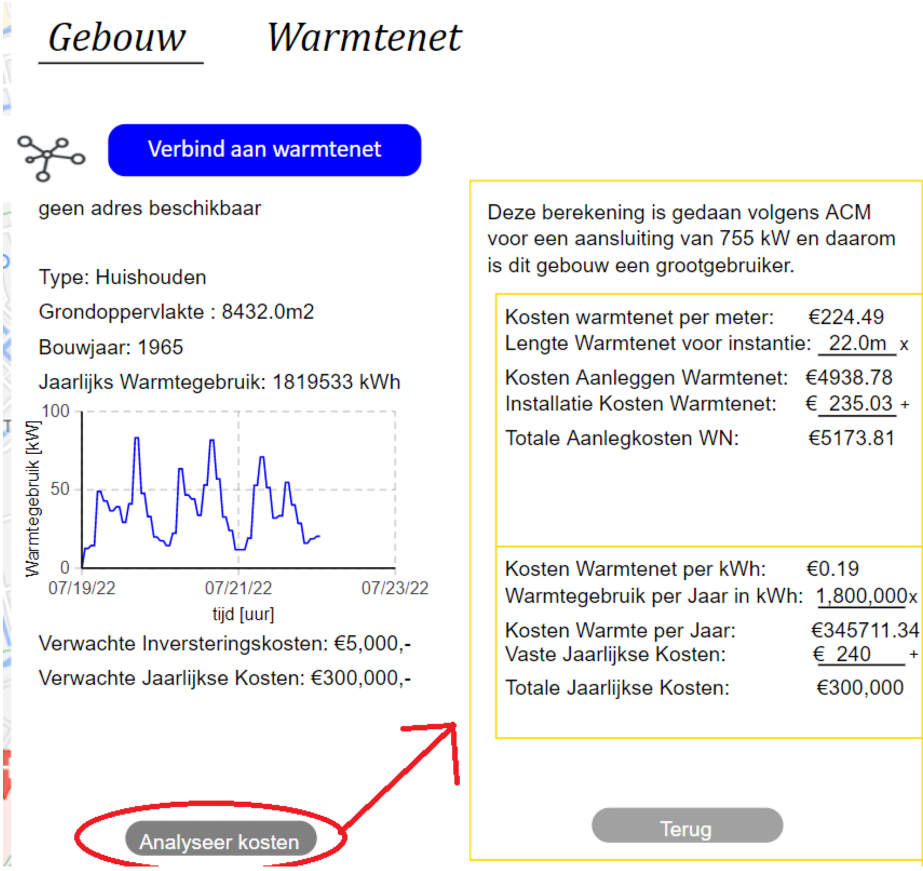


Figure 3.3: Given are two object interfaces, one for the biomass plant (left) and one for the centre of the heat network (right). One can look up information about the objects and change some aspects of it.

The object interfaces are shown when clicking on the specific objects. Here one can see information such as the graphs of the heat production and the demand, but also more specific parameters which can be changed. These interfaces are created such that one can investigate specific parts of the model while the program is running.

3.3 Building Interface



(a) *(b)*

Figure 3.4. The building interface. Given is the information of the specific building (a) with their heat usage and the expected costs for connecting to the heat network. One can choose to connect the building to the heat network in this interface also. When clicked on the analyse costs button, the rundown of how the costs are calculated are shown (b).

When clicked on a building and selecting the *Gebouwen* interface, one gets figure 3.4a. This interface allows us to connect the building to the heat network, but also shows us important data such as the address, the function of the building, the floor surface and the building year, which is all data that can be imported (BAG). One can also see the heat model of this specific instance, as well as the total heat used by this instance in a year. Below, one can also see the total investment and operating costs for connecting this building to the network. When clicked on A*nalyseer kosten*, the window changes into figure 3.4b, which shows us an exact breakdown of the costs for this specific building.

3.4 Displacement Interface

Figure 3.3: The Displacement interface. This interface allows one to click on an object and displace is, such that we can choose the location. For the case of the Heat Network and it's source (in this case the biomass plant), the length of the pipe will be calculated again, such that the investment costs can be calculated again.

The Displacement Interface allows one to change the location of certain objects. One can click on an object and then on a position, and then the object will move to that position. This also means that the total length of the network will be calculated when this happens.

4. Conclusion

In the end we ended up with a fully working model. This model was the main focus of my internship, and hopefully will be used as a basis for the eventual project that will allow distributors of heat networks and citizens work together to investigate the installation of a heating network in their neighbourhood. I especially put a lot of focus on having a clear to use graphical interface and be transparent in my calculations. For this reasons most data of the underlying model, such as specific parameters of objects and financial parameters, are accessible from the main interface.

A second goal was to investigate the heat demand over the year of different industries. This goal was also completed, with the help of another intern, and we used general gas profiles to base on. Although these profiles are based on real data, it is hard to validate the eventual heat model as there is no specific data available, especially for industries as they are more private about it. This model however is never meant to give exact answers, and should be used more to get general indications of the impact certain decisions have.

Another goals was to implement this model in two layers, one UI and the other the underlying model in which calculations happen, such that the underlying model can be applied to other problems without too much effort. Besides that, I have also been able to implement a specific version of the heat network which uses its own version of the heat loss. On top of that, I have implemented my model in a way that it can be loaded from ESDL, a language that describes the structure of data of energy systems in a generalized way, such that one can more easily load other data and allows this model to communicate with other models that implement ESDL. Creating an ESDL implementation for Anylogic was the goal of yet another intern, but it did take me some time to implement his program on my model.

During my internship I have learned quite a few things. Specifically, learning agent based modelling has been quite interesting. I have also done quite a bit of graphical design, which was a skill I didn’t have before. Besides that, I have also participated in some conversations with the municipality of Rotterdam for another project, which gave me some interesting insights into the world of policy makers.

Appendices A: Utility Heat Demand CE Delft

Table A.1: Utility heat demand from CE Delft 'Vereffenen kosten warmtetransitie definitief'. This table shows how much heat per surface area is needed dependent on the BAG-funtion and the building year.

BAG-functie	Bouwjaar	Huidige warmte vraag (GJ/m2)
Kantoor	Tot 1920	1.01
Kantoor	1920-1974	0.8
Kantoor	1975-1989	0.41
Kantoor	1990-1994	0.37
Kantoor	Vanaf 1995	0.31
Winkel	Tot 1920	0.51
Winkel	1920-1974	0.41
Winkel	1975-1989	0.21
Winkel	1990-1994	0.2
Winkel	Vanaf 1995	0.16
Gezondheidszorg	Tot 1920	1.15
Gezondheidszorg	1920-1974	0.84
Gezondheidszorg	1975-1989	0.47
Gezondheidszorg	1990-1994	0.47
Gezondheidszorg	Vanaf 1995	0.39
Logies	Tot 1920	0.75
Logies	1920-1974	0.6
Logies	1975-1989	0.33
Logies	1990-1994	0.31
Logies	Vanaf 1995	0.27
Onderwijs	Tot 1920	0.55
Onderwijs	1920-1974	0.42
Onderwijs	1975-1989	0.23
Onderwijs	1990-1994	0.22
Onderwijs	Vanaf 1995	0.17
Bijeenkomst	Tot 1920	0.55
Bijeenkomst	1920-1974	0.79
Bijeenkomst	1975-1989	0.6
Bijeenkomst	1990-1994	0.61
Bijeenkomst	Vanaf 1995	0.42
Sport	Tot 1920	0.8
Sport	1920-1974	0.65
Sport	1975-1989	0.42
Sport	1990-1994	0.42
Sport	Vanaf 1995	0.35
Cel	Tot 1920	1.21
Cel	1920-1974	0.82
Cel	1975-1989	0.49
Cel	1990-1994	0.49
Cel	Vanaf 1995	0.39
Overig	Tot 1920	0.23
Overig	1920-1974	0.17
Overig	1975-1989	0.09
Overig	1990-1994	0.09
Overig	Vanaf 1995	0.07

Table A.2: The demand for ventilation, cold water, help energy, and warm tap water, dependent on the utility function of the building. From CE Delft 'vereffenen kosten warmtetransitie'.

BAG-functie	Ventilatie (GJ/m²)	Koude (GJ/m²)	Hulpenergie (GJ/m²)	Koudevraag (GJ/m²)	Warm tapwater (GJ/m²)
Kantoor	0,019	0,034	0,007	0,034	0,006
Winkel	0,008	0,011	0,010	0,011	0,006
Gezondheidszorg	0,046	0,030	0,016	0,030	0,095
Logies	0,048	0,077	0,019	0,077	0,065
Onderwijs	0,009	0,002	0,009	0,002	0,007
Bijeenkomst	0,048	0,077	0,019	0,077	0,065
Sport	0,081	0,000	0,042	0,000	0,079
Cel	0,048	0,077	0,019	0,077	0,065

Table A.3: The demand for ventilation, cold water, help energy, and warm tap water, for residential buildings of different isolation levels. From CE Delft 'vereffenen kosten warmtetransitie'.

Woningschil	Ventilatie (GJ/m²)	Koude (GJ/m²)	Hulpenergie (GJ/m²)	Warm tapwater (GJ/pp)
A+	0,03	0,05	0,01	3,0
A	0,03	0,05	0,01	3,0
B	0,02	0,05	0,01	3,0
C	0,02	0,00	0,01	3,0
D	0,02	0,00	0,01	3,0
E	0,01	0,00	0,01	3,0
F	0,01	0,00	0,01	3,0
G	0,00	0,00	0,01	3,0

Table A.4: The different lengths of pipes needed to add a building to a network for different levels of urbanisation. We use this to as an indication of the length needed per building to add it to the heat network. From CE Delft "Kosten van de warmtetransitie".

Buurt	Selectiecriteria	Gasnet (m/aansluiting)	Elektriciteitsnet (m/aansluiting)	Ouderdomsfactor
Oude dorpskern	Stedelijkheid 3 en 4 Ouderdom > 0,5 Aansluitingen > 100	39	44	1
Historische binnenstad	Stedelijkheid 1 Ouderdom > 0,6 Aansluitingen > 250	12	13	1,5
Buitengebied	Stedelijkheid 5 Aansluitingen > 100	61	107	1
Jonge binnenstad	Stedelijkheid 1 Ouderdom < 0,6 Aansluitingen > 250	14	15	1
Gemiddeld	Stedelijkheid 2, 3 en 4 Aansluitingen > 100	22	26	1

Appendices B: Cost Analysis

Table B.1: A table showing the estimates of installing different sorts of networks. From this table, we decided the costs for connecting a building to the heat network are €12000 standard and €270 per meter. From CE Delft "Kosten van de warmtetransitie".

Onderdeel	**Aansluitkosten**	**Eenmalige aansluitbijdragen**	**Bron**
Elektriciteitsaansluiting	300 €/aansluiting	689 €/aansluiting	Netbeheerders/gemiddelde
Elektriciteitsnet	60 €/m	-	Netbeheerders
Netverzwaring	860 €/aansluiting	-	Netbeheerders
Gasaansluiting	500 €/aansluiting	836,14 €/aansluiting	Netbeheerders/Berekening maximumprijs 2017 ACM
Gasnet	60 €/m	-	Netbeheerders
Opslagfactor waterstof	0,5	-	Netbeheerders
Amovering aansluiting	400 €/aansluiting	-	Netbeheerders
Amovering net	50 €/m	-	Netbeheerders
Warmteaansluiting grondgebonden	12.000 €/aansluiting	836,14 €/aansluiting	Warmtebedrijven/Berekening maximumprijs 2017 ACM
Warmteaansluiting gestapeld	10.000 €/aansluiting	836,14 €/aansluiting	Warmtebedrijven/Berekening maximumprijs 2017 ACM
Warmteaansluiting collectief	4.000 €/aansluiting	836,14 €/aansluiting	Warmtebedrijven/Berekening maximumprijs 2017 ACM
Warmtenet	270 €/m	-	Gemiddelde op basis van parameters Vesta 3.0

Appendix C: User Guide to Loading the Model

Below we will discuss how to load the data into our model using the ESDL map editor, and how to prepare the model graphically for usage. This whole process can be a bit tedious, as some steps, like loading the BAG data (information about buildings like found on Kadaster) in ESDL, might take a while.

C.1 Load BAG data via ESDL map editor

1. Investigate the area to see what's already there via https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart
2. Go to: https://mapeditor.hesi.energy/editor (you will need an account)
3. Zoom in and draw the area of interest via *draw area or asset as polygon*

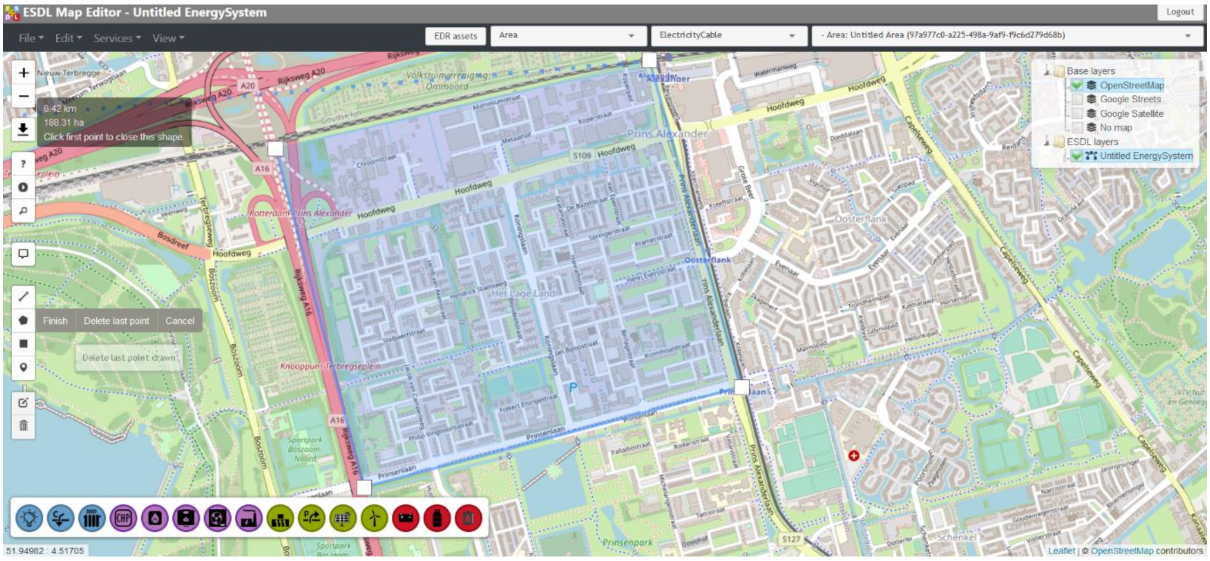


Figure C.1: Using the polygon drawing tool to draw an area (make sure it is selected in the first dropdown menu). Right click on this area to request BAG building data.

4. Right click on the area, and click on *request BAG building*
   This might take a while. Reload the page in a few minutes to see if it has been loaded
5. The BAG data is loaded if there are now shapes that represent the buildings inside the area. If this hasn't happened, repeat step 3 and wait longer, or start all over. The data is loaded if the image looks like figure B.2.
6. Place some extra instances. Some are necessary for the heat network to work:
   a. A biomass plant (or another heat source) which will power the heat network
   b. Heat Network which will be assumed to be the place where the pipe from the source branches out to different streets.
   c. *Optional*: Heat storage, PV panels, heat pump, etc

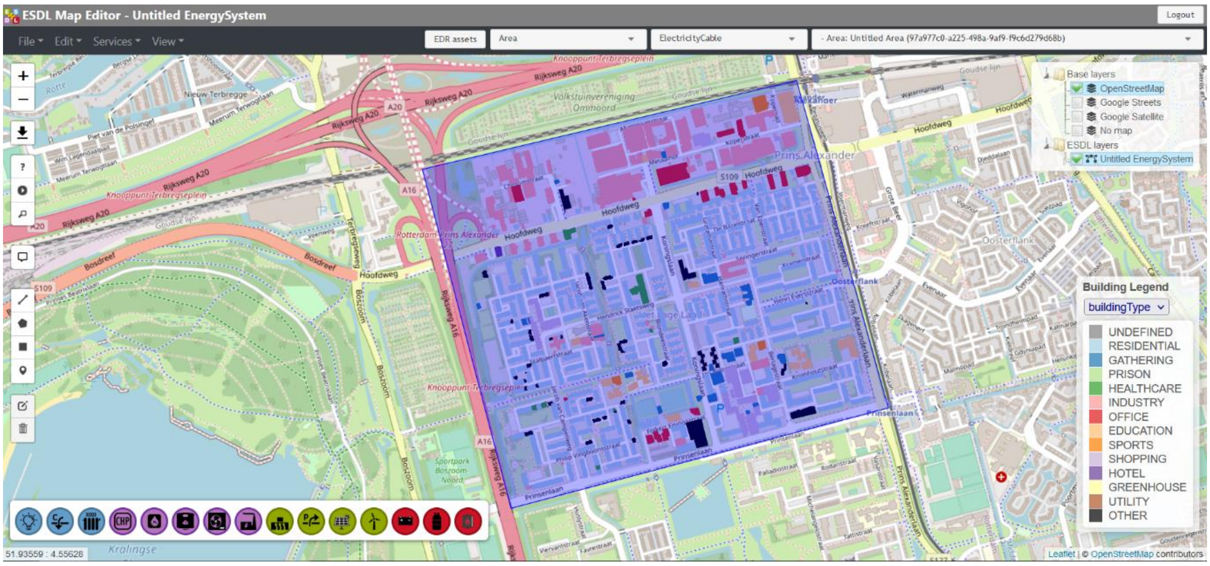


Figure B.2: How the image should look like after loading the BAG data. You can fold open the ESDL layers of the energy system in the top right, and are then able to uncheck the area, so that you can see better if all BAG data is loaded (all buildings should have a shape drawn over them – hover over them to see the data of that building).

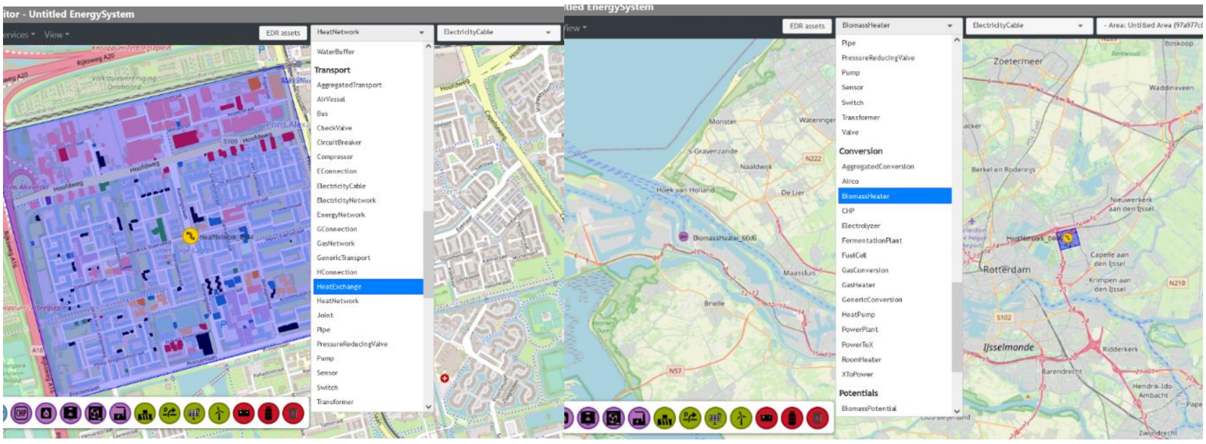


Figure C.3: Adding the heat storage (left) and biomass plant (right) by clicking on the drop down menu and selecting the items. You can then click on a location in the map to place the object there. Make sure you click cancel or finish, otherwise you might accidentally place one object too much. The heat network should be placed in the location where you expect the main pipe to branch off. The biomass plant should be placed in its actual position.

7. Export the ESDL file by clicking on the download button on the top right, and rename the file.

C.2 Loading the data into Anylogic

1. Open both District-heating.alp and District-heating-UI.alp
2. Loading ESDL
    a. Start by putting the downloaded ESDL in to the same directory as the models are
    b. Open District-heating-UI: Model_UI. Go to the function f_startupESDLimporter (top left of ESDL importer block). And change the line
    `p_importer = new ESDLImporter("file.esdl");`
3. Load the maps
    a. Go to google maps and go to the area where the map neighbourhood is in

b. Use your snipping tool or screenshot the area and cut them afterwards in paint.
c. Create two images, one of the area in satellite view, and name this one **satView**, and one of the area in maps view, named **streetView**. Try to make sure both capture somewhat the same area, and make sure you have not zoomed in or out in the meantime.
d. Import these images in District-heating-UI: GeoMap. Rename them **satView** and **streetView** respectively (make sure the older versions are deleted first).

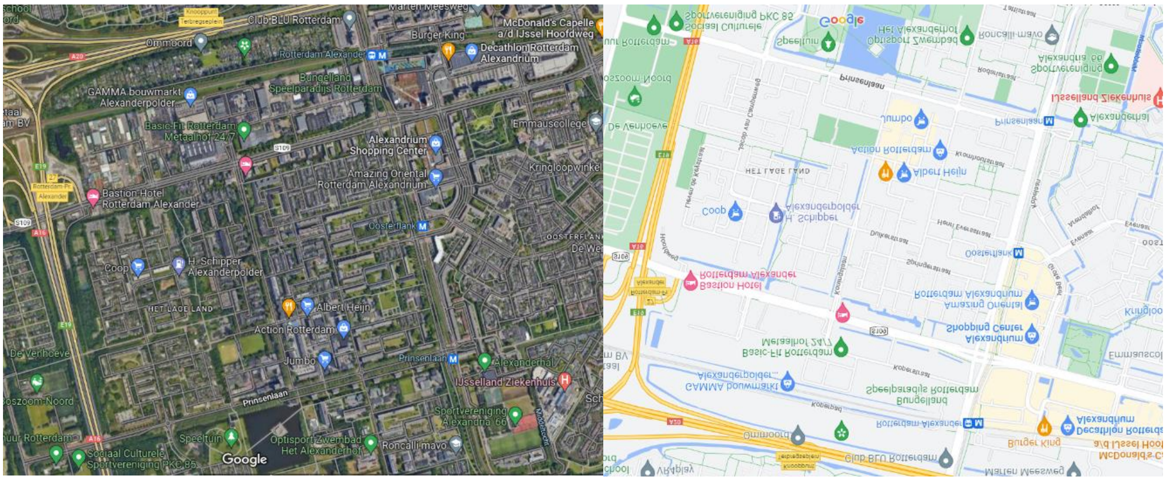


Figure C.4: the images of the ***satView*** *(left) and* ***streetView*** *(right). These should be copied and placed clearly in order to load the program as clearly as possible. Both images should also encapsulate the same area!*

e. Place the images over each other, such that the coordinates overlap.
(*hint*: you can click on the top image and put it on ignore in the top right corner. It will become transparent, so that you can more easily align the images. Make sure to make sure the image does not stay on ignore).
f. Select both images and align them in the top corner. Shrink both of them (while pressing *ctrl* to make sure the ratio stays intact) till they somewhat fit the model interface. Right click on the images and click on *order: send to back*. Realign images again. Clean up the model so it looks neat like this:

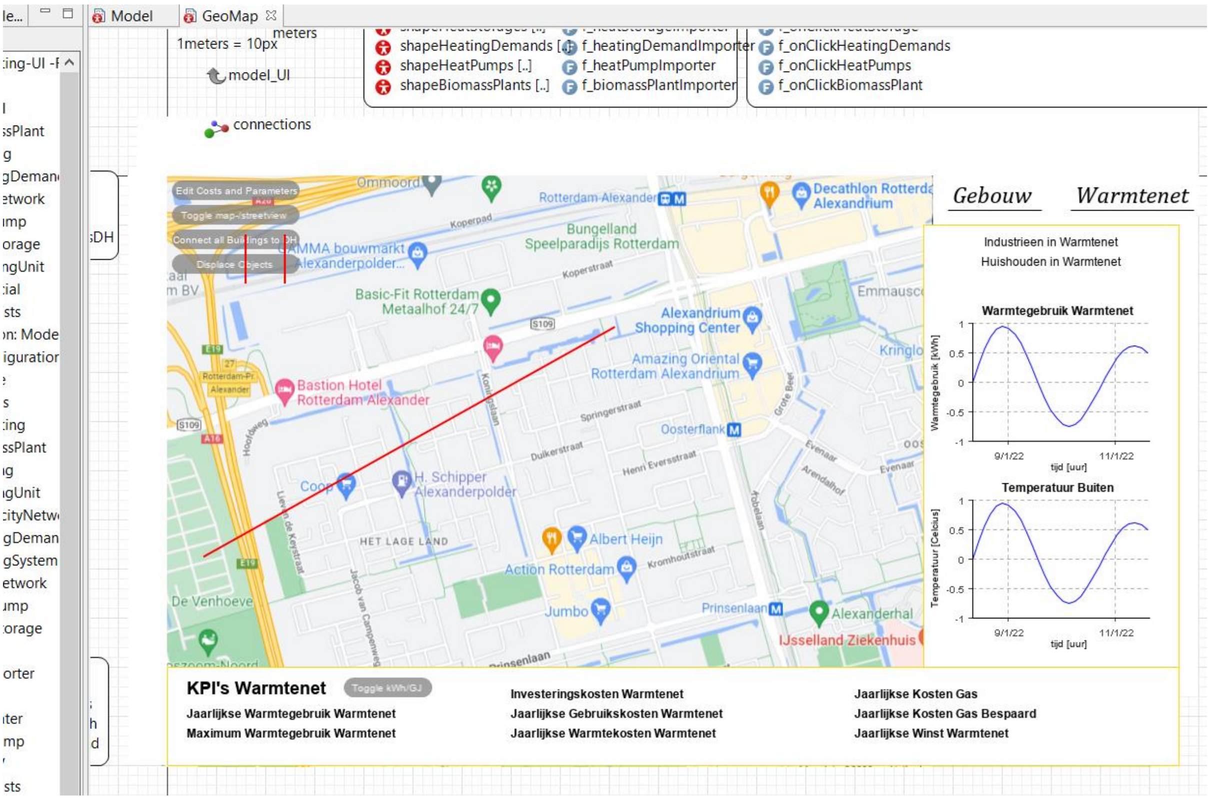


Figure C.5: How the images should look when placed in the GeoMap agent. Note that they do not overshadow other parts of the program, and are neatly cut off on the edges to fit the interface.

g. Click on the red line that you see in the middle, and place it onto two recognisable locations that are far apart (in this case, the bottom left will be placed on the *coop*, and the top right on *decathlon Rotterdam alexander*). Go to google maps and copy the coordinates of both locations and place them in v_coordinateLine_bottomcoordinates and v_coordinateLine_top_coordinates respectively (bottom of the Coordinate mapper). This line will be used to map the shapes onto the map.
   Make sure you are accurate in placing the line and getting the coordinates. The coordinates should have the format of *{lat, lon}*. Coordinate copying can be done in maps via right clicking on the map
h. You should now be able to run District-heating-UI. A window should come up looking like this: (might take a while to load)

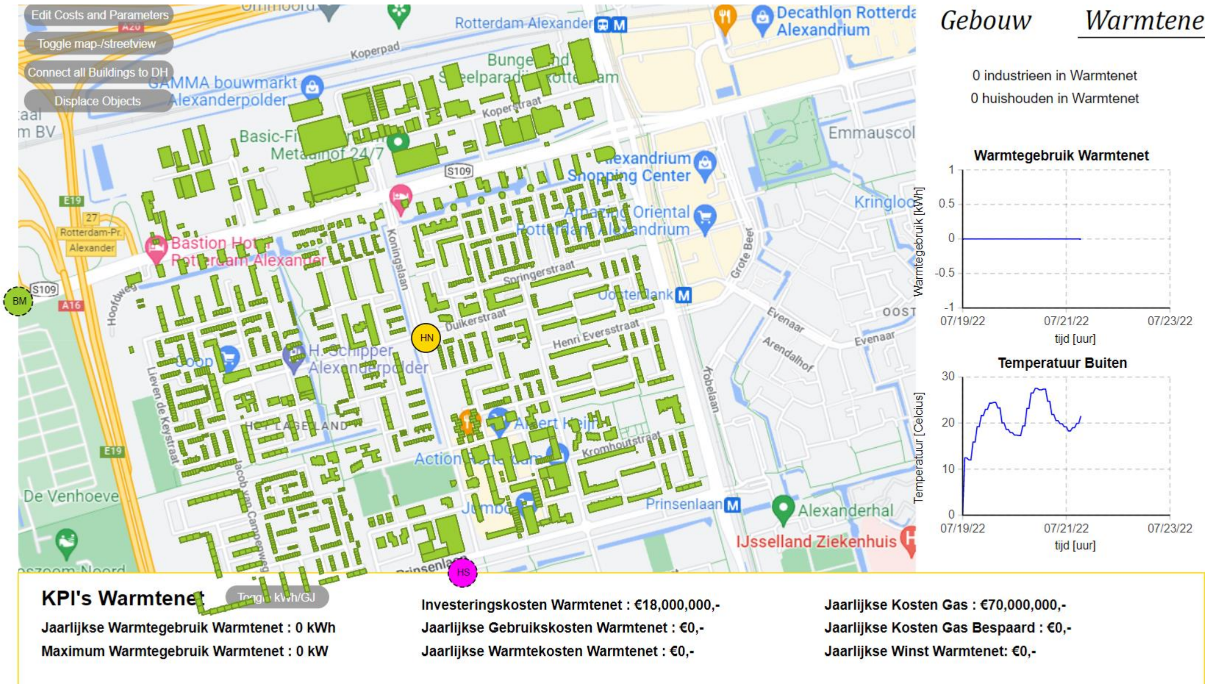


Figure C.6: The interface after aligning the coordinates and running model_UI. The shapes should represent the map somewhat.

   i. As we can see, the model does not completely fit the window. Adjust the GeoMap model until it does. Make sure though that the images and the coordinate line stay aligned.

4. *Extra:* Go to the left of geoMap. This map contains all the objects, such as the powerplant. To make sure we can use this part of the model, go to maps, and make a screenshot or use the snippingtool on the streetview area that contains both the neighbourhood and the powerplant and other objects.
   a. Save this under the name **zoomView** and import it into anylogic under the same name
   b. Align it with the *viewArea*
   c. Right click and *send it to back*. Do the same for *rectangle_backgroundZoom* such that we can see the image again, but now with a coordinateline on top of it
   d. Place the *coordinateLine_zoom* in a recognisable way (I placed them on crossroads), go to maps, copy the coordinates, and put them in v_coordinateLine_bottomcoordinates_zoom and v_coordinateLine_top_coordinates_zoom respectively for the bottom left and top right coordinates. Be sure coordinates are in *{lat, lon}* format.
5. **The program is now finished .**
6. *Extra:* One could import the BAG data separately into the database. This would mean we have the addresses of buildings available in the program.
7. *Extra:* Take a look at the District-heating: Model window at how all tariffs are defined. This might make a huge difference at the outcomes of the program. It is also possible to make

adjustments when running the program, but these will not be saved.

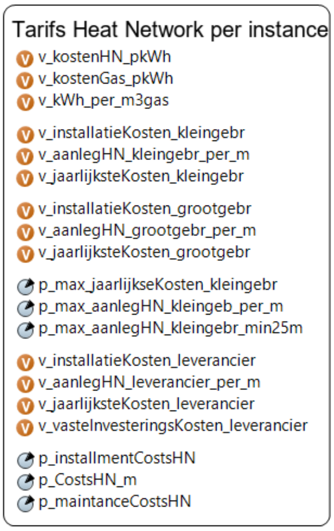


Figure C.7: The tariffs of the heat network. Can be adjusted before starting the program in order to get a better first estimate of the costs.

8. *Extra:* via https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart, use the measure tool to draw an example of the heat network, so that you can estimate its length. Make sure you draw from where you estimate the centre. Add this estimated length to District-heating: A_HeatNetwork: v_extraLength_m.

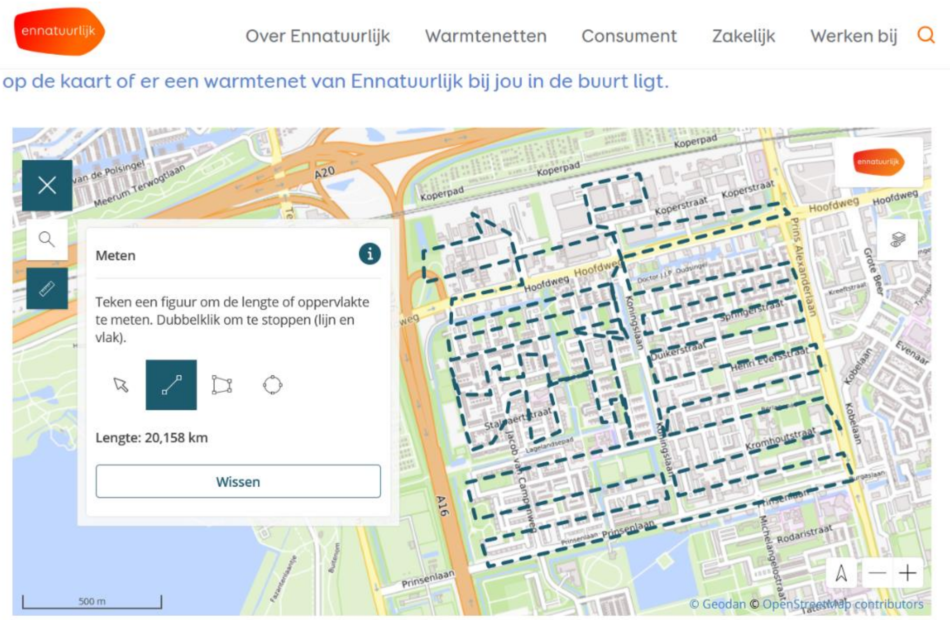


Figure C.8: Estimating the length of the heat network after it branches of via ennatuurlijk.nl.[26] *Note that the length given here is 20.158km.*

[26] https://ennatuurlijk.nl/warmtenetten-van-ennatuurlijk/warmtekaart