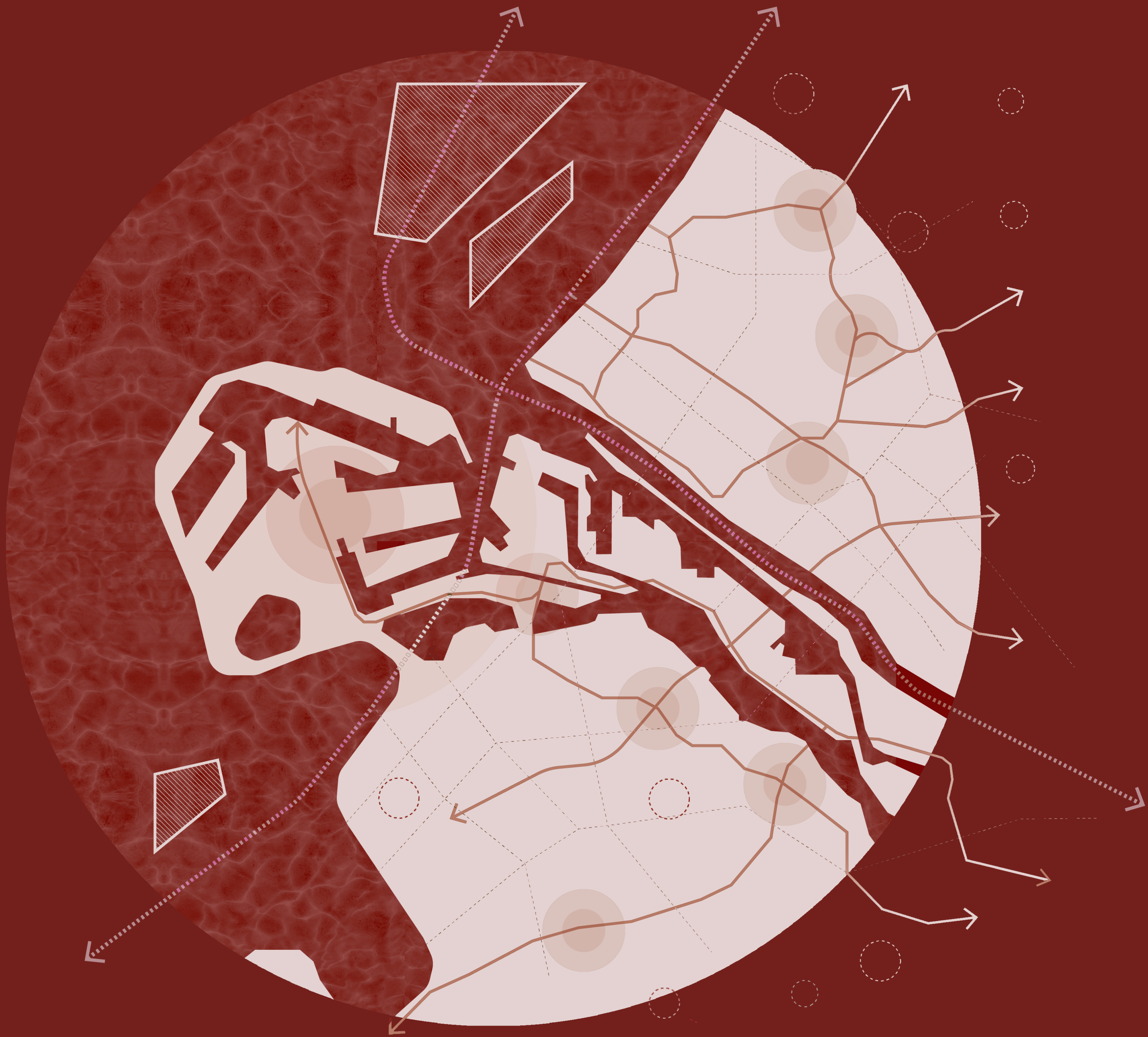
WEAVING OUR ENERGYSCAPES

USING HYDROGEN TO STORE RENWEABLE ENERGY IN A NETWORK COMPOSED OF EXISTING THREADS



TU Delft

Delft University of Technology
Faculty of Architecture and the Built Environment

Msc Architecture, Urbanism and Building Sciences
AR2U086 // R & D Studio; Spatial strategies for the global metropolis
AR2U088 // Research and Design methodology for Urbanism

Students
Yingxing Gu 5788692 // Xinyi Wu 5822777 // Isamu Goiati 5724090 // Merel Garritsen 5055253

Tutors
Verena Balz // Birgit Hausleitner
Roberto Rocco // Marcin Dabrowski

Quarter 3 // February - April 2023

WEAVING OUR ENERGYSCAPES

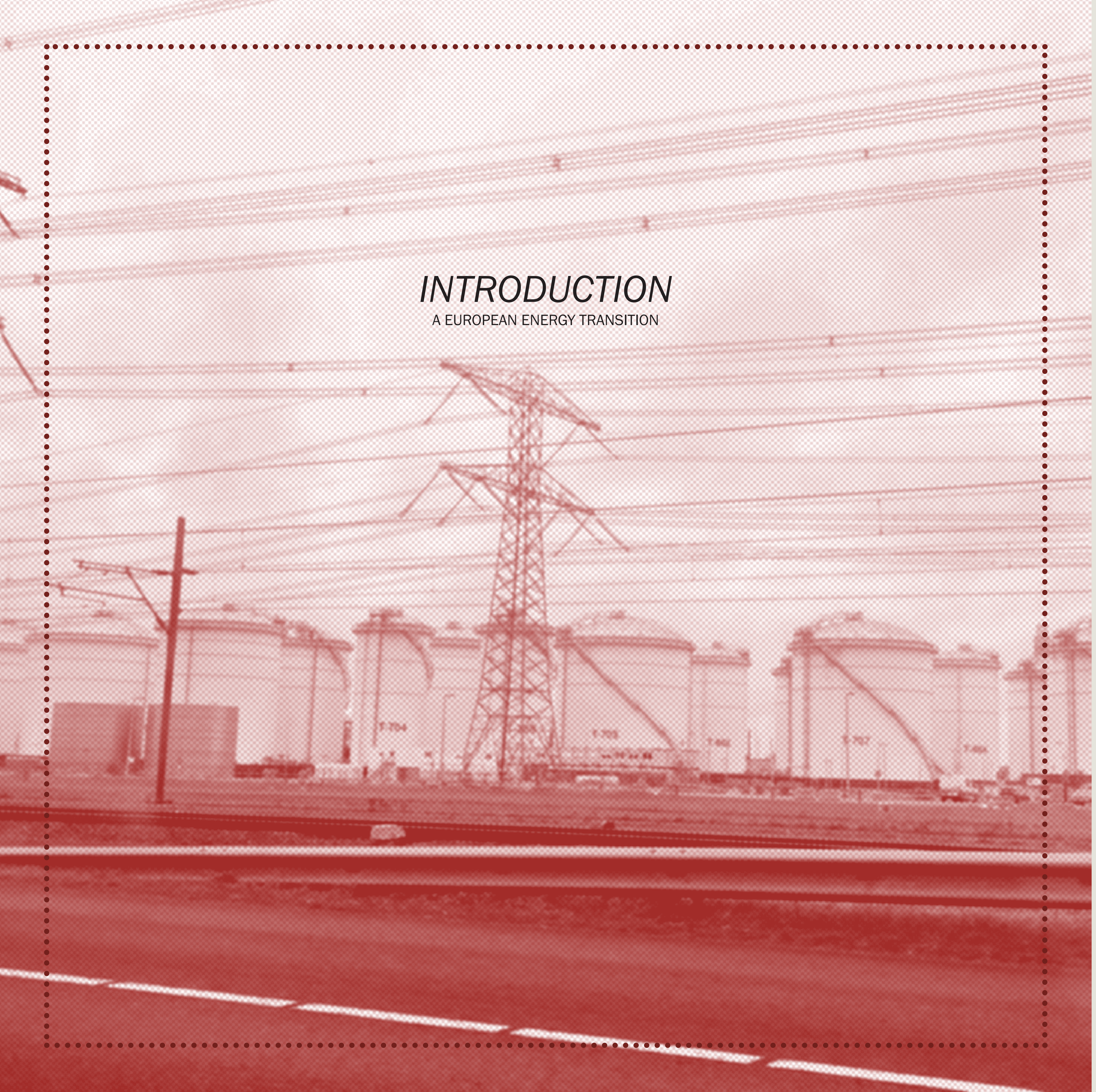
USING HYDROGEN TO STORE RENEWABLE ENERGY IN A NETWORK COMPOSED OF EXISTING THREADS

ABSTRACT

This project aims to address the challenges posed by the transition to renewable energy sources. This will cause an unstable and unreliable energy flow, which does not correspond with the current energy use patterns of society. Different elements of the current energy network are analysed. They have a big role in the transition towards a completely renewable energy system. The proposed solution involves the utilisation of hydrogen as a means to store and transport renewable energy. In order to achieve this, consumption and production patterns in North-western Europe are analysed in relation to existing energy infrastructure that is suitable for carrying hydrogen. With a combination of different data sources and a created algorithm a model is created that is able to generate clusters. These clusters resulted in a continental framework containing 3 typologies of energy landscapes. A centralized, decentralized and a resilient zone; in-between. These landscapes are characterised by their population, proximity and current land use against societal challenges such as justice, resilience, polarisation, and reliability. Self-made algorithms are used to transcribe the landscapes into a collection of physical energy elements that will be needed in areas. These measurements are visualized to propose what the future “energyscapes” could look like. The project suggests implementations on different scales for the new paradigm in the energy transition where hydrogen contributes to a just and reliable energy system.

INTRODUCTION

A EUROPEAN ENERGY TRANSITION



MOTIVE

As planet Earth is warming up at a speed that nowadays seems almost utterly uncontrollable, the human population needs to undertake immediate action to keep ecosystems from collapsing, to keep species of animals from going extinct, and to keep fossil resources from running out. The demand for actions that emit CO2 is higher than this terrestrial environment allows. It has been proven that our increasing emissions of CO2 are causing climate change (NASA, 2023). This will have a drastic impact on all life on Earth. This demands a change from mankind to alter their habits regarding the use of energy in all forms, especially when its production requires exhaustible supplies. We are on the verge of a global transition that will thoroughly impact our lives. A transition that can bridge the gap that emerged between mankind and the other inhabitants of this Earth, but also a transition that has to deal with increasing amounts of polarisation and unfairness in society.

The finite resources that belong among the most popular ones used to turn into usable forms of energy are coal, natural gas, and crude oil, all of which can be found at different depths, often in between two of the Earth's many layers. Unfortunately, considering the current rate of extraction and demand, the coal supply will run out in the next 70 years, the natural gas supply will last us 40 more years and the oil supply will be gone in the next 30 years (MAHB, 2021). The scarcity of these materials will also increase their value, so if this energy crisis cannot be solved with renewable energy sources, energy will become a pricey privilege only a few can afford. These scenarios tell us that immediate action needs to be taken to prepare the next generation for a life without fossil fuels. The world is in an utter state of an energy emergency. The roots of this crisis could be described as an energy addiction all human generations currently inhabiting the planet are born with. Fossil fuels have determined the way humanity has been able to develop its habitats, but that also caused us to have now adapted to lifestyles that are completely dependent on fossil energy forms. We have used gigantic quantities of it since the first industrial revolution. As the club of Rome already stated in 1972, it needs to be accepted that there are limits to growth (The Limits to Growth, 1972). As we cannot imagine a life without energy and therefore cannot drastically lower the demand in the next few decades, we have to solve this crisis. We need to transition to energy sources that are sustainable, renewable, and reliable.

GLOBAL PLAYER

Even though the country has little oil of itself, the oil industry plays a significant role in the economy of the Netherlands. The strategic location of the country in the Delta of multiple important rivers, results in an optimal position for international commerce and trade. The Netherlands has the biggest port in Europe, located in Rotterdam. The Port of Rotterdam can also be defined as an energy hub with influence on a global scale, as it holds a share of half of all fossil fuel products used in North-Western Europe (Bosman et al., 2018). Crude oil is imported into the harbour and processed into fuel in one of the many oil refineries, before being exported again to other (neighbouring) countries. These refineries define the industrial character of this port landscape. It is a place where tonnes of raw materials are stored in bulk, a sight that is normally hidden from the public eye. The landscape feels alienated. Endless empty fields function as a buffer zone between the publicly accessible roads and the giant tanks filled with easily inflammable energy sources.

Although The Netherlands has some active oil platforms in the North Sea and the controversial gas field causing earthquakes in Groningen, their revenues are not enough to support the demand of the densely populated country. The oil that is processed in the harbour, before being distributed over the whole continent comes from multiple different countries. Before the Russian-Ukrainian war that started in 2022, most of the oil and gas that was imported by The Netherlands came from Russia. Since then, import from Russia has come to a halt (Ministerie van Economische Zaken en Klimaat, 2023). This caused gas prices to skyrocket, making energy unaffordable for some socio-economic classes. An opportunity that arose alongside this catastrophe is the fact that by consciously thinking about the use of (fossil) energy, the consumption of energy from gas was lowered by 16% in comparison to the year before. The share of energy from all fossil fuels decreased by 11% that year (Centraal Bureau voor de Statistiek, 2023).

IMPORTING COUNTRY:
NETHERLANDS

IMPORTING FROM:
28,9% RUSSIA
21,7% UK
12,8% USA
10,8% BELGIUM
9,2% NORWAY
7,95% KAZACHSTAN
5,62% NIGERIA
4,81% GERMANY

world map based on data from (Observatory of economic Complexity, 2022)

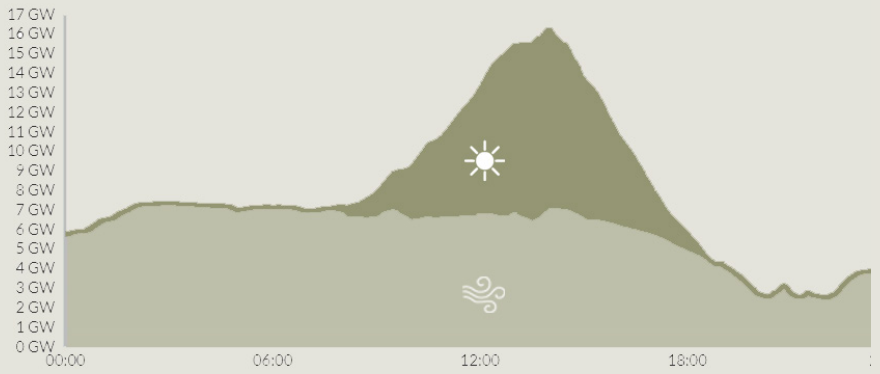
CONTEXT

The transition to renewable energy also leads us to substantial challenges that need to be solved along the way. The road towards a world without fossil energy is far from smooth. One of these challenges is caused by the capacity of the powerline network. The Dutch news has recently attended to this issue extensively (NOS, 2022). As visible on the map, in the majority of the provinces the energy network is overcrowded, while other provinces experience a scarcity of energy (Capaciteitskaart Invoeding Elektriciteitsnet, 2023). The overcrowding of the energy network causes a lot of problems for local residents, while it also slows down the energy transition. The places that are confronted with an overflow in the electricity network are now discouraged to add new renewable sources of energy, such as solar panels or wind turbines. This is the complete opposite of what the energy transition should bring about. This measure is the result of an obsolete electricity network that cannot deal with the high demands that occur nowadays. Both the consumption and production sides are affected by the maximum capacity of the network. This problem is amplified by the fact that more facilities (want to) run on electricity instead of gas or petrol and the fact that more individuals are installing facilities like solar panels to produce a share of their own energy (NOS, 2022). To handle the energy demand of the future, the electricity network needs to be relieved.

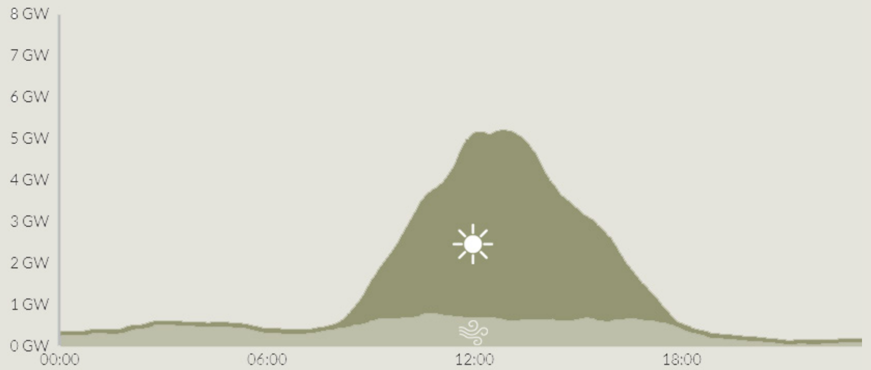
These problems regarding the electricity network will continue to increase when transitioning to more renewable energy sources. When the decision is made to rely on renewable energy sources like solar energy or wind energy, it comes with a big element of unpredictability. Sun and wind are both dependent on the weather. The weather varies year by year, season by season, week by week, day by day, minute by minute. These graphs show the difference in the generation of wind and solar energy during a day in July and a day in January. During the day, there is a peak in the production of solar energy. At moments like these, the already filled-up energy network will not be able to handle the peak, which would mean that the energy would be wasted. Even though the wind availability at sea is more consistent than on land, the production of wind energy does not have a repetitive pattern like solar energy, making it even more unpredictable.

The instability of the energy flow that is generated can be stabilised by storing the energy overflow during peak moments in a battery, so the energy can be stored and saved for a later moment. Another good reason for introducing a battery is that the pattern in which this energy is generated does not correspond to the pattern in which society uses energy.

Another problem that renewable energy brings along is a social one. For many people that support the energy transition a visible wind turbine is one of the worst things that could happen to them. This makes the energy transition more difficult. People want to transition, but they do not want their open views to be disturbed by giant rotating arms. When transitioning, solutions must also be selected on the aspect of creating the least amount of protest, to keep the population willing to transition. Compromises must be made on both sides. Challenges like these must be faced and confronted to make this crucial transition a success.



July



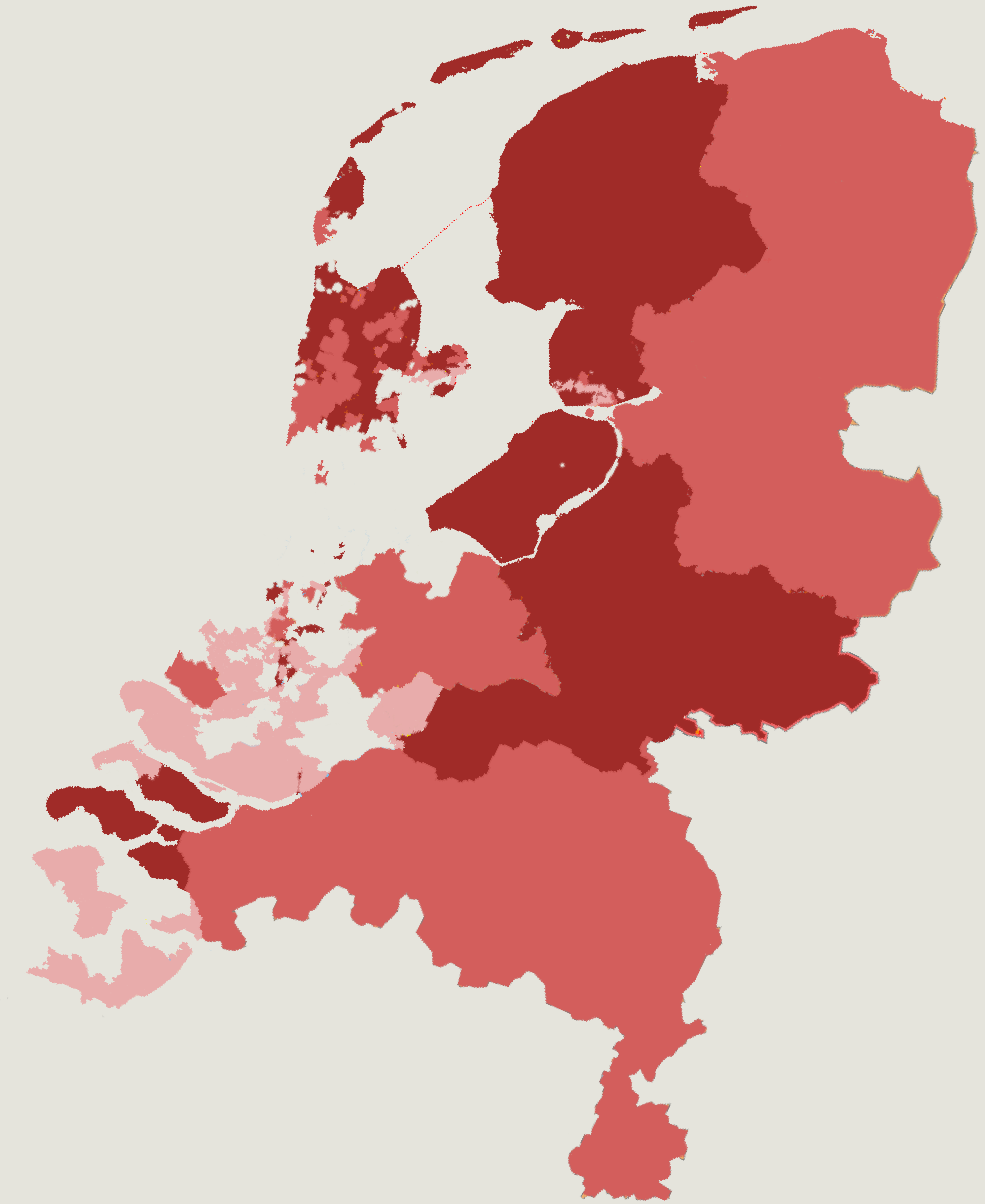
January

limited transport capacity available

provisionally transport capacity available

no transport capacity available

data from (Energieopwek.nl - Inzicht in De Actuele (Near-realtime) Opwekking Van Duurzame Energie in Nederland, n.d.), altered images



data from (Capaciteitskaart Invoeding Elektriciteitsnet, n.d.), altered image

PROBLEM STATEMENT

1 // Energy transition
As the energy transition continues to progress and conflicts arise, Europe is reducing its reliance on fossil fuels. It is crucial to swiftly determine how the energy transition of Europe should be shaped.

2 // Land scarcity
North-western Europe faces a unique challenge due to its high population density and limited land availability. Although clean energy sources such as wind or solar power are environmentally friendly, their energy production requires a significant amount of land. This presents a potential obstacle to a sustainable future in the region, as the land must also be utilised for other essential purposes such as housing. It is necessary to identify alternative spaces that can be utilised for clean energy production to ensure that the region can meet its energy needs while preserving its limited land resources.

3 // The unpredicatbility of the weather
Sustainable energy production is heavily influenced by weather conditions, which may result in days when there is a scarce amount of wind or sun and thus a scarce amount of energy available. To avoid such situations, it is essential to develop sufficient storage capacity to store the energy generated by wind and solar. This will ensure a consistent energy supply for people, even when natural resources are limited.

4 // Mismatch in energy use and energy generation
Although North-western Europe currently has a large number of windmills that produce electricity, the production time of this electricity is often different from the time the population wants to use the energy, whether talking about a 24-hour period or over a year-long period. This can result in wasted energy, which is produced but not used, and therefore goes to waste. It is necessary to find ways to save this otherwise wasted energy for times of underproduction.

POTENTIALS FOR A RENEWABLE ENERGY FUTURE

North Sea // A huge renewable energy production site.
As a region containing large amounts of sea, North-western Europe has a strong advantage in wind power generation. With scarce land resources and access to the North Sea, Europe can relocate a large number of windmills at sea.

Battery // Storage of electricity
As stated earlier, with the use of renewable energy sources, the chance of wasting energy becomes increases. In order to make full use of the “wasted” energy, enough storages are needed to store the excess energy in the form of hydrogen.

Hydrogen // the material of the battery
Regular batteries need a lot of resources. These resources are scarce and often have a big environmental impacts. Using hydrogen as a way to store energy uses significantly less materials than regular batteries. Hydrogen can be stored in tanks that are made from metal (Ustolin et al., 2020).

ALIGNMENT OF GOALS WITH EXISTING POLICIES

The Sustainable Development Goals (SDGs) are a set of 17 goals established by the United Nations in 2015 to promote sustainable development worldwide. The goals cover a wide range of issues including poverty, hunger, health, education, gender equality, clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action, and more (United Nations, n.d.). This project is also strongly connected to these values, especially the following goals:

Affordable and clean energy // Ensuring access to reliable, sustainable and modern energy at an affordable price.

Industry, innovation and infrastructure // Building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation.

Reduced inequalities // Reducing inequalities within and among countries through social, economic and political inclusion.

Sustainable cities and communities // Creating inclusive, safe, resilient and sustainable cities and communities.

Responsible consumption and production // Ensuring sustainable consumption and production patterns that promote resource efficiency and minimize waste and pollution.

Climate action // Taking urgent action to combat climate change and its impacts.

Life below water // Conserving and sustainably using the oceans, seas and marine resources for sustainable development.

Life on land // Protecting, restoring and promoting the sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, and halting and reversing land degradation and biodiversity loss.

Peace, justice and strong institutions // Promoting peaceful and inclusive societies for sustainable development, providing access to justice for all, and building effective, accountable and inclusive institutions at all levels.

The European Union has adopted the SDGs as a key part of its sustainability strategy, aiming to achieve them by 2030. The EU has also developed its own set of 17 sustainable development goals, known as the EU SDGs, which align with the global SDGs but are directed towards the specific challenges and priorities of the EU (European Commission, n.d.).

The harbour of Rotterdam is a place where a big transition will take place in terms of sustainability. There has been a growing focus on hydrogen as a clean energy source. The port of Rotterdam is one of the largest ports in Europe and is a key hub for energy imports and exports. In recent years, the port has been exploring ways to reduce its carbon emissions and become more sustainable. One of the main ways the port is working towards sustainability is by developing a hydrogen economy. The port is currently working on several projects related to hydrogen, including the construction of a hydrogen production facility and the development of a hydrogen refuelling network for trucks (Port of Rotterdam, n.d.). The harbour of Rotterdam is taking a proactive approach to sustainable development, with a focus on reducing emissions and transitioning to cleaner energy sources like hydrogen.

(Sustainable Development Goals - UN Global Compact NL, 2023)

METHODOLOGY

VALUES OF A JUST ENERGY TRANSITION

RESEARCH QUESTIONS

To structure the research and analysis in this project, research questions were asked. This resulted in a main research question and a number of sub-questions.

The main research question is:
How can the network of existing infrastructure contribute to solve the spatial implications of the energy transition by introducing hydrogen as a sustainable energy carrier?

The sub-questions are:
How can existing energy landscapes adapt to renewable energy while preserving their current identity?

What are the spatial implications of the energy transition?

How can hydrogen contribute to the energy transition?

How can renewable energy production become more stable?

THEORETICAL FRAMEWORK

Electrolysis // Hydrogen production by water electrolysis converts electrical energy into chemical energy in a process that does not require a complex chemical industry. Alkaline electrolysis is a well-established technology for hydrogen production, in which electrodes are inserted into an alkaline electrolyte (usually potassium hydroxide NaOH solution) to electrolyse water into hydrogen and oxygen. The efficiency of hydrogen production by electrolysis of water is 70-80% (Tinghai, 2022).

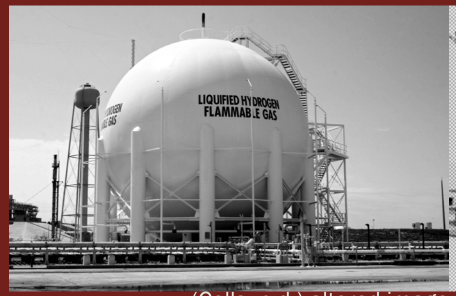
$H_2O \rightarrow H_2 + 1/2\ O_2$

(Fraunhofer ISE, n.d.) altered image

Storage options // Hydrogen storage can be divided into three categories according to applications: large-scale stationary hydrogen storage facilities, hydrogen storage tanks for hydrogen transportation, and on-board hydrogen storage tanks for fuel storage in fuel cell vehicles (Chijun, 2018). The first two types of hydrogen storage are mainly used in this project proposal.

Large-scale stationary hydrogen storage facilities are mainly used in areas with large populations, which can provide large amounts of hydrogen energy to the local area. Hydrogen storage tanks for hydrogen transportation are mainly used for rail and water transportation.

Large-scale stationary hydrogen storage facilities can hold compressed hydrogen or liquified hydrogen. Compressed hydrogen storage is a method of compressing hydrogengas to increase the storage density of hydrogen through high pressure. The higher the pressure, the stricter the requirements for the pressure-bearing capacity of the tank and the valves, including the pressure relief valve.This is a very expensive method. Currently, liquified hydrogen is mainly used in the field of aerospace enigneering (Yatsenko, 2022). Liquified hydrogen storage also has advantages for large-capacity, long-term storage in stationary hydrogen storage facilities and for long-distance transportation in the civilian sector, which is a current development direction of the hydrogen energy industry.



(Cells, n.d.) altered image

(Ltd, n.d.) altered image

Transportation // The development of hydrogen energy industry is directly related to the breakthrough of hydrogen energy storage and transportation technology. Hydrogen transportation forms a separate part of the hydrogen energy industry chain. The ways of hydrogen transportation are mainly divided into: gaseous transportation, liquid transportation, solid transportation and organic liquid transportation. Internationally, hydrogen is mainly transported in a gaseous state in tanks. Liquid hydrogen is mainly transported in ships and pipelines. The disadvantage of transportation tanks on trailers is that hydrogen is an explosive, which is dangerous to transport in the public sphere. Pipeline transportation will be safer and can accommodate longer distances. Pipelines are the preferred option and realistic choice to solve the problem of large-scale and low-cost transportation of hydrogen energy. A stable and reliable transportation of hydrogen energy can be realized through pipelines(Laureys, 2022). If the existing natural gas pipeline system could be used to transport hydrogen, the range of hydrogen pipeline transmission could be rapidly expanded.

(Schröder, 2022) altered image
(Hydrogen Energy Supply Chain (HESC) Project, 2023) altered image

Decentralization // In this project, the decentralization of the energy distribution plays an essential role. The centralized system for our project uses energy generated by off-shore wind farms Its excess electricity will be stored as hydrogen in storages, thereby increasing the stability of the energy flow. This network will cover a large part of northwest Europe.

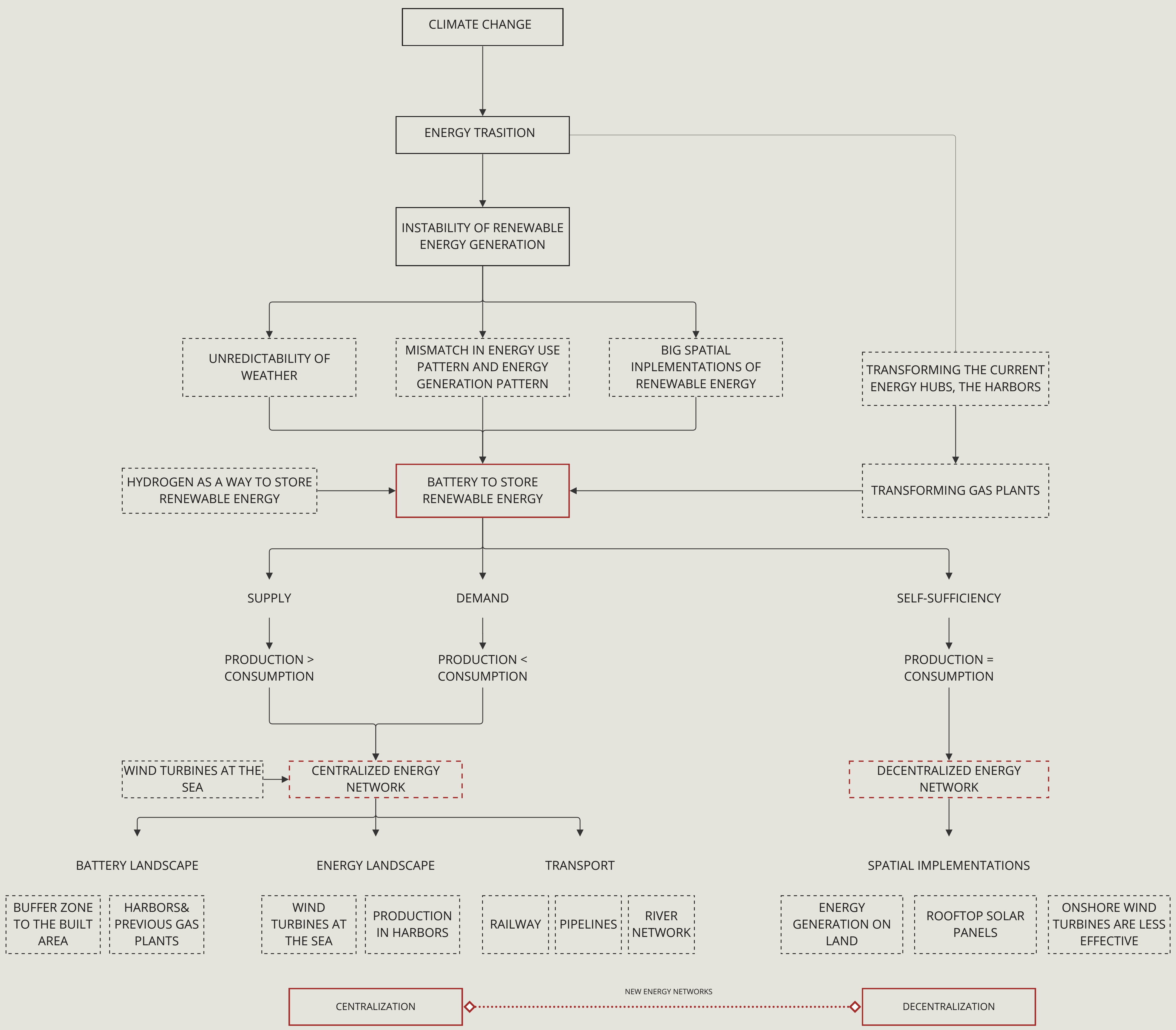
Decentralized systems, on the other hand, make use of smaller facilities spread out over a larger region. In the context of energy, this can refer to a network of modest-sized windmills, solar panels, in compact groups. Decentralized systems are frequently easier to maintain and repair than centralized systems and can be more versatile and adaptable. By lessening reliance on centralized infrastructure, they may also encourage energy independence and resilience (Nolan Gray, 2020). Both centralized and decentralized systems work together to create a more stable and secure energy environment.

Energy justice // The fair and equitable allocation of the advantages and expenses related to the production, distribution, and consumption of energy is referred to as energy justice (IEA, n.d.). It acknowledges that having access to energy is a basic human right and works to make sure everyone has access to dependable, safe, and inexpensive energy services (IAEE, n.d.). In order to promote equality and lessen inequalities in energy access and use, energy justice also takes into account the social, economic, and environmental repercussions of energy production and consumption (Sovacool B K et al., 2013).

Energy safety refers to the policies and procedures put in place to make certain that energy is produced, transported, and used in a safe manner (UNDP, n.d.). To avoid interruptions to energy services, energy safety includes assuring the security and dependability of energy supplies and infrastructure (NIOSH, n.d.).

In the context of this project, energy justice refers to giving both urban and rural areas equitable access to dependable and reasonably priced energy services. The project aims to guarantee that all individuals have access to energy services regardless of their location or socio-economic situation by utilizing a combination of centralized and decentralized systems and the storage of energy excess with hydrogen storages. The social, economic, and environmental effects of energy production and use are also a focus of this plan.

CONCEPTUAL FRAMEWORK



METHOD

In this report, the following elements were used to conduct the analysis:

Data // Various datasets were collected from reputable sources such as official government websites, academic institutions, and non-governmental organisations. The data were selected based on their relevance to the research question and the research objectives. Data sources have been connected to each other to come to new findings.

Research papers // A literature review was conducted to identify and analyse previous research related to the topic of this report. Peer-reviewed research papers from academic journals, conference proceedings, and reputable online databases were consulted.

Journals // Journals were reviewed to gather additional insights and knowledge related to the research question. These journals were selected based on their relevance to the research topic and the quality of the articles.

News articles // Recent news articles were also consulted to understand current trends and events related to the research question. The articles were selected from reputable news sources and analysed to identify any potential impacts on the research topic.

To translate the analysis, various tools and techniques were used:

Mapping // Geographic Information Systems (GIS) software was mostly used to create maps and analyse spatial relationships between data points. Maps where also made with visualization programs as Illustrator and Photoshop.

Data // New insightful data has been generated by making connections between findings. This data is often generated by self made algorithms that translate spatial questions to code. Python was used in making this code.

Graphs // Several types of graphs were created to visualize trends and patterns in the data. Python was used for this.

Visualizations // Other types of visualizations such as sections, axonometric drawings and collages were also used to present the findings in clear, but also creative ways.

ANALYSIS

BETWEEN NETWORK AND DECENTRALIZATION

SPATIAL IMPLICATIONS OF RENWEABLE AND FOSSIL ENERGY

The transition to renewable energy sources, such as solar and wind power, will undoubtedly have a significant spatial impact on people's lives. Unlike fossil fuel extraction and transportation, which typically occur in remote areas away from populated centres, renewable energy production often takes place closer to where people live and work.

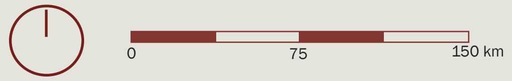
For example, solar panels can be installed on rooftops of buildings, and wind turbines are often built in rural areas near residential communities. This means that renewable energy infrastructure will be much more visible and tangible for people than traditional fossil fuel infrastructure, which is often hidden from the public eye. These projects will also have a significant spatial impact, as they will require the acquisition of land and the construction of new infrastructure in undeveloped areas.

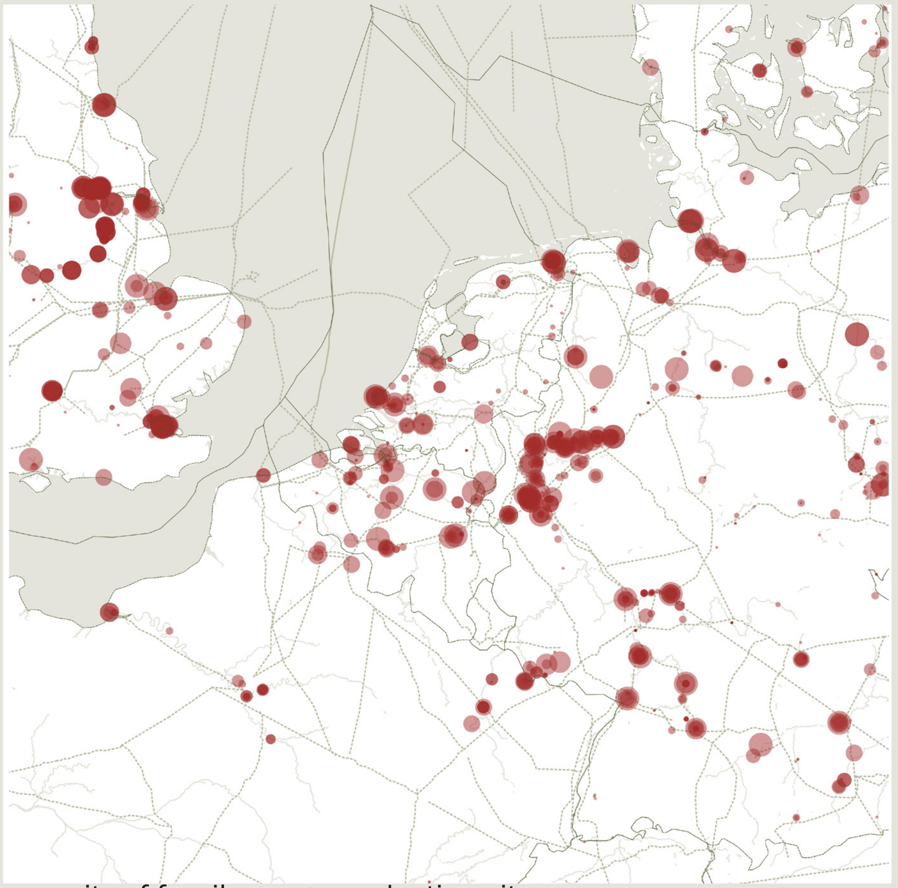
The North Sea is an interesting topic in this transition. It is a place where a lot of windmills and energy infrastructure will be placed. This is an intervention people will likely not notice that much. At the same time this brings up the question, 'Who owns the sea?' Placing these elements can have a rather large impact on marine life (Bergström et al., 2014). At the same time, a lot of research still needs to be done to really know if it is harmful and in what way (Bergström et al., 2014). Other factors as climate change do not give us the time to wait on these findings, putting us in a position where decisions need to be made, without knowing all the outcomes. However, the benefits of this shift, including reduced greenhouse gas emissions and a cleaner environment, will outweigh the challenges of adapting to these changes.

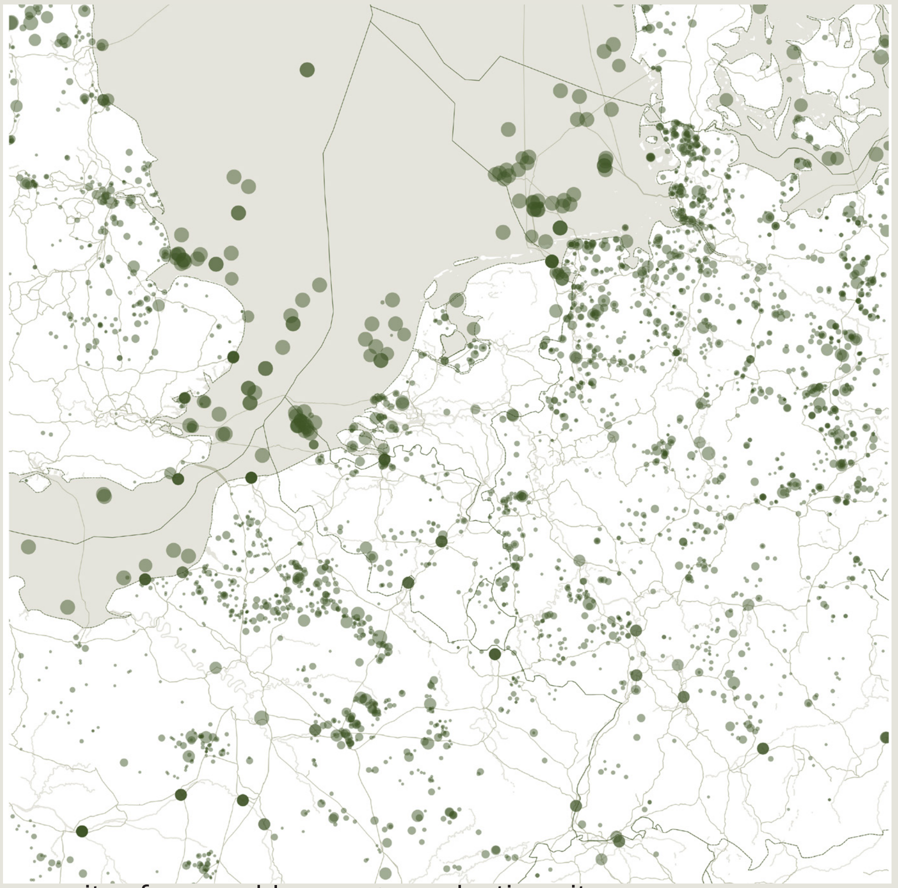
The heatmap on the right shows the difference in intensity of the fossil and renewable energy power plants. The spatial implcations of renewable energy generation can be derived from this. The renewable sources need a lot more space. The most efficient renewable production sites are situated in the North Sea. Most of the fossil energy that is produced in North-western Europe comes from the German Rürhgebied.

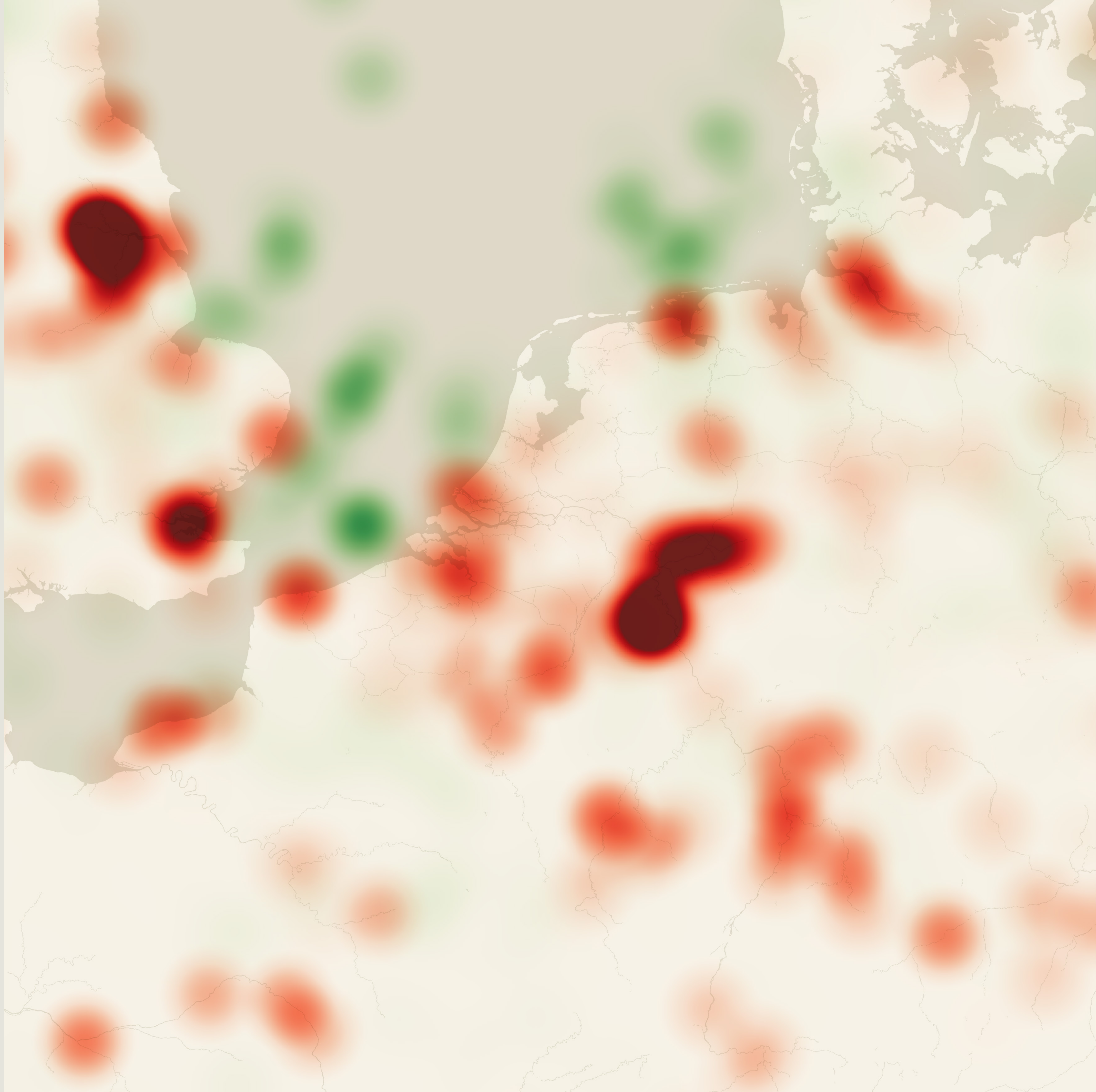
intensity of renewable energy production

intensity of fossil energy production



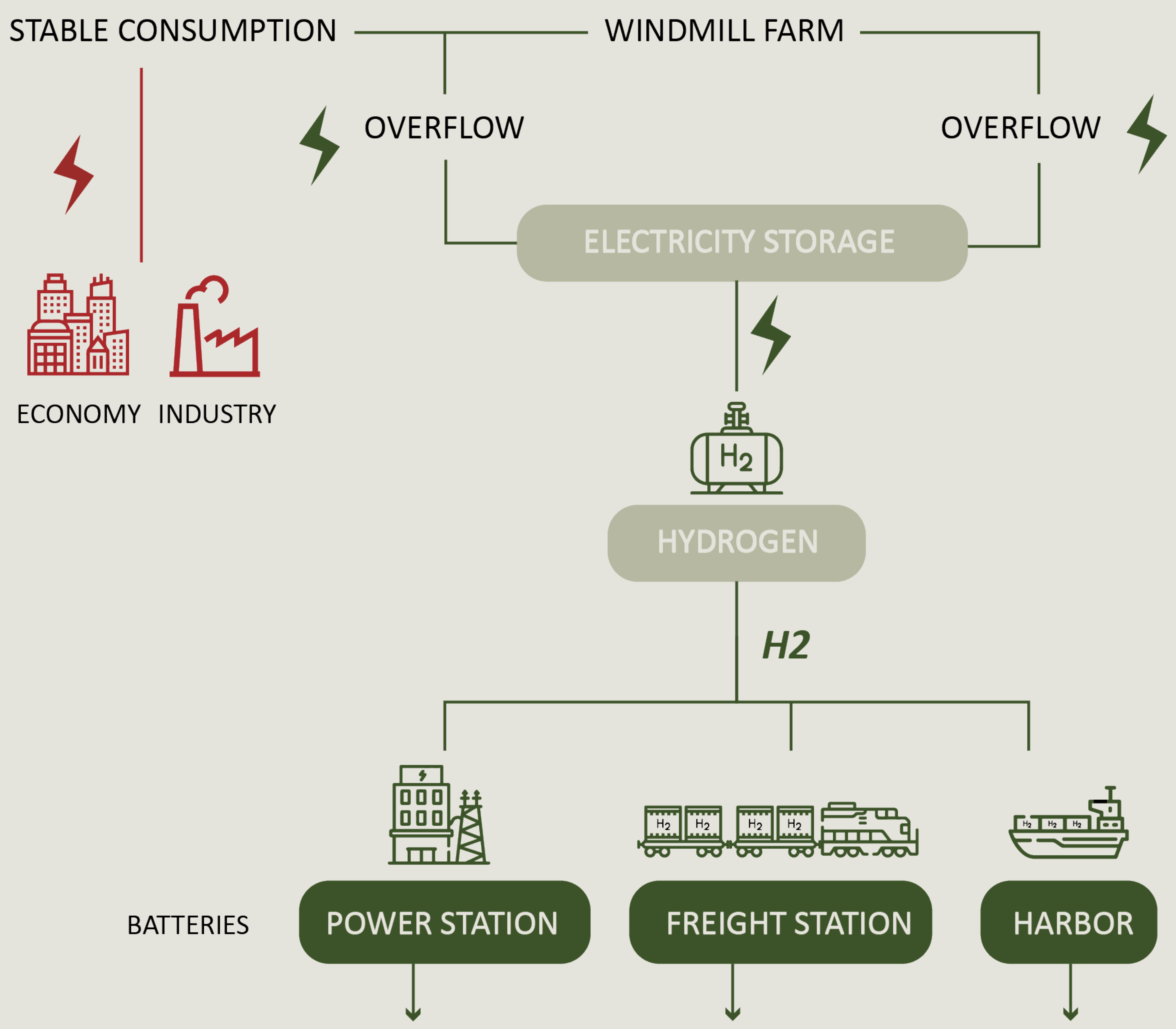

capacity of fossil energy production sites


capacity of renewable energy production sites



HYDROGEN AS AN ENERGY CARRIER

The overflow of energy generated during peak hours can be stored in multiple different ways. This energy could be directly put in batteries to store for later use, but electric battery production requires lithium, a metal that is mostly mined in China. Lithium is becoming very scarce due to great global battery demands. Lithium shortages are already threatening the electric car industry (Narins, 2017), which makes nationwide energy storage in electric batteries an impossible task. Another way in which energy can be stored is by producing hydrogen. Hydrogen has some great advantages that will stimulate the energy transition. The production of hydrogen does not emit any CO2, which makes it a clean carrier of energy. The only resources needed for the production of hydrogen are water and electricity. Another advantage is that the current energy infrastructure can be converted to facilitate the transportation of hydrogen. In plans for the energy transition, hydrogen fulfils a big role with its futuristic character. Significant progress has already been made in terms of the efficiency of medium to large-scale hydrogen plants (Rostrup-Nielsen, 2005).



INFRASTRUCTURE & NETWORK

Infrastructure is a fundamental element in our society, it connects us to our needs in the broadest of terms. To ensure an efficient and effective energy distribution system in the future, it is important to analyse and understand the current ones. The focus of this project is on networks that fit in a future where renewable energy is produced and transported in a sustainable way. To build up this overview of this future network, the current networks are analysed in a sequence of maps.

Water // Water is maybe the oldest transport network known to mankind. Ships can transport energy (and thus hydrogen, too) over rivers and seas.

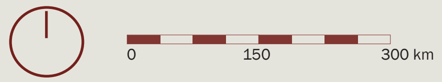
Harbours // Nowadays, harbours are already important elements in our energy systems. Therefore, the question is not if, but how they will be used in our future energy system. With the generation of a lot of energy on sea, the harbour not only can become a storage place for hydrogen, but also a place of production.

Railways // Trains transport a lot in our society, also energy. Although not as efficient as transport over water, transporting via railways can supply areas with hydrogen.

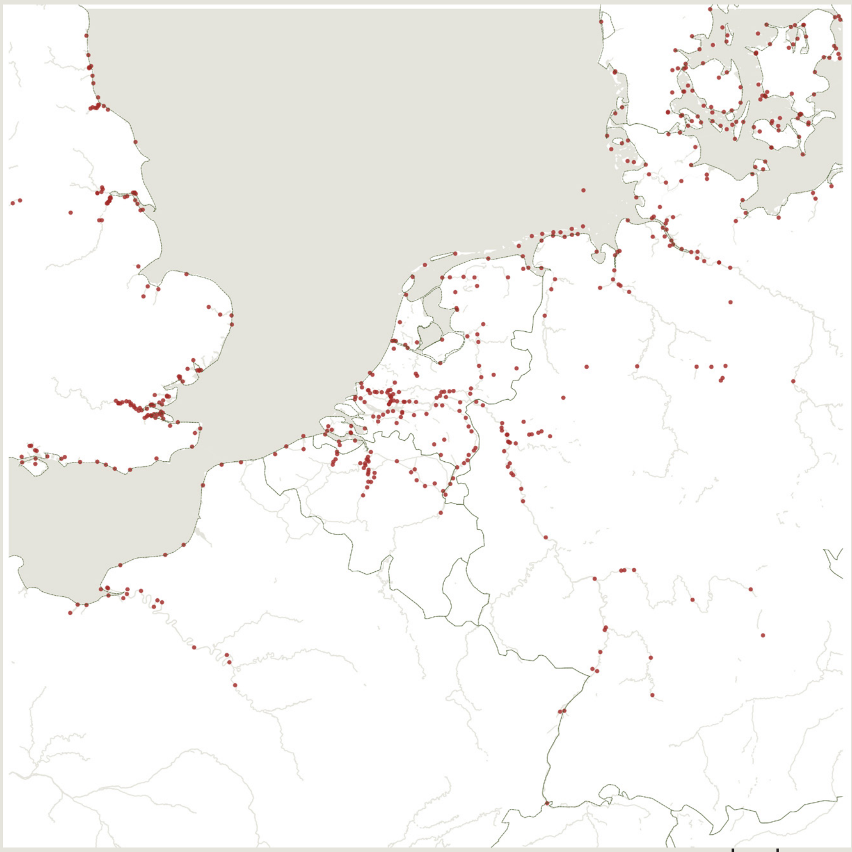
Pipelines // Pipelines are an efficient way of transporting energy sources, if applicable. Hydrogen can be transported via existing gas pipelines with only a small number of adjustments (Gebouwd & Duurzaam Gebouwd, 2022).

Electricity network // The electricity network currently is overcrowded in many places in the Netherlands. The network transports renewable energy to all homes, but is not capable of withstanding the peak the generation of renewable energy is paired with.

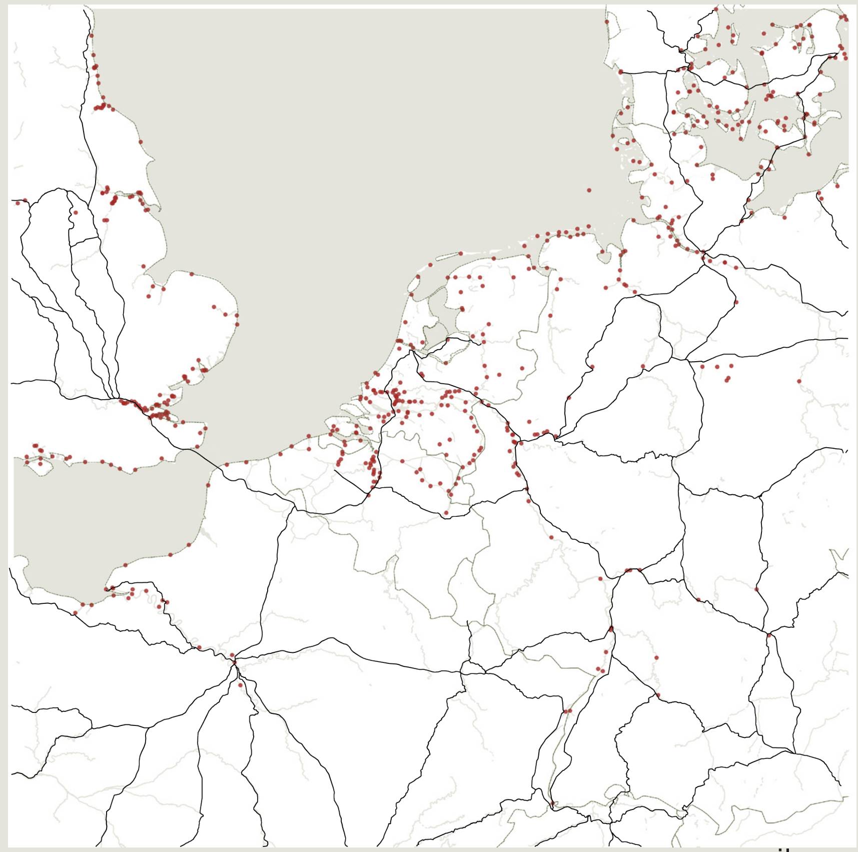
Gas plants // In our energy system gas plants already have a big role. With the knowledge that these plants can be transformed (Prospects for using hydrogen in gas power plants are becoming tangible, z.d.), they can be taken into the future hydrogen network.



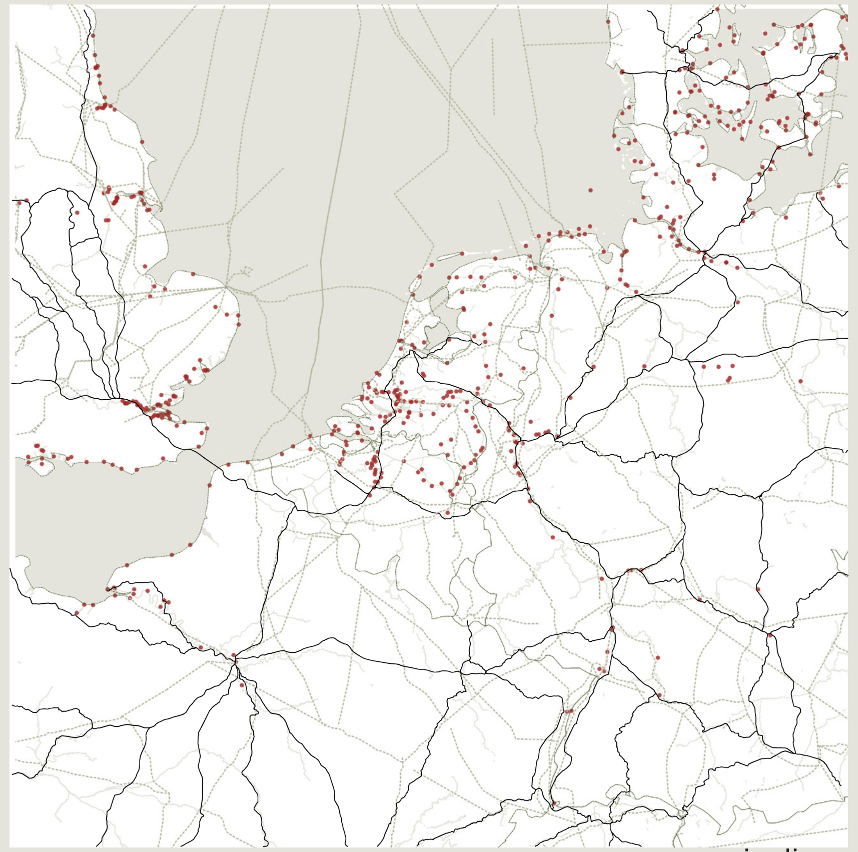
water



harbours

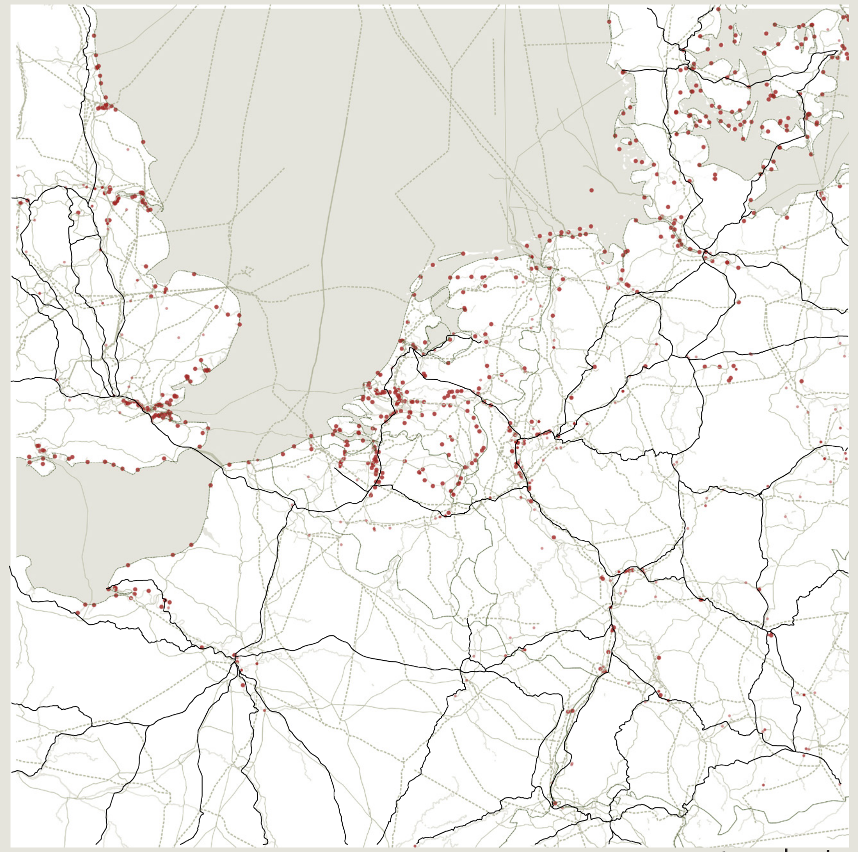


railways



pipelines

electicity network

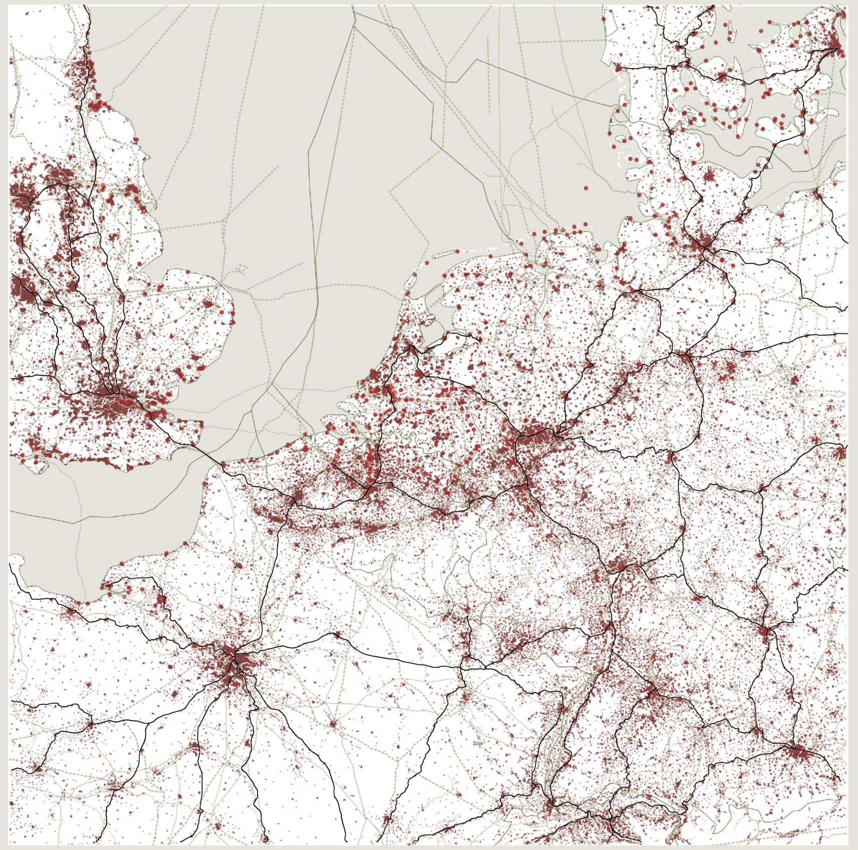


gas plants

POPULATION

The density of the network correlates with the population density across the continent. The places where many people live are places where energy is used and demanded greatly. What also outstands in this map is the presence of rivers in the large urban areas, for example the Seine flowing through Paris and the Thames flowing through London.

The complete energy network will emerge when the locations with the highest population density are added to the network map, as shown on the right. Along the river Rhine is a distinctable chain of populated areas, while the Rürhgebied seems like a node in the network



COMPOSING THE FRAMEWORK

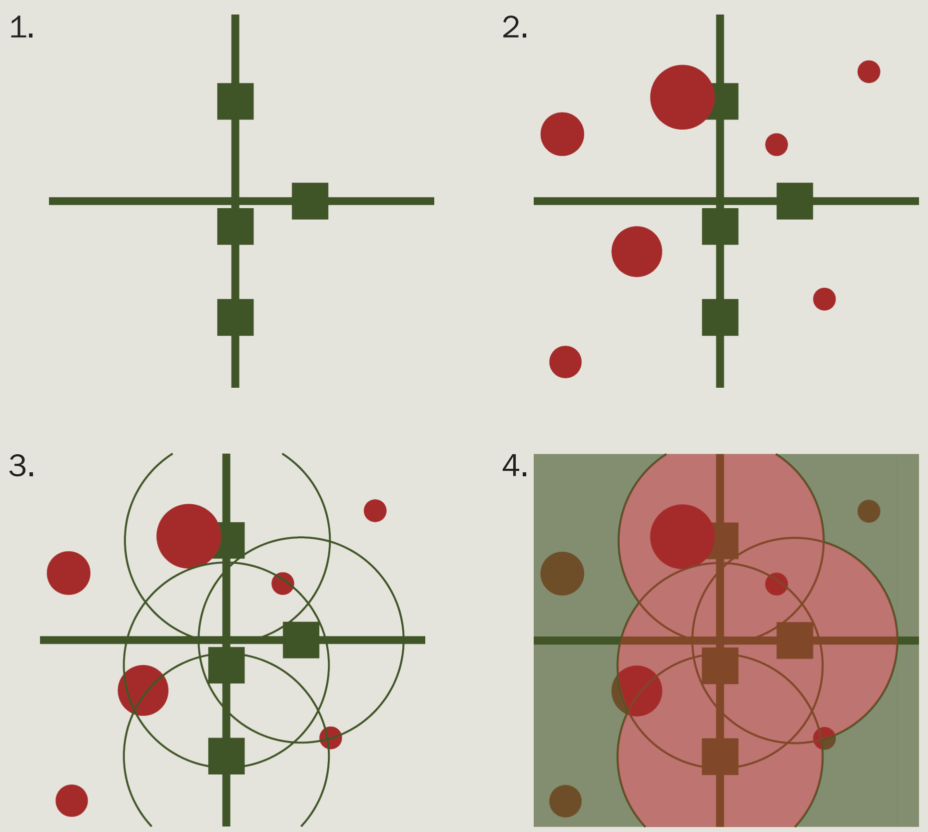
To determine the centralized and decentralized landscapes, the elements that have an influence should be highlighted. These elements are:

1. The network // A centralized network is composed of transportation systems that can move hydrogen from one place to another. Hydrogen can be transported by ship, train, pipeline and truck (Ustolin et al., 2020). In this scenario trucks will not be taken into account, because of its limited range of transport (Ustolin et al., 2020). Hydrogen is transported through the network, and distributed at the battery points. The battery points are places where large storages of hydrogen are located and from where the hydrogen can be distributed to the network. Different types of spaces can function as distribution points. With our goal to use existing infrastructure, three types of spaces emerge, which can function as battery or storage: Harbours, train stations and gas power plants. Harbours and train stations already are large energy hubs and are used to receiving, storing and facilitating big amounts of energy. Gas power plants can be transformed to hydrogen plants with some alterations (Prospects for using hydrogen in gas power plants are becoming tangible, z.d.).The composition of this model is visualised in a schematic diagram and a projection on a Northwestern European scale.

2. The demand // Another important element in this model is the demand for energy. The network and the battery deliver the energy according to the demand of the population. For areas with a high energy demand, its is important to be close to the battery or storage facility. The further away the area is from the battery, the less hydrogen it can get from these storages. This is because longer transportation is more costly and less efficient. In principle, other areas closer to the battery use the hydrogen before it gets to a location further away.

3. The range // The demand and supply play a big role in determining the range of the centralized system. The centralized system will have a certain range it can reach, which is determined by where the supply and demand are located. The locations near the boundary of the range are able to switch between a centralized and a decentralized system. Determining where the border exactly lies is a task that takes into account a lot of complex factors which are intertwined with each other.

4. (De)centralized // When the boundaries of the networks are defined, a system with a centralized and decentralized part emerges. The centralized areas get their hydrogen from the central network that distributes energy via harbours, train stations and powerplants that are connected to rivers, train tracks and pipelines. A large amount of this hydrogen originates from the sea where the surplus of energy that is generated by wind turbines gets transformed into hydrogen. The decentralized area is self-sufficient. It produces its own energy on land. Because these areas are not densely populated they have more space to place energy infrastructure such as windmills, solar panels and hydrogen storages on land.

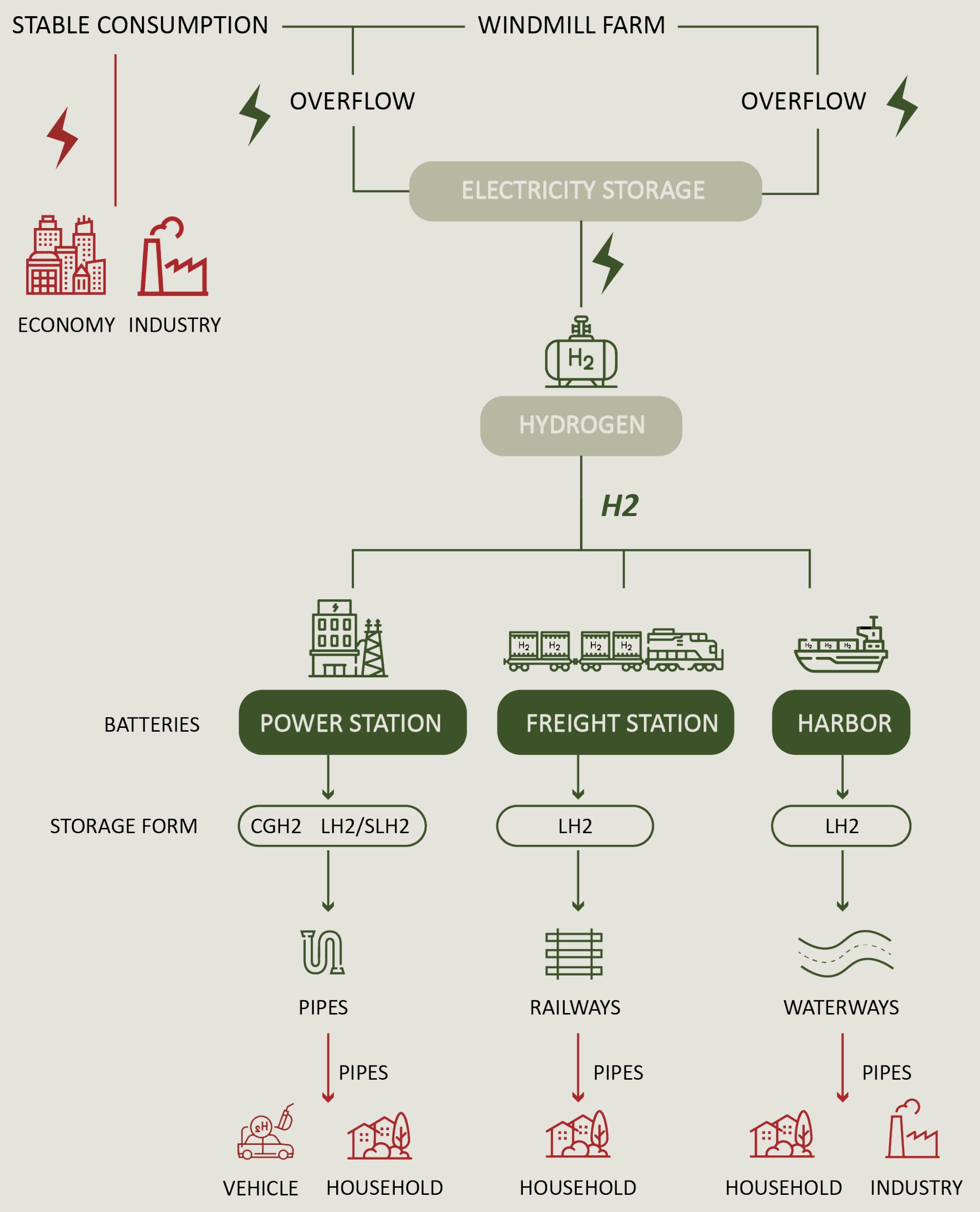


HYDROGEN FLOWS

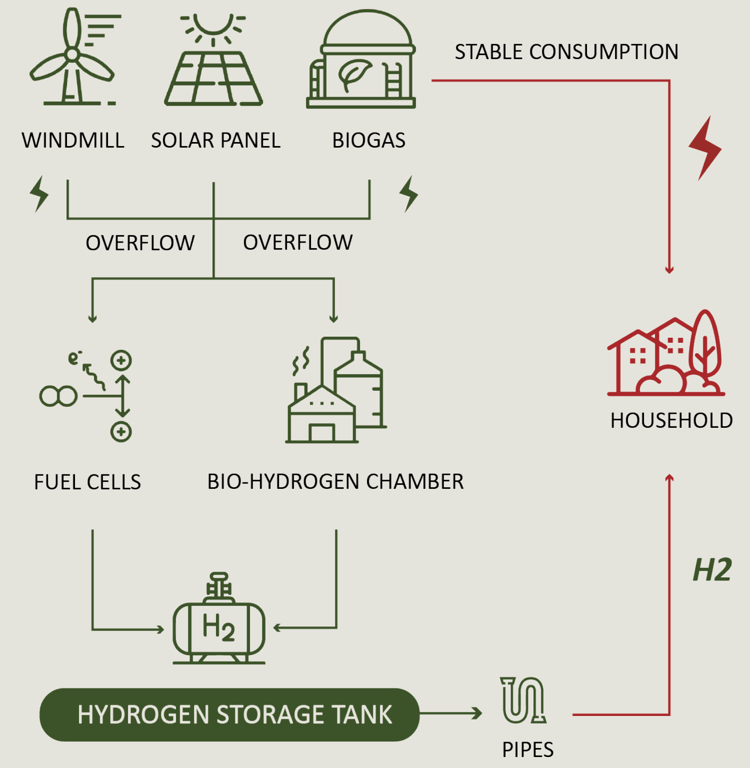
The following diagram shows how these two systems work. The first pertains to the centralized area, where energy is generated at sea and directed towards two outlets. A portion of this energy is utilised directly by households and industries, while any excess energy is transformed into hydrogen and stored in one of three available forms. To facilitate this process, we plan on utilising existing infrastructure and upgrading the necessary stations, which will effectively serve as the batteries required for hydrogen storage. This hydrogen will then be transported by pipes, trains, and ships to the endpoint of the centralized system, which includes households, vehicles, and various other industries.

In the second system, which operates on a self-sufficient basis, energy is generated by small-scale windmills, solar panels, and the biomass produced by local farms and fields. Any excess energy is stored in smaller batteries and transported through pipes to households as and when required.

CENTRALIZED NETWORK FLOW



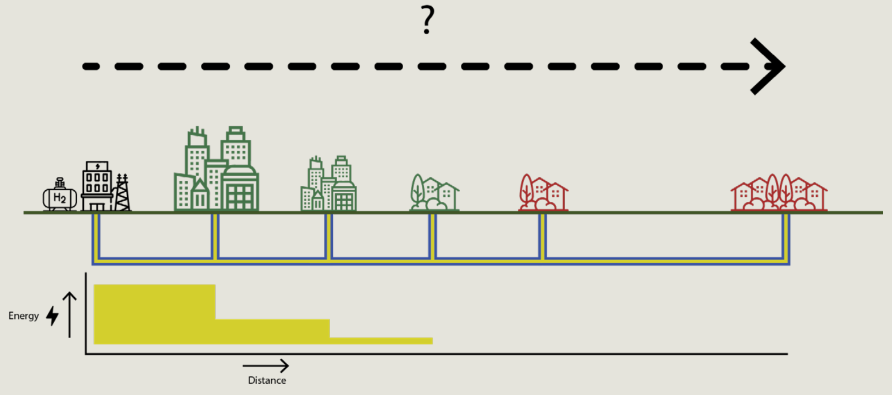
DECENTRALIZED NETWORK FLOW



DETERMINING THE BOUNDARIES

The centralized and decentralized structures form a complex system which is defined by numerous elements that not only influence the system, but also each other. To not get lost, the simplicity behind this complexity needs to be uncovered. Which elements define this system?

This system can be seen as a first come, first served system. Areas that are closer to the energy distribution point have a higher chance of getting more of their energy from this central distribution point, which is part of the centralized system. The example below shows this scenario. The hydrogen point gives a certain amount of energy to the system, the places that use energy take a share of this energy until there is no more left. The areas that are located beyond the area where the last bit of energy from the central system has been served, should be decentralized. This shows the importance of two elements, the amount of energy an area uses, and the proximity to a hydrogen point.

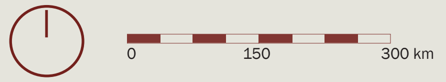


population

proximity

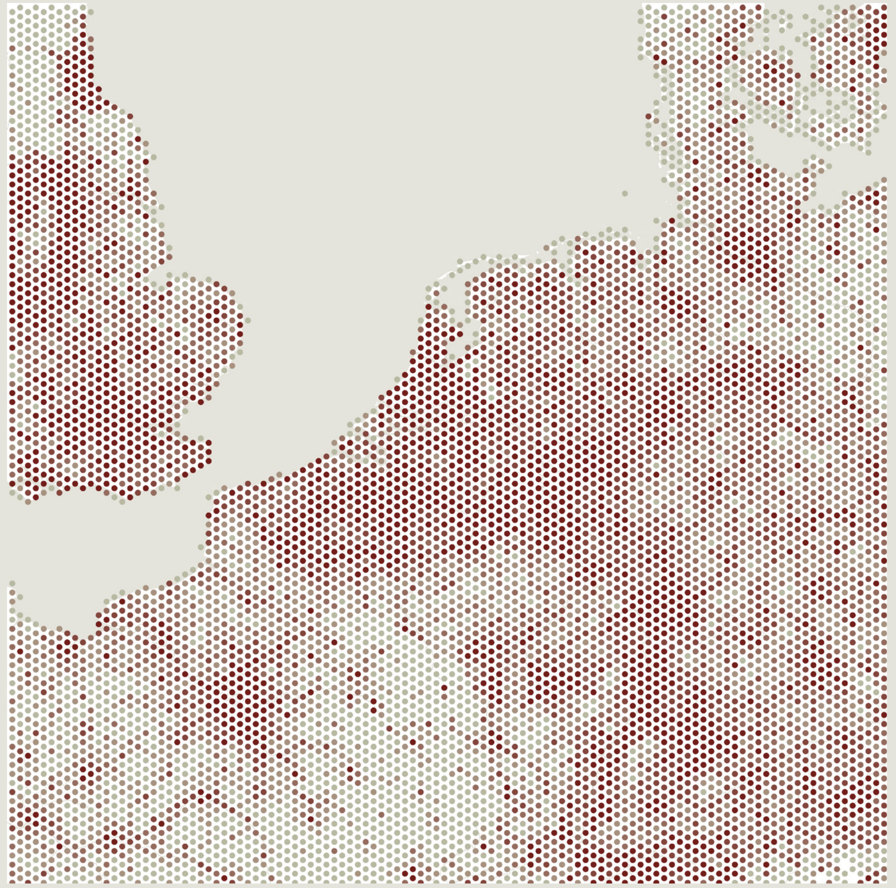
To be able to process the data, North-western Europe will be defined by a grid. Grid maps do not introduce biases due to different sizes of the regions, they make processing of data more efficient too. A hexagon grid is used in this case, because they represent geographic data in a better way, as they provide better coverage, a more natural representation of features, a more uniform cell size, and less directional bias.

To show energy in a spatial way, the population data of the concerned area is taken into account. A person uses a certain amount of energy, combining this with the amount of people living at a certain location will result in the information on how much energy is being used per hexagon in the grid. The second element, proximity, can be calculated by measuring the distance to a hydrogen storage or to the infrastructure of the network. This can be done by measuring the distance from every hexagon to the nearest hydrogen storage and to the network. The distance to the network and to the storage point is calculated seperately. The following maps show the result of these calculations.



POPULATION

PROXIMITY



RASTERISED POPULATION

RASTERISED PROXIMITY

This information does not yet result in what the reach of the centralized area is. Every area now has this information connected to it. When plotting this information on different graphs, certain patterns can already be spotted in the data. By making use of a clustering algorithm, clusters can be formed in the data. The algorithm used, K-means, aims to partition a set of data points into a certain amount of clusters. It does this by repeatedly assigning data points to the closest cluster centre, and then updating the cluster centres based on the new assignments. The process is repeated until the clusters no longer change.

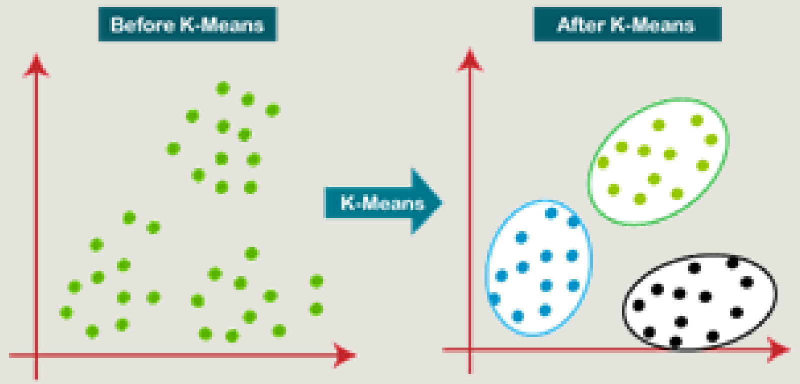
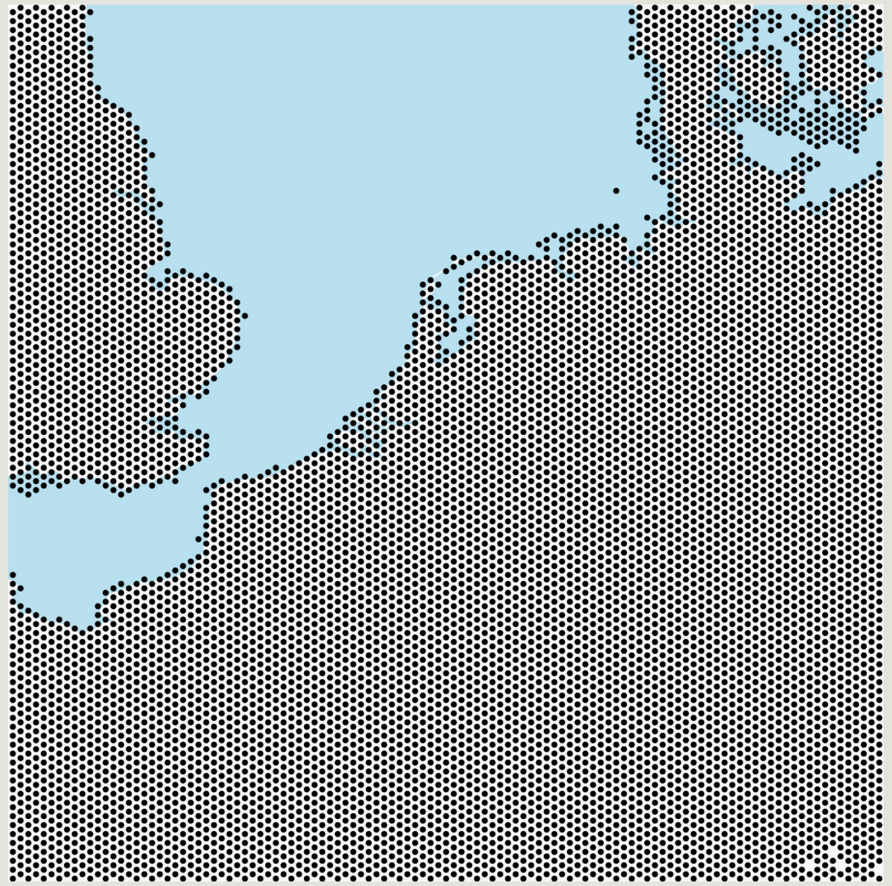
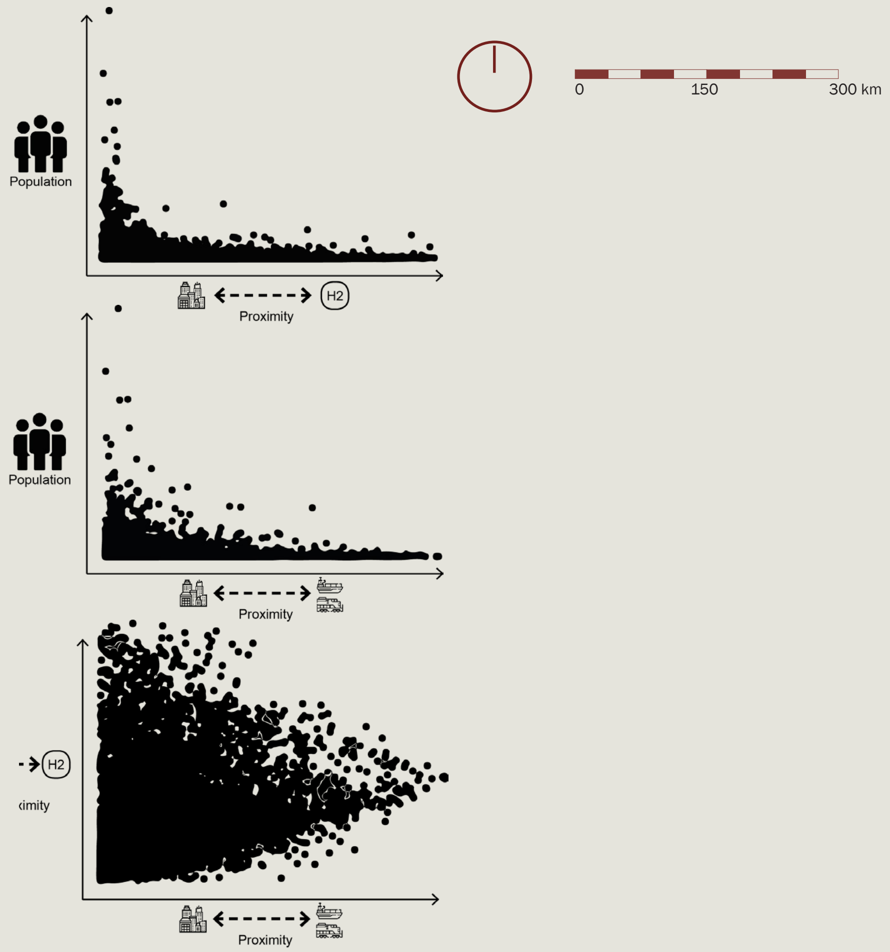


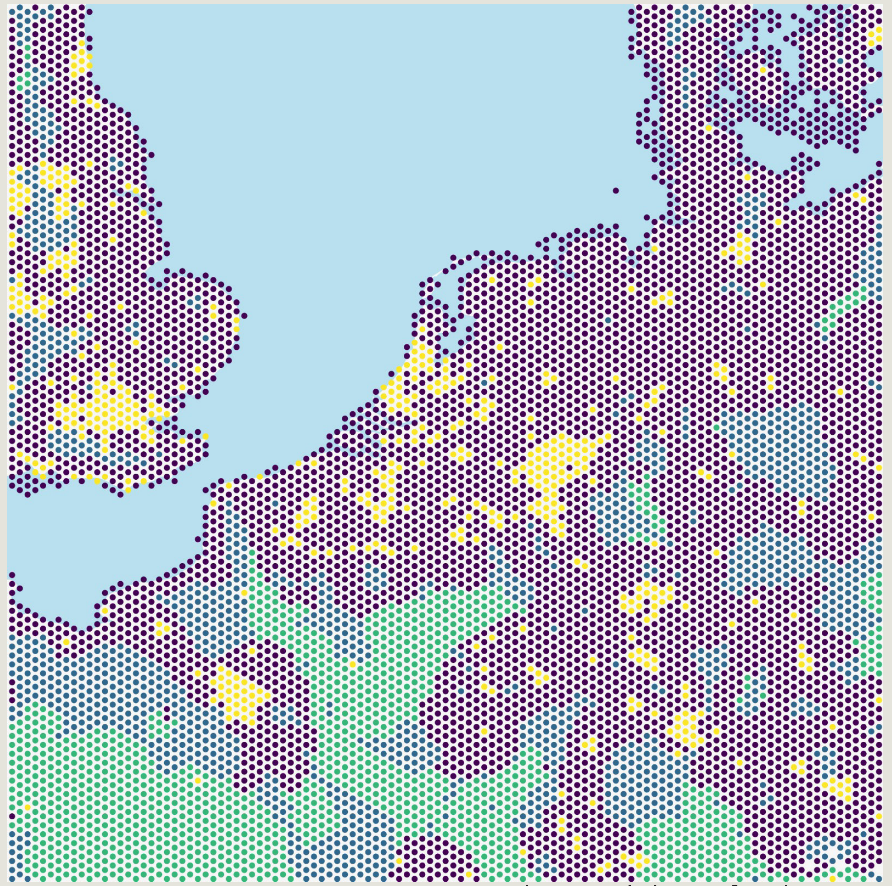
image from (K-Means Clustering Algorithm - Javatpoint, n.d.)

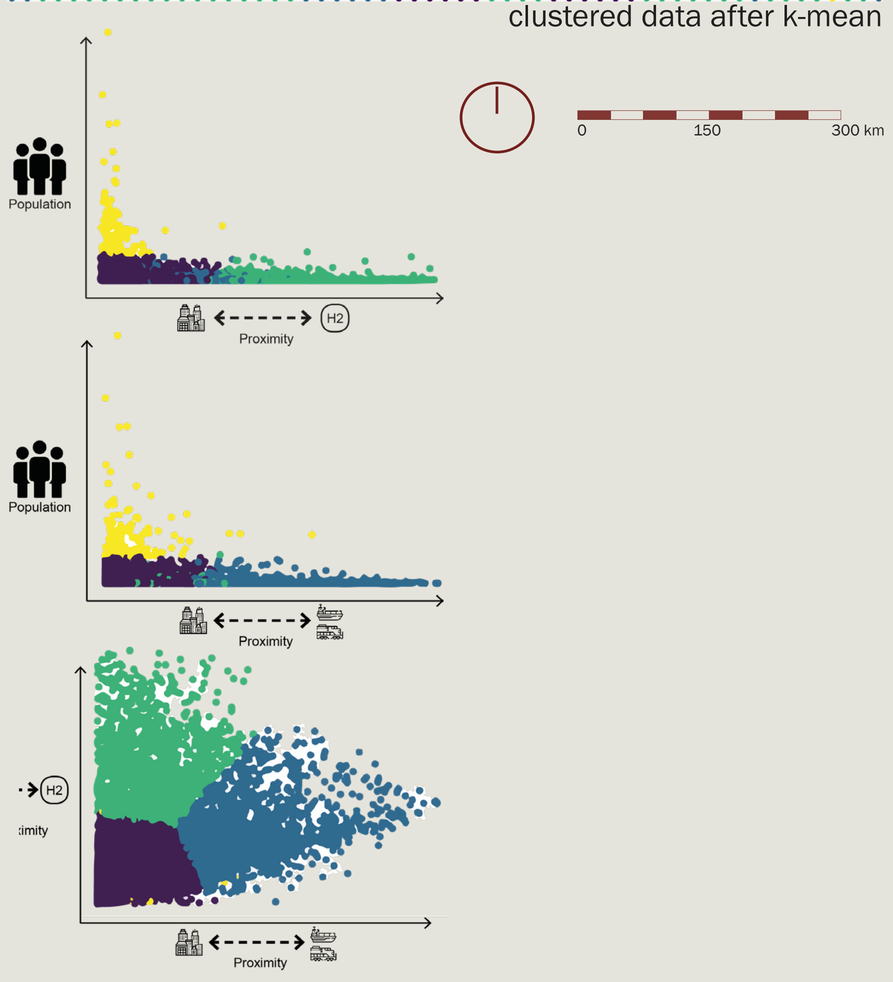
To know how many clusters should be used, the elbow method is used. The elbow method is a way to determine the optimal number of groups/clusters to use in K-means clustering. The method starts by trying different numbers of clusters and calculating how compact the data points are within each cluster. Then, results are plotted. A point in which adding more clusters does not make much of a difference in how compact the data is, is a point that is called the "elbow". It shows how many clusters to use. In this case, four clusters is the optimal amount.

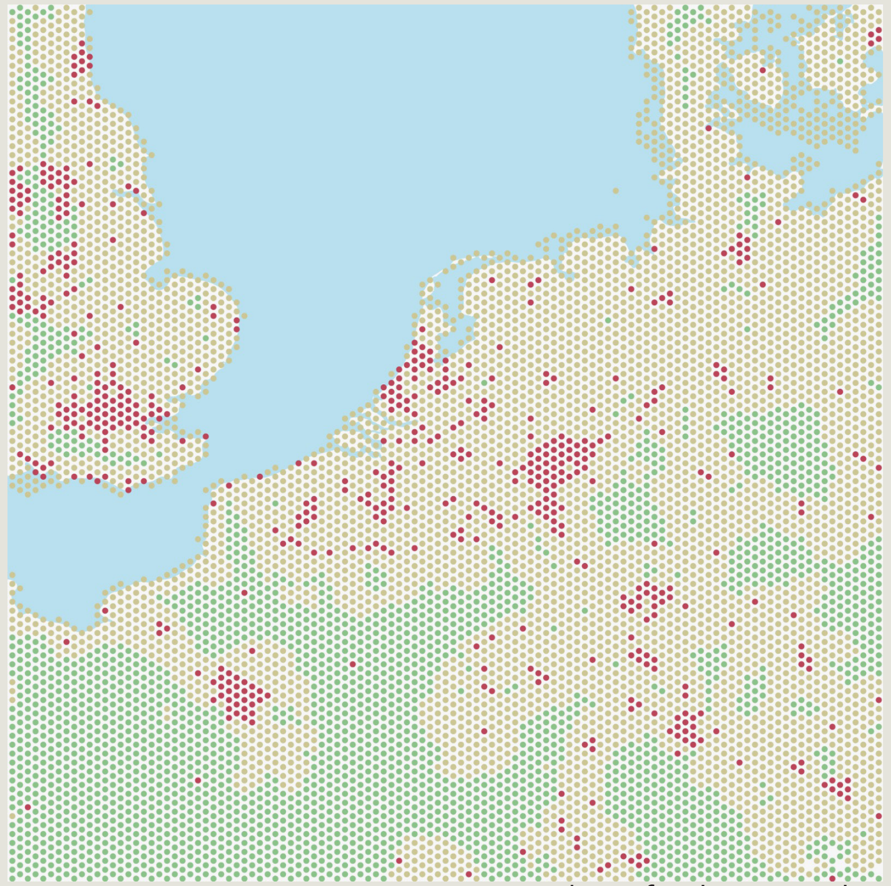
The K-means algorithm can generate four clusters, this results in the middle map. The four clusters show different areas on the map. Through the analysis of the map generated by the algorithm, there can be concluded that there should be three types of areas. Centralized, decentralized, but also an in-between area. The in-between area is an area where both the centralized and decentralized system could be active. The distinction between centralized and decentralized is not a very tight line. In reality it could change at any moment because, of the dynamic supply and demand. The final map shows the three systems. The inbetween area is the area gradually goes from centralized to decentralized, consisting of a balance of both.


non-classified data




clustered data after k-mean




data after interpratation

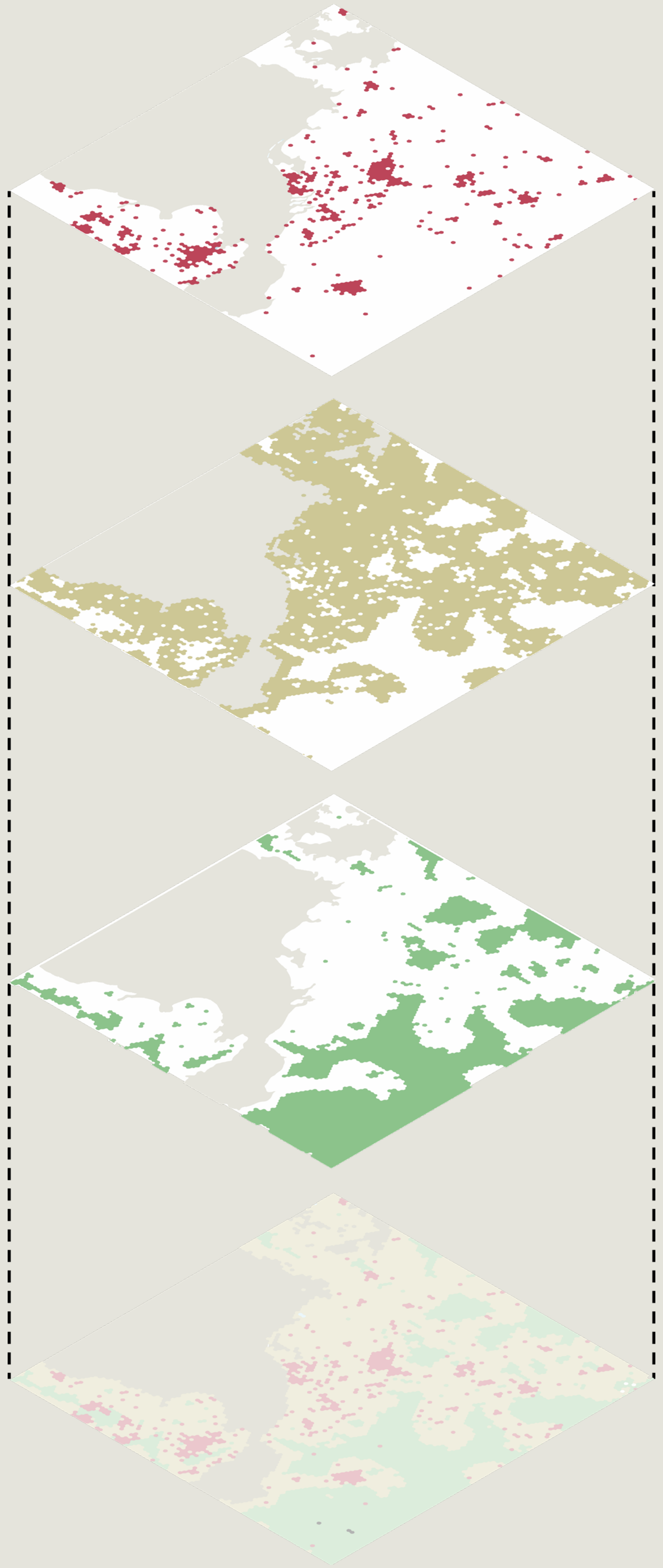
It is clearly visible that the centralized areas consist of the areas with the highest human population. The decentralized areas are the rural areas with less people. It is also interesting to see that the Netherlands, besides a small part of the Veluwe, does not have a fully decentralized area.

Each type of area has their own qualities and vulnerabilities. One is not necessarily better than the other. Hot summers can be beneficial for decentralized areas that can store a lot of the energy they do not use from solar panels. At the same time, it can be a problem for the centralized network when rivers dry up and the delivery to the cities becomes harder. This also shows the importance of an in-between area that can function as a resilient layer because of its diversity in sources of energy.

Centralized areas are areas where a lot of people live. They have a close proximity to a hydrogen storage and to a hydrogen network. These areas are often big cities or areas surrounding big cities.

The inbetween areas are fairly inhabited. They are a bit further away from the hydrogen storage and network than the centralized area, but closer than the decentralized area. They often consist of areas that are a combination of medium-sized towns and rural space inbetween them.

Decentralized areas are sparsely inhabited. For a big part, they consist of farmland and nature, with some villages in-between them. They have a big distance to hydrogen infrastructure, making being self-sufficient the best choice for these areas.

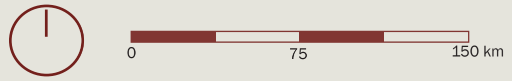


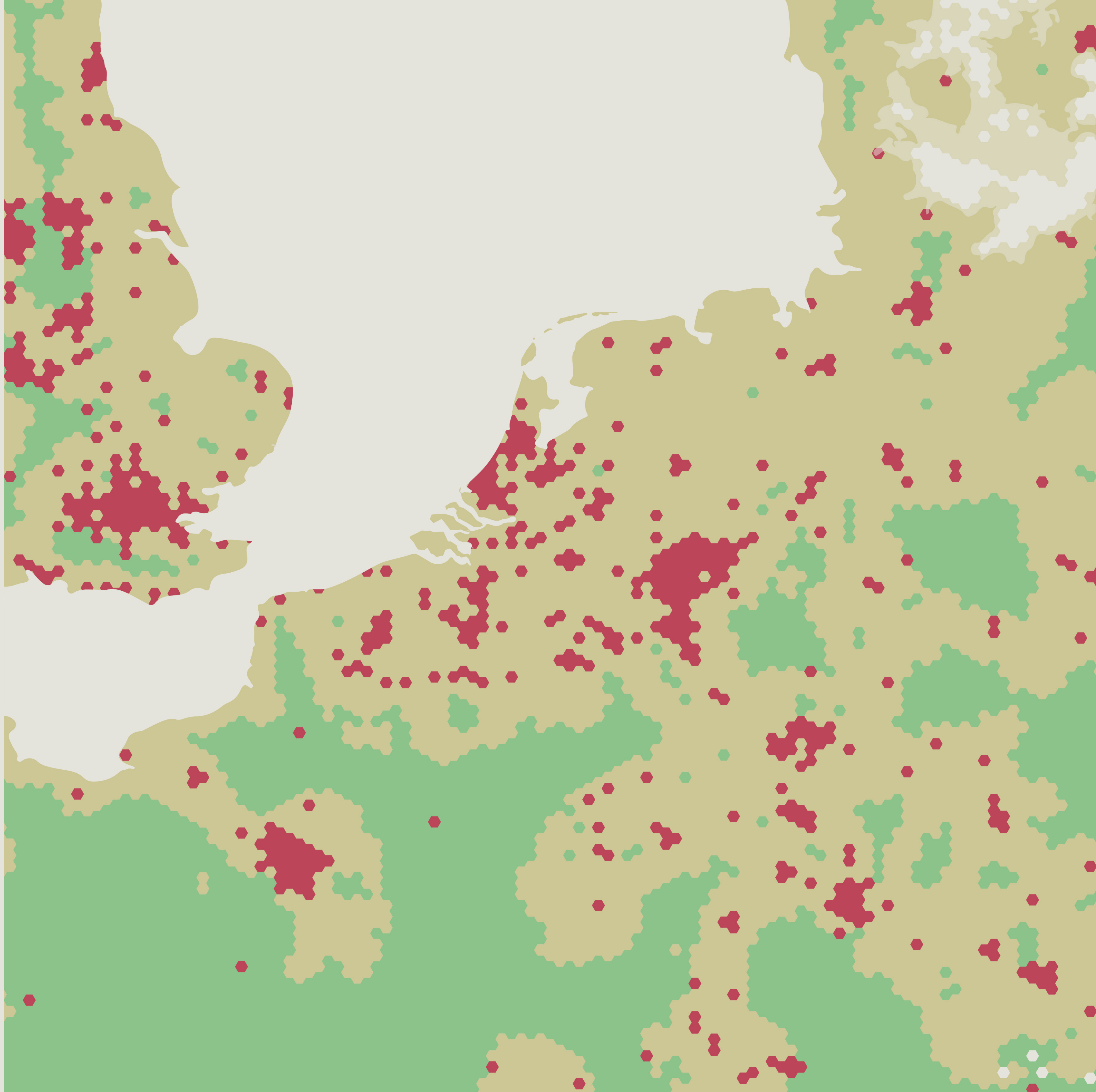
water

centralized network

in-between network

decentralized network





THE INFLUENCE OF LAND USE

The result of the model results in three types of energy landscapes, but this is not the only element influencing the future of the area. Every area/hexagon has an existing underlying landscape which is already there. The Corine Landscape Cover data is used to identify the current land use. The data divides the land in three types of land use: Urban, Agricultural and Nature.

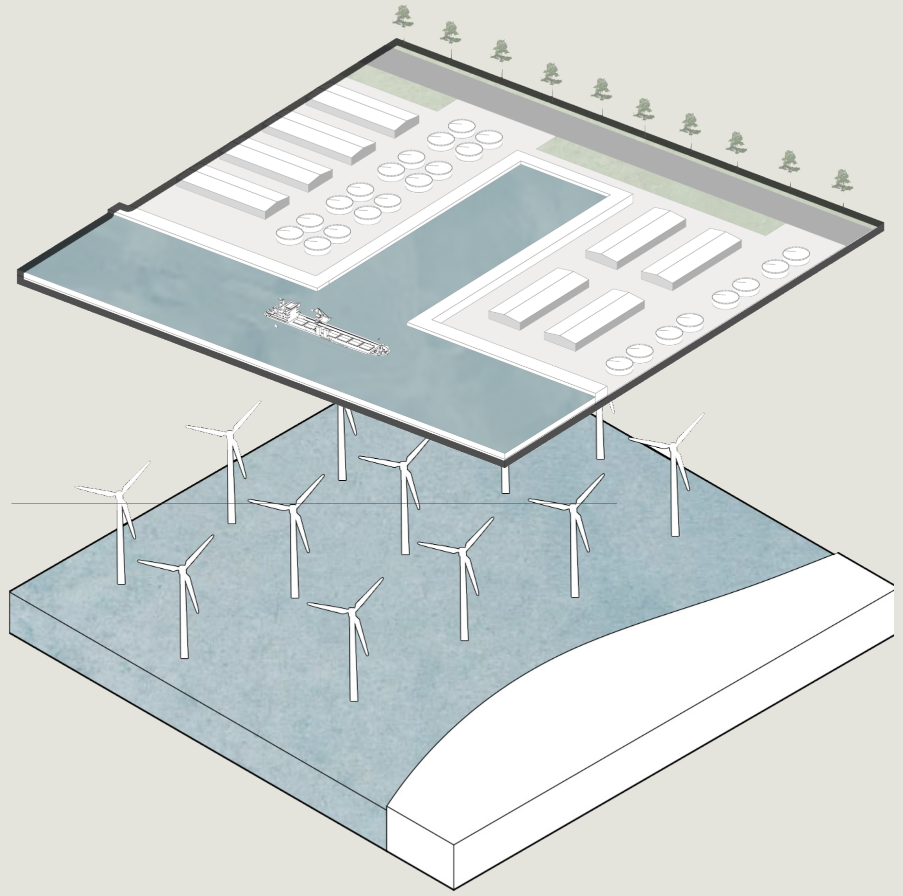
Combining the current land use with the landscape classification of the model results in different types of categories. The current environment should be leading in deciding how the future energy system should be implemented. However, the precise result of every area should be a carefully balanced decision of both needs.

CHARACTERISTICS OF ENERGYSCAPES

When the three energy landscapes are combined with the landuse, areas with different characteristics emerge.

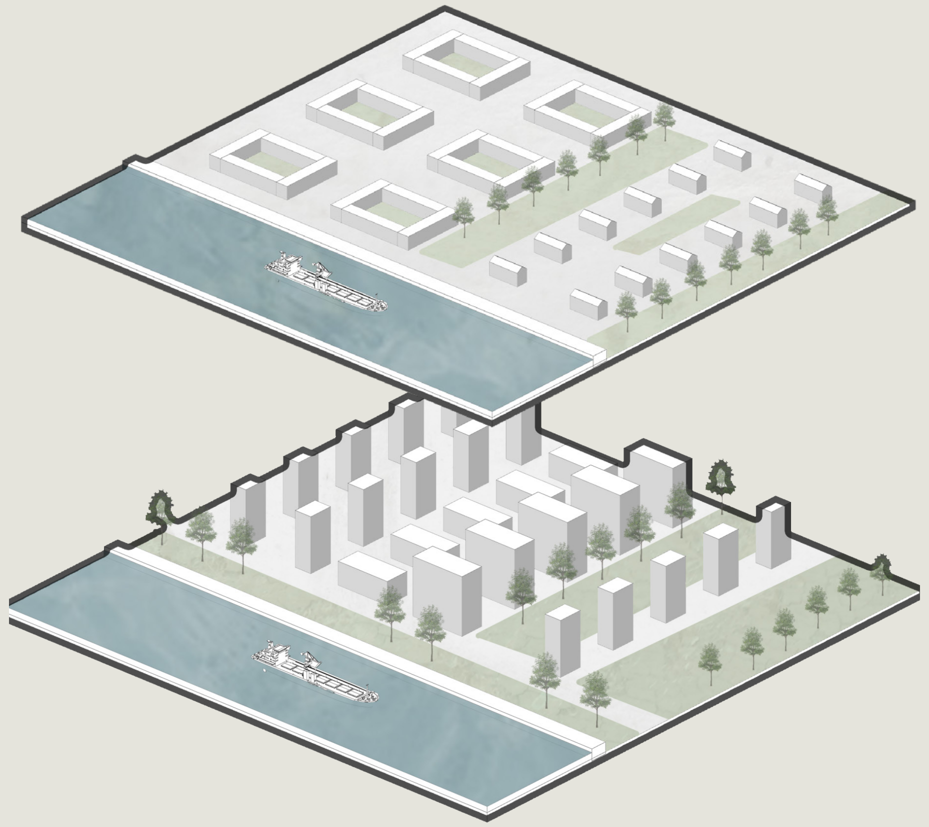
The land use of a centralized area can be divided into two types, a production landscape and a consumption landscape. The production landscape consists of areas that produce, transport or store energy. The production areas control the supply. Typical landscapes in this category are power plants, harbours, freight stations, but also the windparks on the North sea.

consumption < production



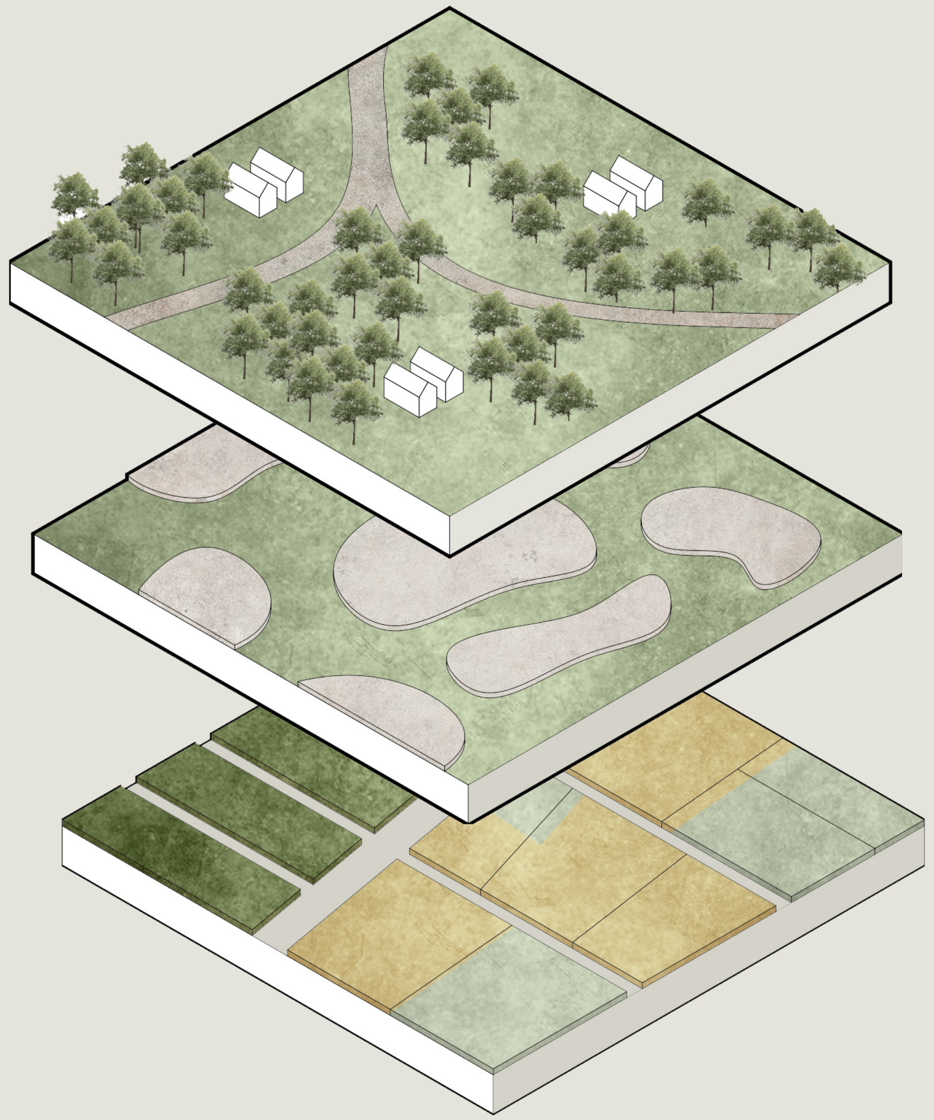
Consumption landscapes are areas that consume the energy that comes from the production areas. The consumption landscapes consist mostly of city, towns and industrial areas. The consumption areas control the demand. Typical landscpaes in this category are cities, towns and industries.

consumption > production



The land use of decentralized areas is classified in one type, where production and consumption are equal. These areas mostly consist of nature areas, villages and agricultural areas. Different type of energy elements can be found in this landscape. Typical landscapes in this category are villages, nature and agriculture.

consumption = production



CONCLUDING THE NETWORK

After analysing the various aspects of renewable energy, fossil fuels, and hydrogen, there can be concluded that transitioning towards a sustainable energy system is imperative. There is no doubt that renewable energy will be the future, but at the same time it is also certain that it requires large amounts of space. A way to use less space of our valuable living environment, is using the North sea as a site to place the energy generation infrastructure, such as wind turbines. This also has downsides, as the vibrations of wind turbines might disorientiate marine mammals.

While phasing out fossil fuels gradually and replacing them with sustainable energy sources, new challenges arise. Energy generated by sustainable sources is often connected to the patterns of the climate and not to our usage patterns. To not waste the surplus of generated energy and also have energy at times when not enough of it is being generated, finding a way to store energy is essential. Hydrogen can play a crucial role in stabilising the unpredictable energy flow generated by renewable sources, without any $CO2$ emissions. Another positive aspect of hydrogen is that it can be implemented with existing infrastructure, which is a sustainable option. The current gas network can be transofrmed to carry hydrogen instead.

The shift towards sustainable energy will require a change in land use, with the emergence of production and consumption areas. This will lead to the establishment of different energy landscapes with unique characteristics. The created model brings together elements, proximity and population, which are determining factors in deciding in what kind of system an area belongs to. It is important to consider the location-specific factors while deciding on the type of energy system. The local land characteristics of the surface influence the model, and vice versa.

In North-western Europe, there will be three energy system landscapes, decentralized, centralized, and in-between. Each of these models has its own advantages and disadvantages. Therefore, it is important to assess the characteristics of each area when taking into account outcomes of the energy system model.

Transitioning towards a sustainable energy system is a complex process that requires careful planning and implementation. However, it is essential to move towards sustainable energy to mitigate the impact of climate change and ensure a better future.

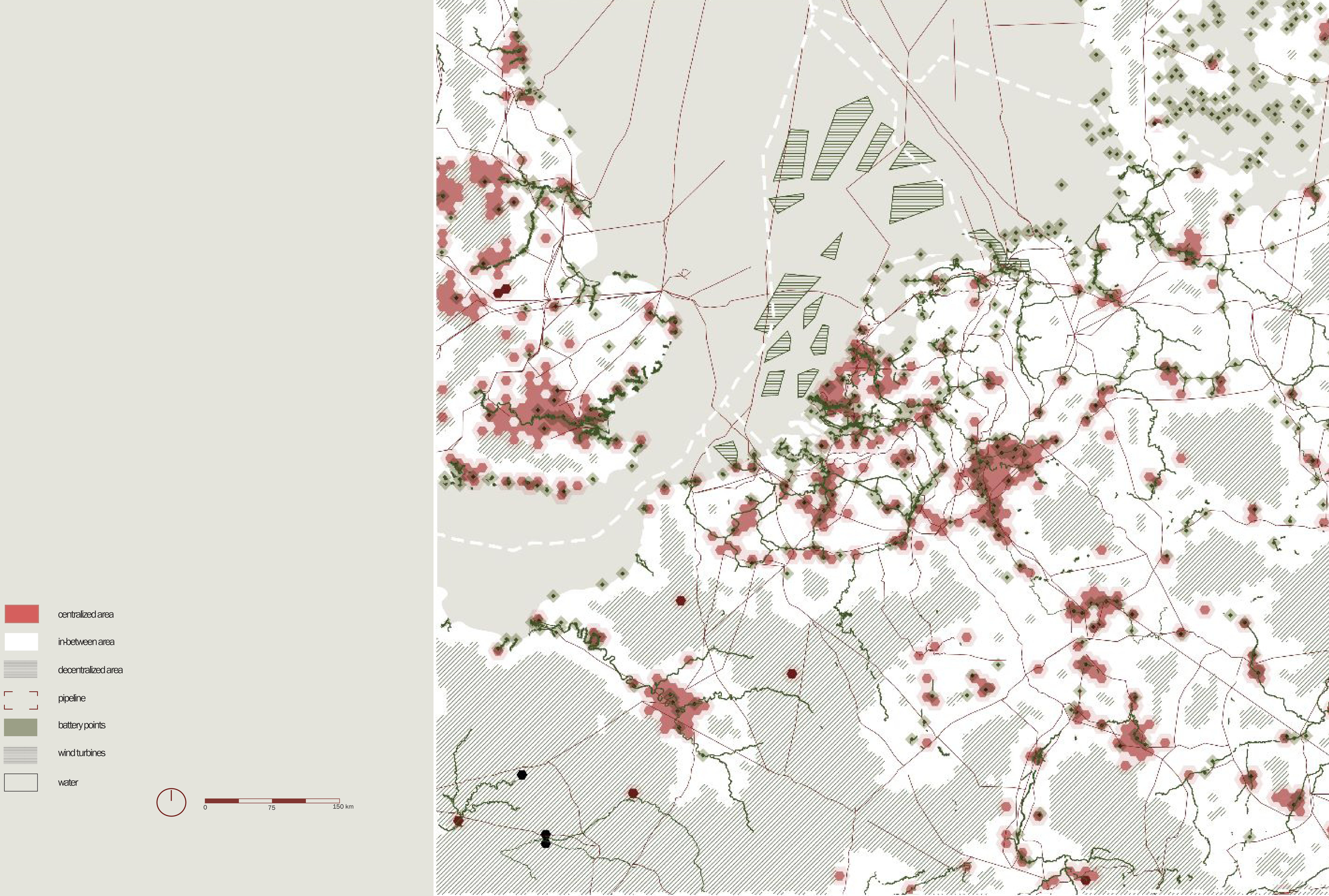
VISION

WEAVING ENERGYSCAPES USING EXISTING THREADS

WEAVING ENERGYSCAPES

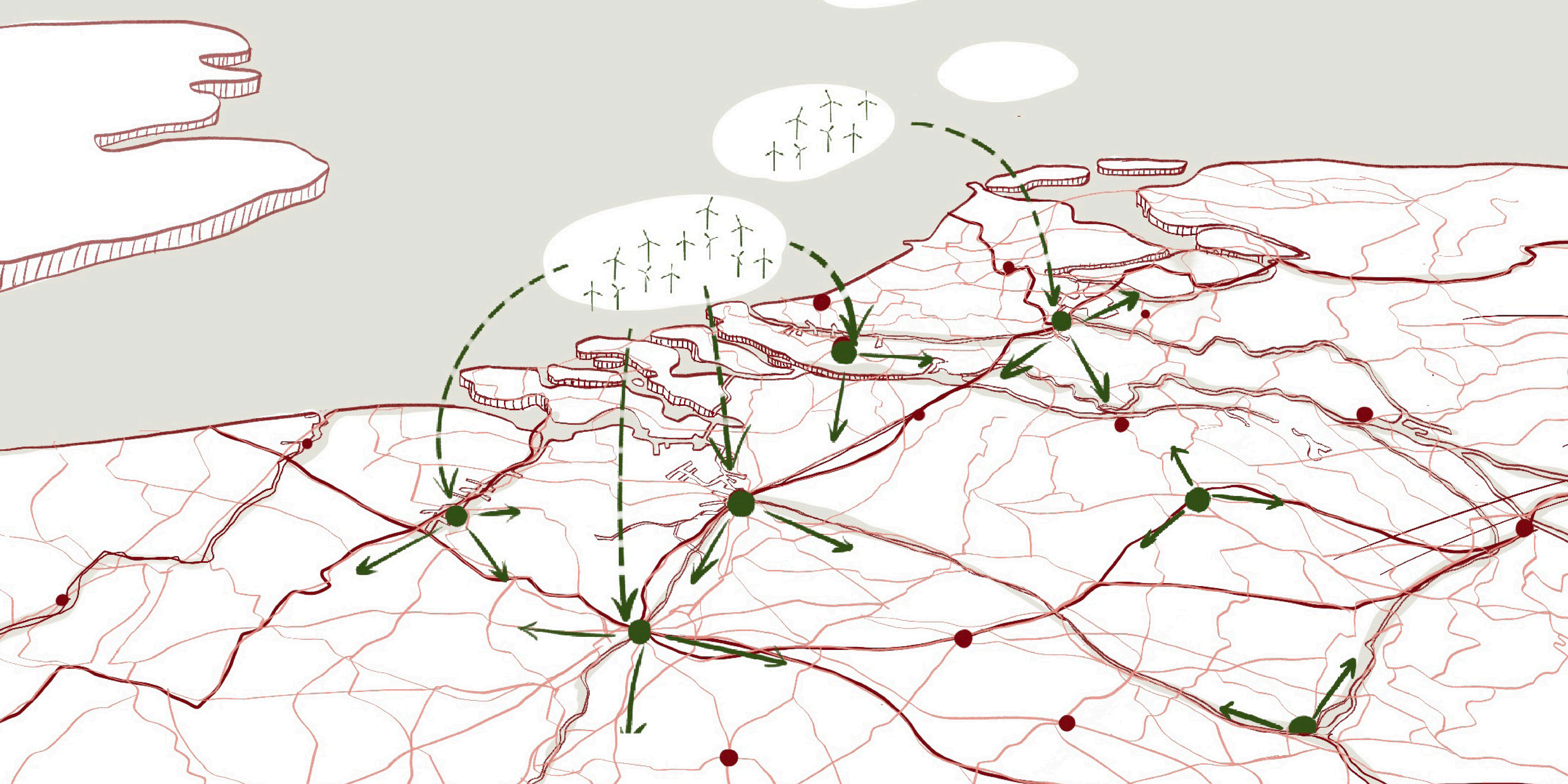
The vision map outlines the energy generation plan for the entire region of North-west Europe. This vision aims to generate a majority of the energy on the North Sea. The parts marked in red on the map are locations that typically house the largest population and industrial hubs. The energy generated on the North sea will be distributed directly to the electicity network, while any surplus of energy will be stored in batteries and transported to the central and intermediary areas, as far as the infrastructure reaches. The green hatch denotes the self-sufficient area where energy will be produced by local sources such as windmills and solar panels.

The entire energy system will be interwoven by an intricate of infrastructure in the form of pipelines, water, railway systems and harbours.



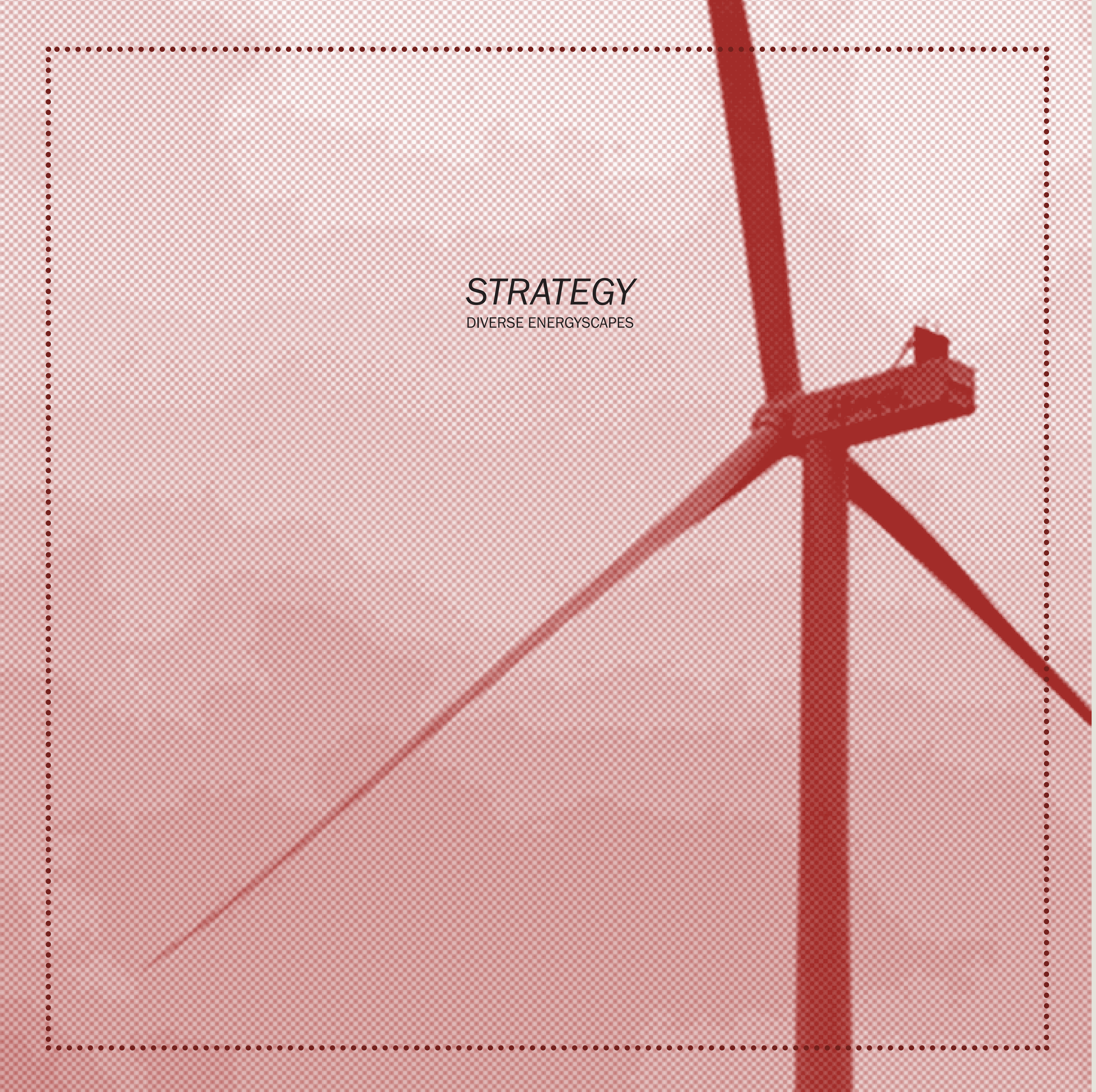
CORE VALUES OF ENERGYSCAPES

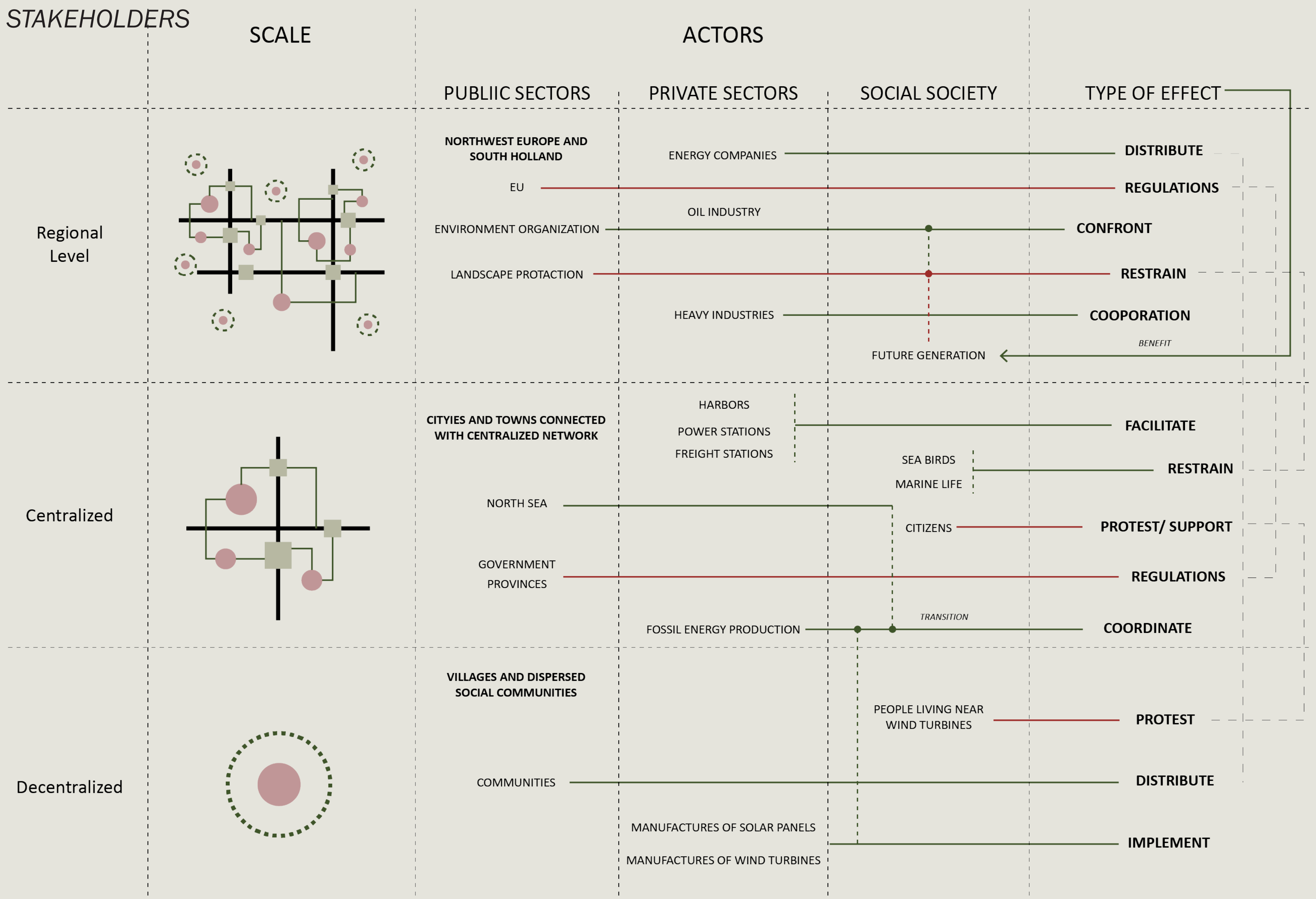
	PRESERVATION	JUSTICE	RESILIENCE	AVAILABILITY
	A right balance between urbanisation and nature. Usage of the right system in the location.	Energy should be accessible and reliable for every citizen.	The energy flow should be stable and be resilient to extreme weather conditions..	A system that has the ability to supply energy to all people
REGULATING & ENCOURAGING	Laws should be enacted to protect existing natural areas, as well as appropriate policies to guide natural growth areas and compensate residents who live in villages that may disappear in the future. In addition, a new North Sea use regulation is needed.	Laws should give the citizens the right to have a reliable energy source. Industries will have a more market oriented price, to stimulate consciousness and efficiency. This should be implemented on big scale to prevent the migration of industries. To also stimulate a more concious energy usage for citizens taxes will be implemented for big energy users. Infrastructure investments by government, To stimulate energy production in rural areas subsidies will be given to start initiatives on different scales, from individuals to whole villages	By making policies/laws that quantify the amount of storage needed per area/municipality/residents governments will know how much storage they should have. This will be based on the energy usage of the inhabitants. This also enables a just distribution of energy in the normal or extreme situation. Centralized regulating top-down, decentralized regulating bottom-up, stimulating corporation forming of citizens in decentralized areas, governments should facilitate big energy projects for centralized areas, stimulate renewable energy production by giving the ability to sell energy back to the network but with regulations. Making a lot of private profit by selling energy will be banned.	Every area, centralized, inbetween and decentralized, will have their own policy. People will get direction from the government to take the right steps in this transformation. This help will also take place in the form of subsidies for building batteries on the right places, for example helping decentralized areas in supplying the right tools for a self-sufficient energy system. Making the right places suitable in the right will also contribute too less transportation of energy , so also less loss of energy.
SHAPING	More windmills will be put at sea and more nature even agriculture landscape will be protected, this leads to less of an impact on the living environment of people, therefore leading to less protests. The nature will expand to the space with few people, finally becoming the green corridor. With these measurements the infrastructure also has to be strengthened.	Energy will be rationally distributed to all users, but the resources of the land owned by different areas are not the same, so in some places where land is scarce, the energy will be transported from nearby energy-producing places with abundant land resources. Windmills that requires a lot of area, will be built in open agricultural areas and transported to neighboring energy-using sites through a better network.	To have a more resilient energy infrastructure there will be bigger hydrogen storages, in centralized and decentralized areas. In the decentralized area, more batteries will be built near by the windmills and villages to supply enough energy.	There will be a stronger and more diversely connected network between centralized and decentralized. More batteries and new pipelines connected to the big batteries will be built in centralized and in-between area to supply the energy for local people. There will be small scale pipelines in the decentralized area to transport the energy, mainly electricity, from the batteries to neighbor villages.



STRATEGY

DIVERSE ENERGYSCAPES





The government has a crucial role to play in the centralized networks, since it must enact laws and manage the interests of both citizens and energy firms. To improve the network, sufficient funding is required. Since the energy for the transitional region is generated both centrally and independently, manufacturers of solar panels and wind turbines contribute to the system's success.

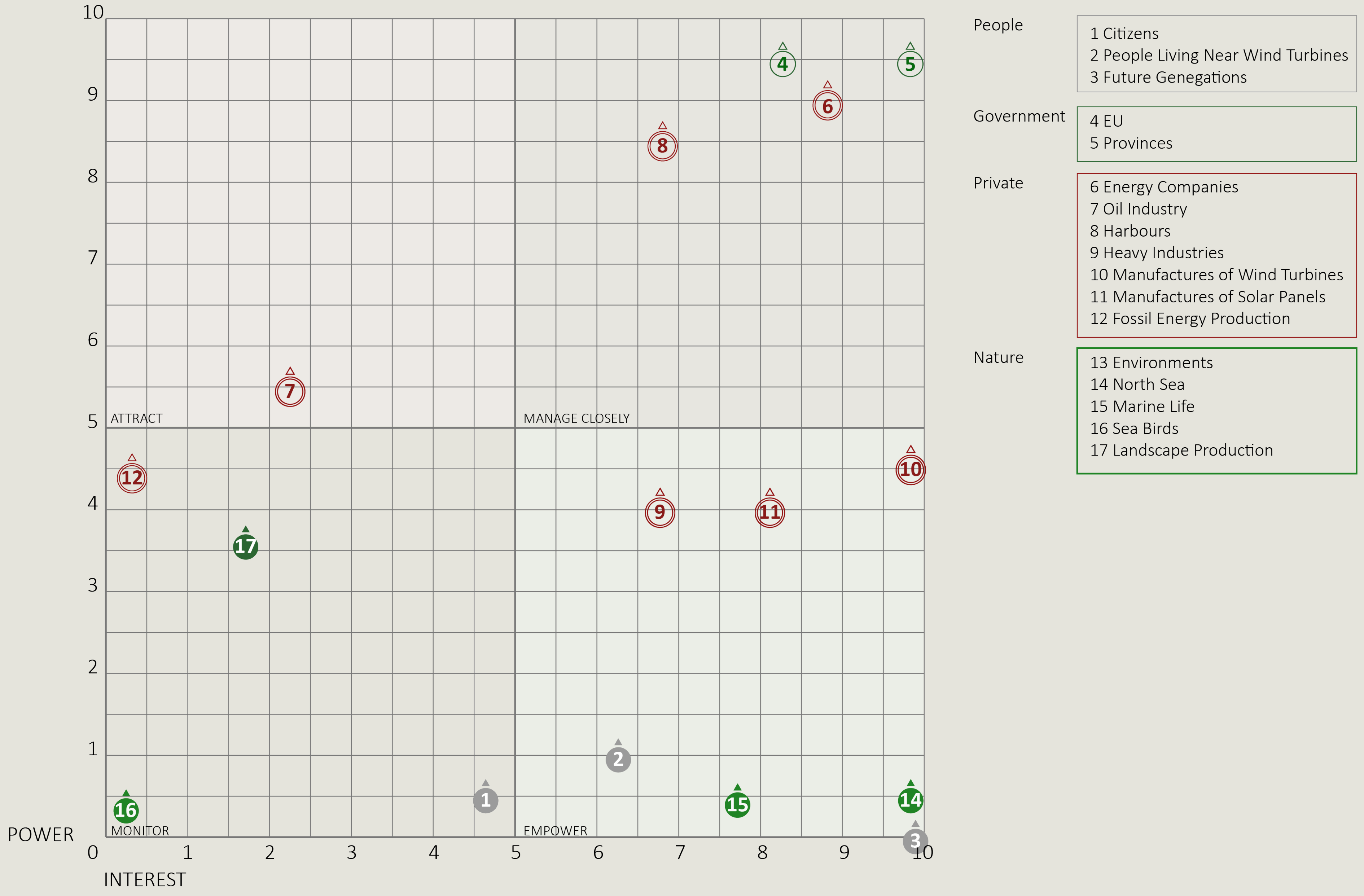
Cities with a centralized system are required to improve the network while also taking into account smaller batteries, like freight depots and power plants to place new infrastructure, such as hydrogen tanks. Little communities in the decentralized region should be self-sufficient, and there will be space for installing rooftop solar panels and individual windmills. For the natural area, we intend to establish boundaries to protect it.

In decentralized areas, where a self-sufficient approach to energy production is happening and where villages are dispersed, communities and individuals play a dominant role. Depending on the size of the village and land use, there will be decided whether a community cooperative approach to production could be adopted, a process that requires the cooperation of the inhabitants and also results in the urbanisation of the various villages.

STAKEHOLDER MATRIX

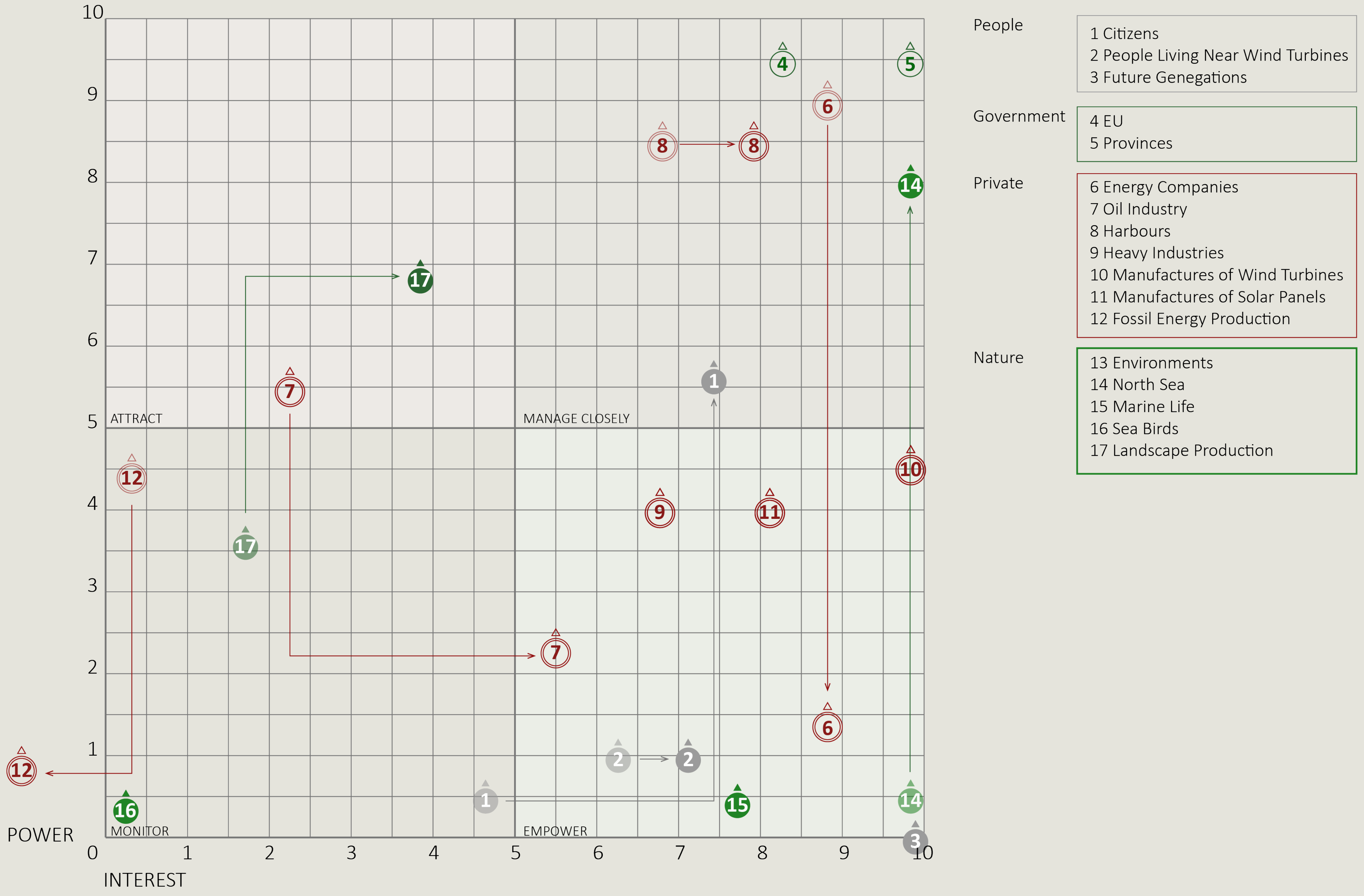
In order to understand how power and benefits are distributed among the parties in the energy system, this table was created. Through this table, the basic needs and positions of the stakeholders when facing the energy transition become visible. Some potential conflicts are highlighted, too.

In the current fossil-based energy system, the private sector occupies a position of power and authority, it has access to a large number of benefits. The public is not taken into account and is neglected. They have multiple demands and grievances, but are always in a weak position in the system, because of the lack of power. Their rights are easily violated. The natural part is even less taken into account. Natural factors such as marine life, seabirds, and the North Sea are often not a priority in planning. The public sector is an interesting point, as it has the power and authority to set existing policies and give directions for the future.



In the new hydrogen energy system, the power and influence of private sector entities associated with fossil fuels will witness a significant decline, thereby forcing them to either transform or face closure. However, the associated benefits will now shift towards the private sector that is engaged in hydrogen-related activities. Ports that offer hydrogen production and storage, and manufacturers of windmills and solar panels that facilitate renewable electricity production. In the future, citizens can expect to recieve more energy subsidies through the use of hydrogen, and all policies and planning will be designed with greater sensitivity towards the needs of future generations.

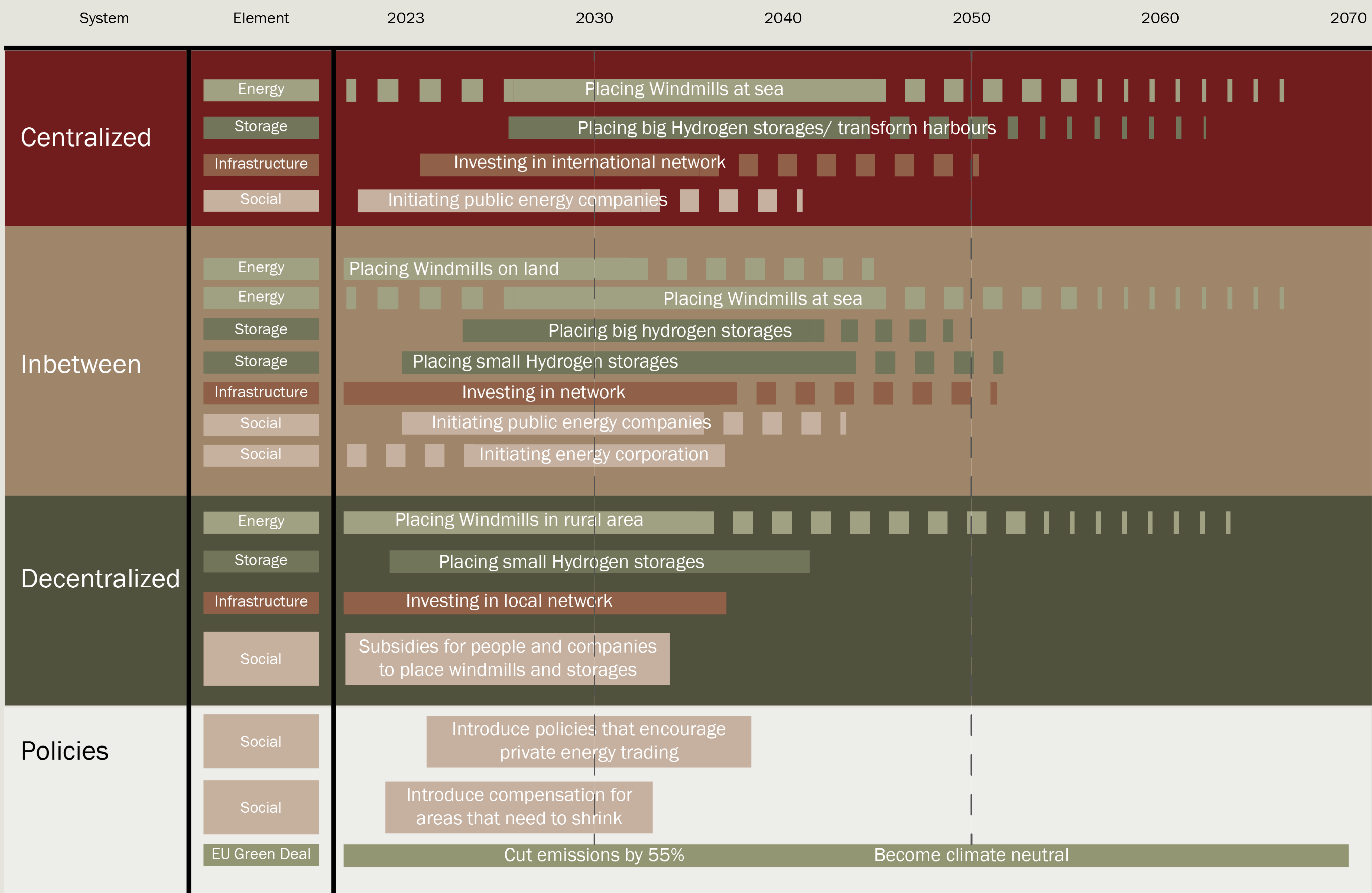
Moreover, the future energy system will not only account for energy usage, but also contribute towards shaping the landscape, thereby making hydrogen energy landscapes a crucial aspect of the future horizons.



PHASING OF IMPLEMENTATIONS

Implementing the steps that need to be taken asks for the right timing. The network should be able to transport the energy at peak hours, while at the same time enough renewable energy should be produced to actually manufacture the needed hydrogen. Simultaneously, the people need to be motivated at the right moment to support the transition. The differences in areas also influence the phasing of the measurements.

Decentralized areas have more of a bottom-up approach, which can start today. The centralized area asks for a more top-down approach, which is more reliant on big projects at sea, harbours and powerplants. The further we look into the future, the more unreliability comes into play, as the share of renewable energy increases. Yet, with this vision the energy network will become more stable, considering the element of resilience hydrogen brings.



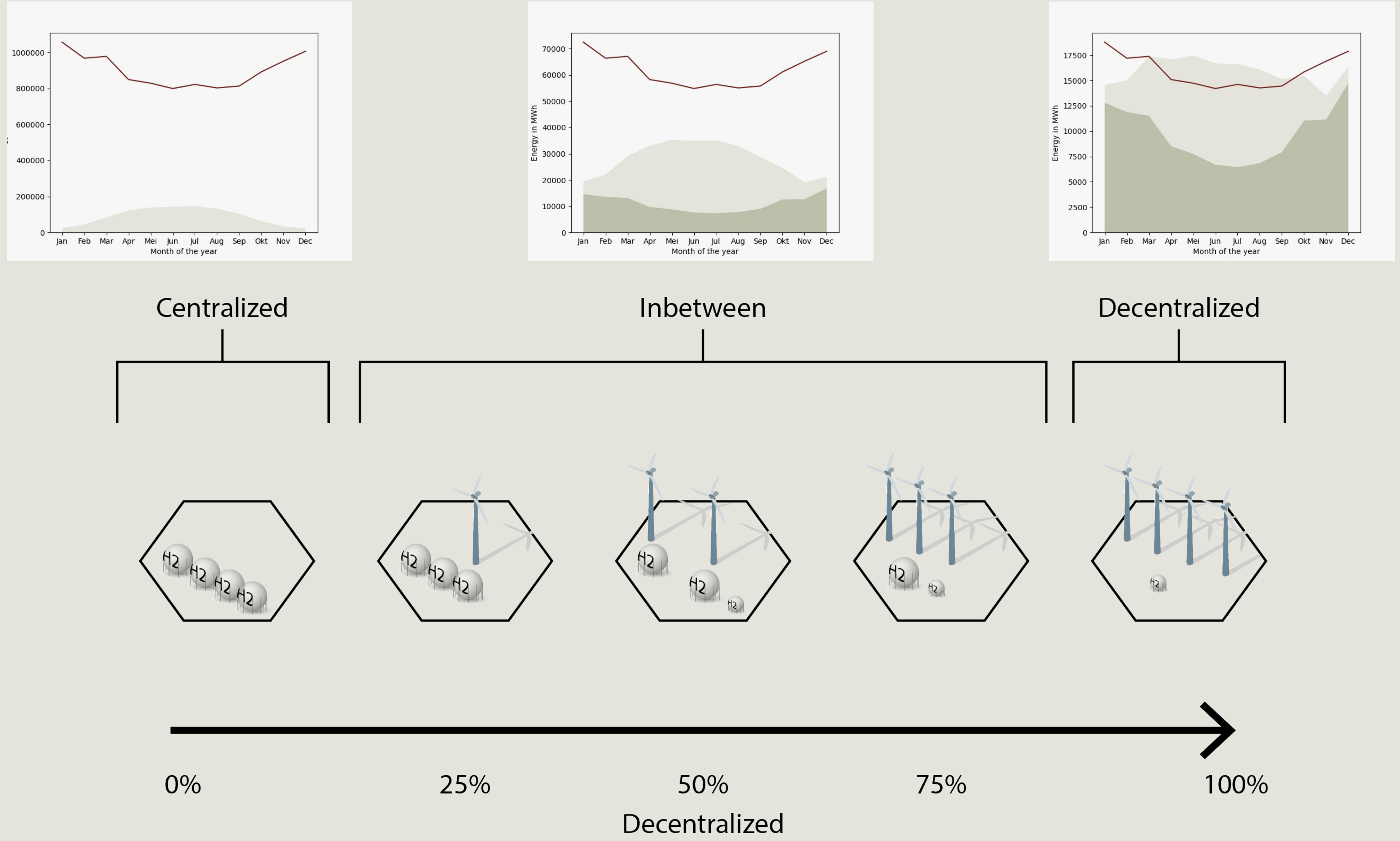
COMPOSING THE ENERGYSCAPES

The framework describes how certain areas will be used in terms of energy. This is a process that a lot of elements are involved in. To understand what the spatial implementations will be for the landscapes of the concerned areas, influential elements need to be studied.

The energy consumption and level of (de)centralization are the two main elements the calculations will be based upon. The level of (de)centralization implies the share of energy the area needs to produce locally. A decentralized area needs to produce and store all of its own energy, a centralized area does not need to produce its own energy and is relying on the centralized network. The in-between area is partially self-sufficient and partially relying on the centralized system. The exact balance between centralized and decentralized in the inbetween areas could be shown in a more detailed way.

In-between locations that are close to centralized areas are probably more centralized than decentralized, and vice versa. To bring this into account with calculations; the in-between area will be divided in three classes of decentralization, 75%, 50% and 25%. This means that an in-between area which is 75% centralized should locally produce 25% of its own energy and will receive the remaining 75% from the centralized network. A centralized area is of course 0% decentralized, meaning it does not produce any of its own energy. A decentralized area is 100% decentralized, being self-sufficient.

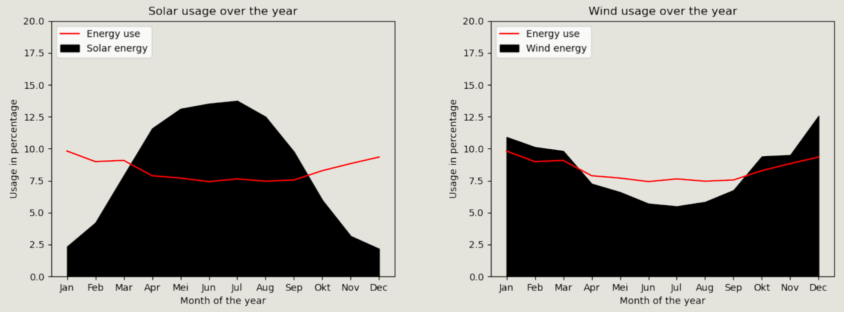
As stated earlier, solar and wind will be the main sustainable energy sources in the future. In this scenario it is presumed that every (suitable) roof will carry solar panels, the amount of energy needed that will not be produced by these solar panels will be produced by wind.



PATTERNS

To calculate the amount of storage needed, the instability of the energy sources of an area need to be studied. As stated earlier, solar and wind energy are reliant on the weather, while the usage pattern is not. To understand the differences in these patterns, the patterns of the countries in North-western Europe are studied.

The patterns of solar and wind are complementing each other. This means that having an energy source, consisting of wind and solar, contributes to having less unreliability in the energy production and therefore also decrease the need for storage. The amount of storage needed can be calculated by taking the month with the biggest difference between energy use and production, this could be a situation with a surplus of energy or a shortage.



To calculate the amount of energy a certain hexagon or area uses, the population data will be used. The average amount of energy used in a country differs, an average number that will be used in these calculations is 40.000 kWh per person. This is based on the energy use in North-western Europe (Our World in Data, z.d.). This is the amount of energy that was used in 2020. Energy use is not something that is constant, it changes over time according to decreasing or increasing demand. EnerData shows a 34% decrease in energy use in Europe in 2050 (Enerdata, z.d.). Taking this into account, the future average amount of energy use will be 26.400 kWh per person per year.

The amount of energy being produced from a solar panel is reliant on the efficiency, lifespan, place on earth and orientation of the roof. Besides, not every roof is suitable for solar panels. With the absence of reliable data on this subject for all the countries in North-western Europe, numbers need to be estimated. Do do this, data that includes the footprint of every building in North-western Europe is used. An assumption that is made is that every roof is the same size as the footprint of the building. It is also assumed that there is a 50% efficiency for every roof to place solar panels. This is based on two factors, 70% percent of a roof is used for placing the actual solar panels (Ace, 2019) and by taking the average of all possible angles we get a 75% efficiency on orientation (Howell, 2023). This gives us 0.7 x 0.75 ≈ 50%,. 50 percent of the roof area will be seen as suitable to produce 100% of solar energy. These roof surfaces can also be calculated per hexagon to calculate the amount of energy that can be produced in total. An energy prouction of 177 kWh per m2 per year is used (Vattenfall, z.d.). Multiplying this by the total roof surface of a region results in the amount energy being produced per year.

The share of the energy demand that is still left after subtracting the amount generated by solar panels will be the amount of energy being generated by wind turbines. The energy situation for every area or hexagon can be calculated precisely. The last step is to take the level of decentralization into account. The amount of energy being produced by wind is multiplied by the percentage of decentralization. For example, this means that a fully decentralized area keeps the amount of wind calculated previously, but a centralized area dismisses all the wind it should produce, because it gets that energy from the centralized network. This concludes the production and usage patterns of energy.

The amount of storage needed is dependent on the level of unreliability of the energy flow. This unreliability can be calculated by combining the usage and production of an area per year with patterns per month. The graphs on the previous page show the different patterns of areas/hexagons from the three different systems. The combination of wind and solar in the decentralized area is helpful for having a more reliable energy supply. The centralized area has a way bigger reliability on hydrogen delivered by the centralized network.

The area between the usage and production shows the amount of needed storage, and therefore unreliability. The month where the difference is the biggest shows how much hydrogen is needed in MWh. In the centralized and inbetween areas it is clear that the month where the usage has the biggest difference from the production, is decisive in knowing the amount of storage needed. In the decentralized area the surplus of energy should also be taken into account, the difference in these could be bigger than the shortage in other months. Taking the month with the biggest difference gives us the needed amount of hydrogen storage in MWh.

Knowing where the biggest difference between supply and demand is for every area in MWh, it is possible to calculate the amount on hydrogen needed to store this difference. Further in the calculations kWh will be used, instead of MWh. The form of hydrogen that will be used is liquid hydrogen. Liquid hydrogen (LH2) is a method to store hydrogen. The table on the right page shows different methods of storage, in this case liquid hydrogen is most efficient, because of its high gravimetric density.

Liquid hydrogen stores 2.5 kWh per kg. 70.9 kg can be stored in one cubic meter. By dividing the amount of storage needed in kWh by 2.5 kWh the amount of hydrogen is calculated in kg. Dividing this amount of hydrogen in kg by 70.9, the hydrogen density, the needed volume in cubic meters (m3) is calculated.

In this scenario two types of storages are used, a large collective storage and a small personal one. The storage type can differ in different types of areas, for example small storages for decentralized areas with a small amount of inhabitants and large storages for areas with a bigger amount of inhabitants. Big storages can contain 4732 m3 of hydrogen and have a diameter of 25 meter (Howell, 2023b). Small hydrogen storages contain about 27 m3 per tank, the size of a train wagon. They have a dimension 2.4 x 6 x 2.4 m (Wikipedia contributors, 2023).

These two options will also be given in a similar way for the windmills. Big land wind turbines are an option, but also small wooden windmills. The smaller windmills can be used in the same circumstances as stated in the storage example. Smaller less dense area are sometimes suited for the use of smaller windmills, which are less dominant in the landscape. In the calculations windmills that produce 6.000.000 kWh per year, with an axis of 80 meter are utilised (Good Energy, 2023). Small windmills that will be used are 15 meters tall and produce 46.000 kWh per year (EAZ wind, z.d.), they are also partially made of wood. These small windmills are less visually dominant in the landscape, as they are not much taller than a tree.

The amount of windmills and storages needed per area/hexagon can be visualized. This is a major insight in what the energy landscape of the future will look like.

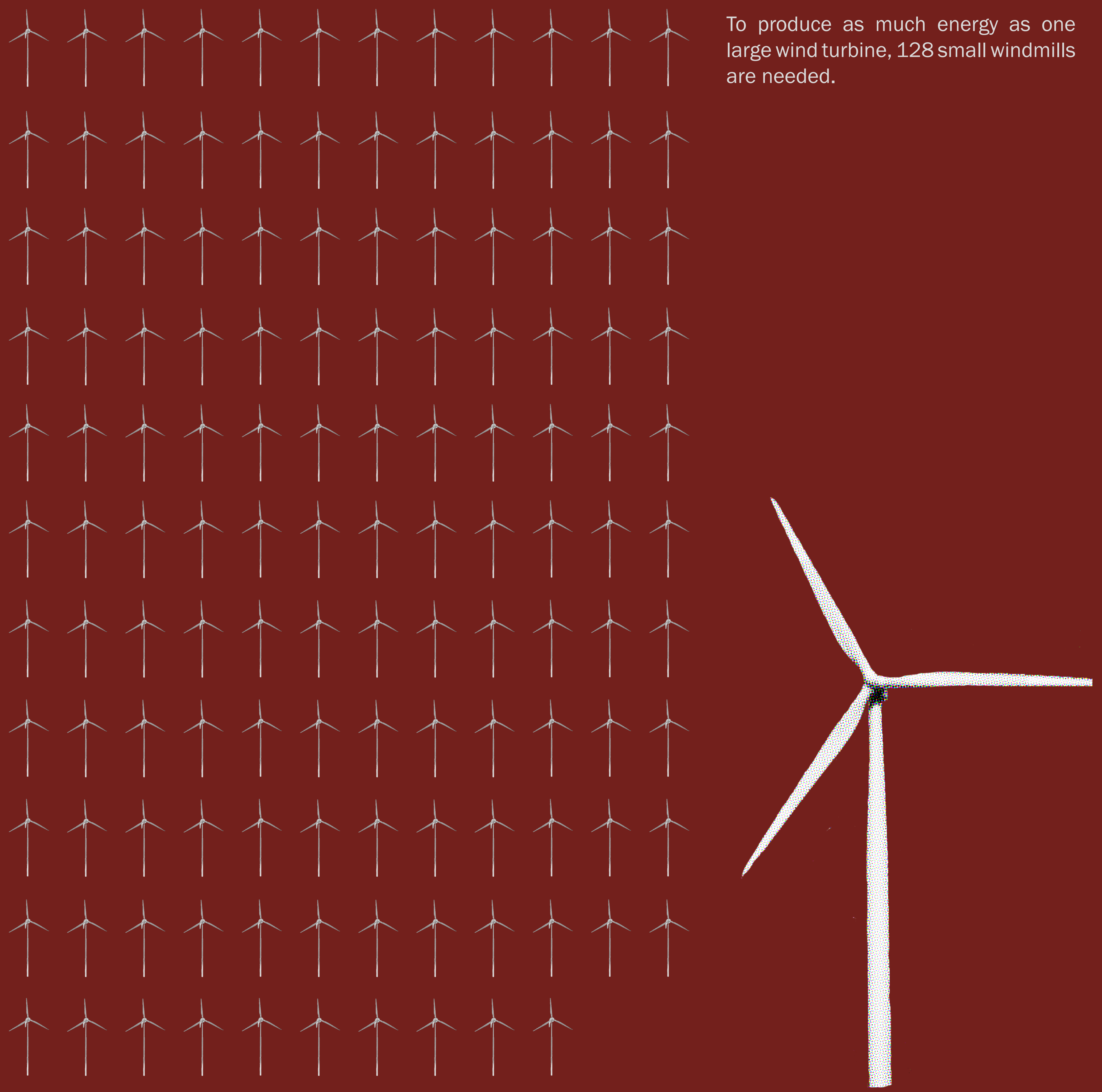
Table 5 – Hydrogen storage methods.

Storage method		Hydrogen density/content	Gravimetric density (kWh/kg_{sys})	Volumetric density (kWh/L_{sys})	Storage temperature (°C)	Storage pressure (bar)	Energy provided during the storage process (kWh/kg_{H2})	Vessel type	Substance used
Compressed gaseous hydrogen (CGH_2)		39.2 kg/m³ at 700 bar [58]	1.8 at 300 bar [65]	0.8 at 700 bar [65]	25 (298 K)	Up to 700	1.7 (from 20 to 350 bar) 6.4 (from 20 to 700 bar) [66]	Type I, II, III and IV) [59]	–
Liquid hydrogen (LH_2)		70.9 kg/m³ at 1 bar [58]	2.5 [67]	1.1 [67]	−252.75 (20.4 K) at 1 bar [58]	Up to 7	10 ÷ 13 [66],[a]	Double walled tank [60]	–
Cryo-compressed (CcH_2)		Up to 80 kg/m³ at 300 bar, 38 K [59]	2.3 at 500 bar [65]	1.4 at 500 bar [65]	−235.15 (38 K) ÷ 25 (298 K)	Up to 500	2.0 [68] ÷ 8.0 [69]	Insulated pressurized vessel [69]	–
Physical adsorption		Up to 5.60 wt% with $Mg_{50}Ni_x$–TiO_2/MWCNTs[b] [70]	1.3 [65]	0.7 [65]	≈ −203 (70 K) [71] ÷ ≈ 100 (373 K) [70]	1 [71] ÷ 100 [72]	6.7 (at −176 °C and 40 bar)	Pressurized or insulated metal tank filled with porous or nanostructured material	MOF[c], zeolites [73], MWCNT[b], graphene [74]
Chemical bond (absorption)	Metal hydride	Up to 5.60 wt% with $NaAlH_4 \leftrightarrow Na_3AlH_6 \leftrightarrow NaH + Al + 3/2H_{2(g)}$ [75]	0.4 [65]	0.4 [65]	25 (298 K)	Low pressure	2.8 (for IM[d] at T < 80 °C, 50 bar) ÷ 11.0 (for MgH_2 at 300 °C, 30 bar) [76]	Pressurized metal tank filled with metal hydride	Alloys composed by Mg, Na, Al, Li, B, Ti, Zr and Fe [38]
	Chemical hydride	Up to 12.1 wt% with methanol [77]	1.5 [65]	1.3 [65]	25 (298 K)	P_{atm}	6.3 (for ammonia at T > 425 °C) ÷ 11.2 (for MCH at 350 °C) [76]	Conventional steel tank [78]	Ammonia, methanol, formic acid, LOHC: DBT, NEC [77], MCH[e] [79]

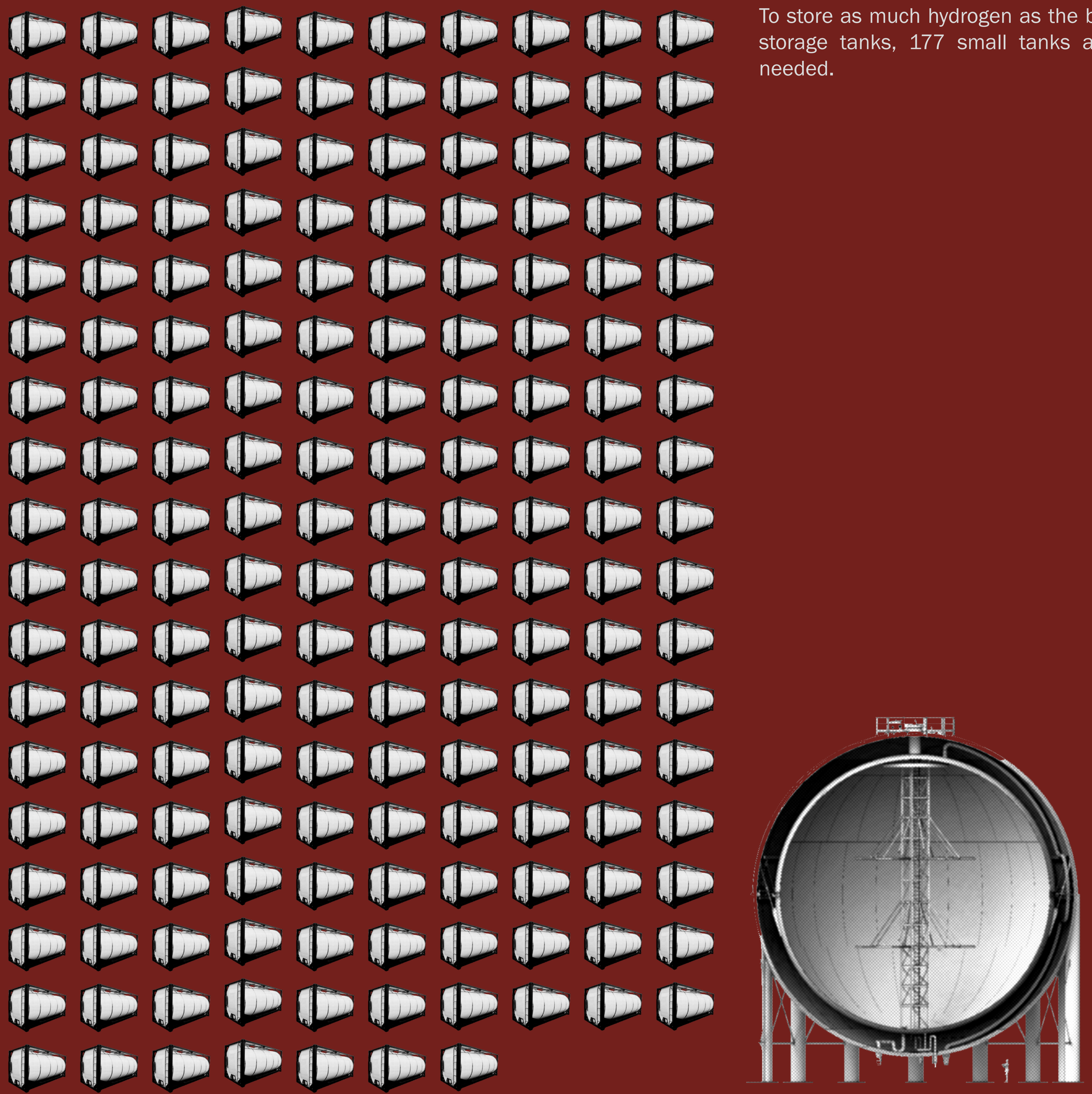
[a] according to Ref. [80], a potential energy consumption of 5.9 kW h/kg_{H2} for an optimized liquefaction plan with a capacity between 25 and 100 tons per day (tpd_{LH2}) was estimated.
[b] MWCNT: multi-walled carbon nanotubes.
[c] MOF: metal-organic framework.
[d] IM: intermetallic hydride.
[e] LOHC: liquid organic hydrogen carrier; DBT: dibenzyltoluene NEC: N-ethylcarbazole; MCH: methylcyclohexane.

table from (Ustolin et al., 2020)

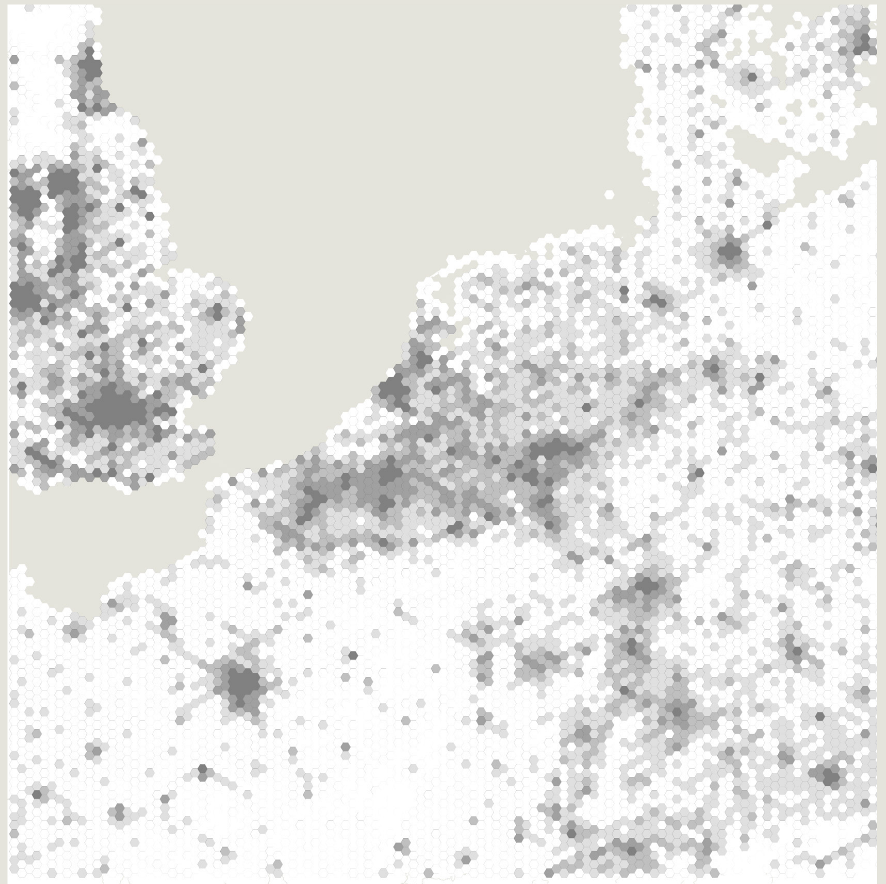
To produce as much energy as one large wind turbine, 128 small windmills are needed.



To store as much hydrogen as the big storage tanks, 177 small tanks are needed.



m2 solar panels per hexagon



water

0 - 2153

2153 - 4554

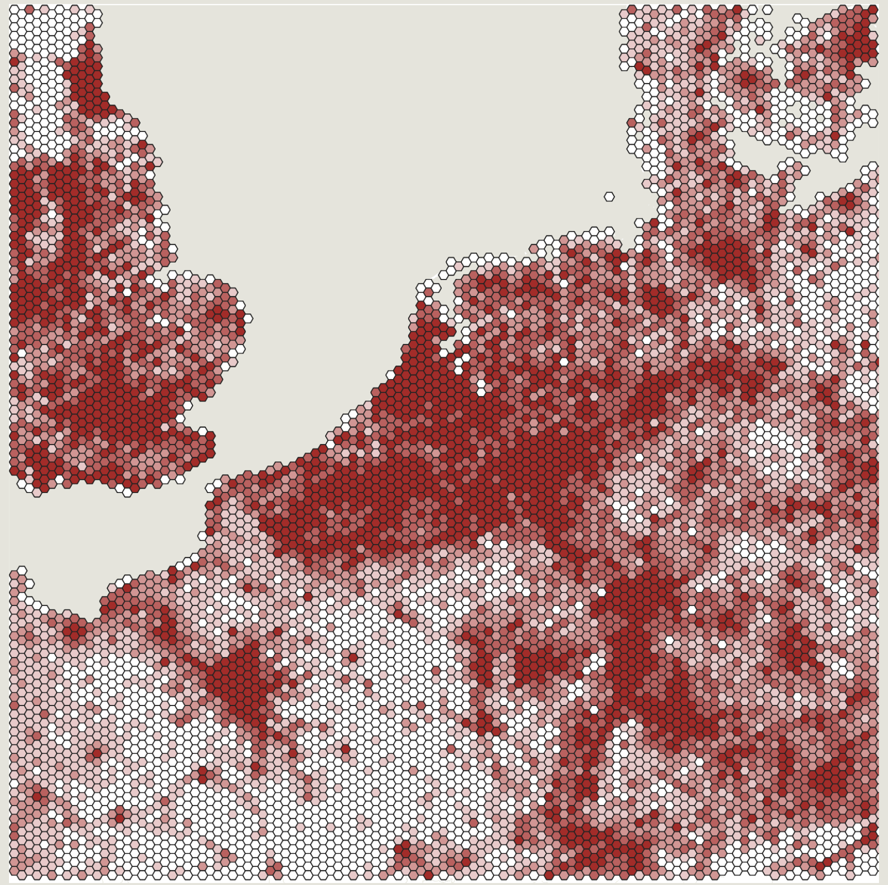
2153 - 4554

8310 - 16504

16504 - 449708

0 150 300 km

m3 hydrogen storage per hexagon



water

38 - 19602

19602 - 40001

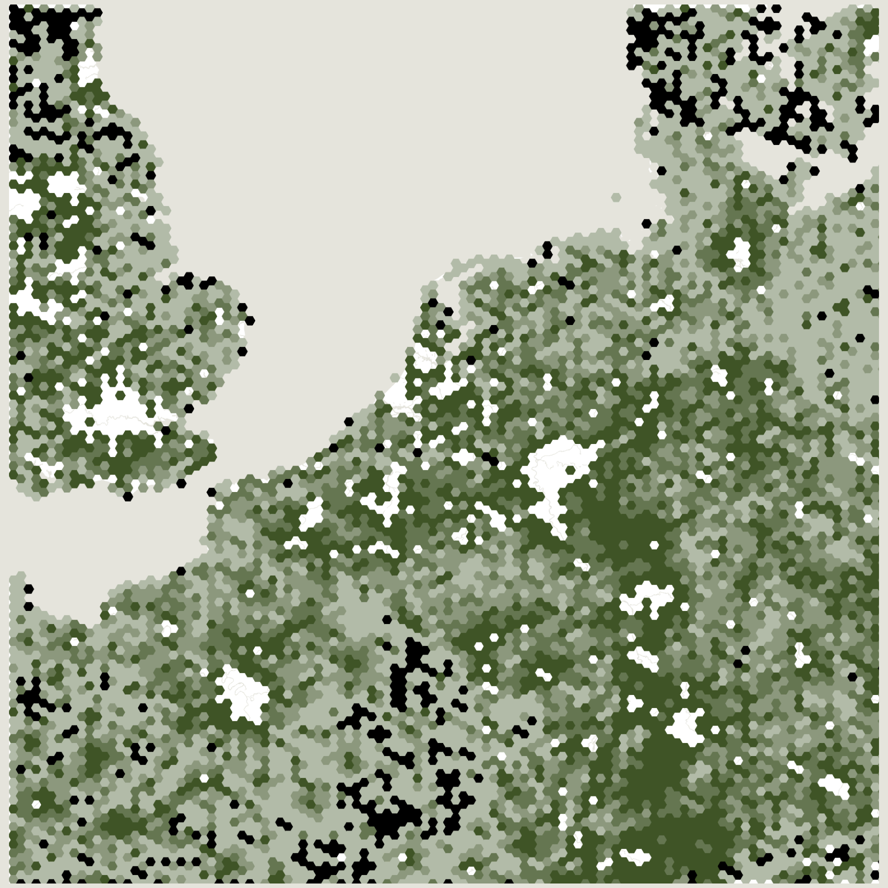
40001 - 80957

80957 - 21373

212373 - 24299106

0 150 300 km

number of windmills per hexagon



water

-16 - 0

0 - 4,9

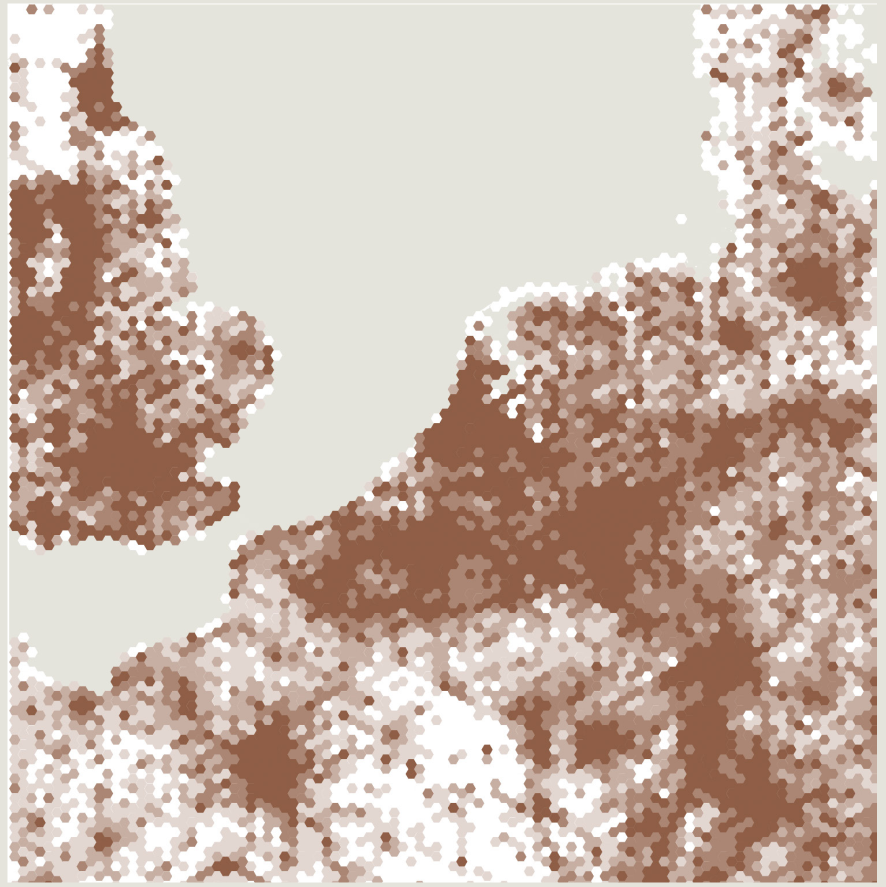
4,9 - 10,8

10,8 - 23,3

23,3 - 710,9

0 150 300 km

number of windmills per hexagon on land



water

2 - 5613

5613 - 12098

12098 - 22893

22893 - 54497

54497 - 4367680

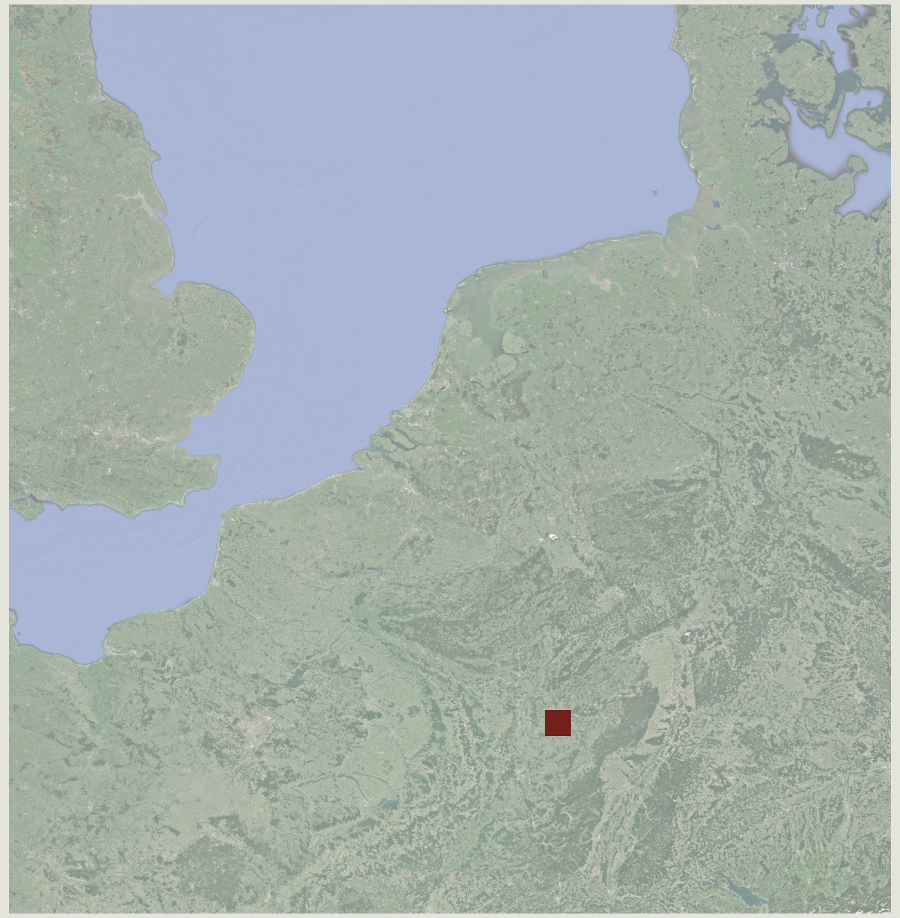
0 150 300 km

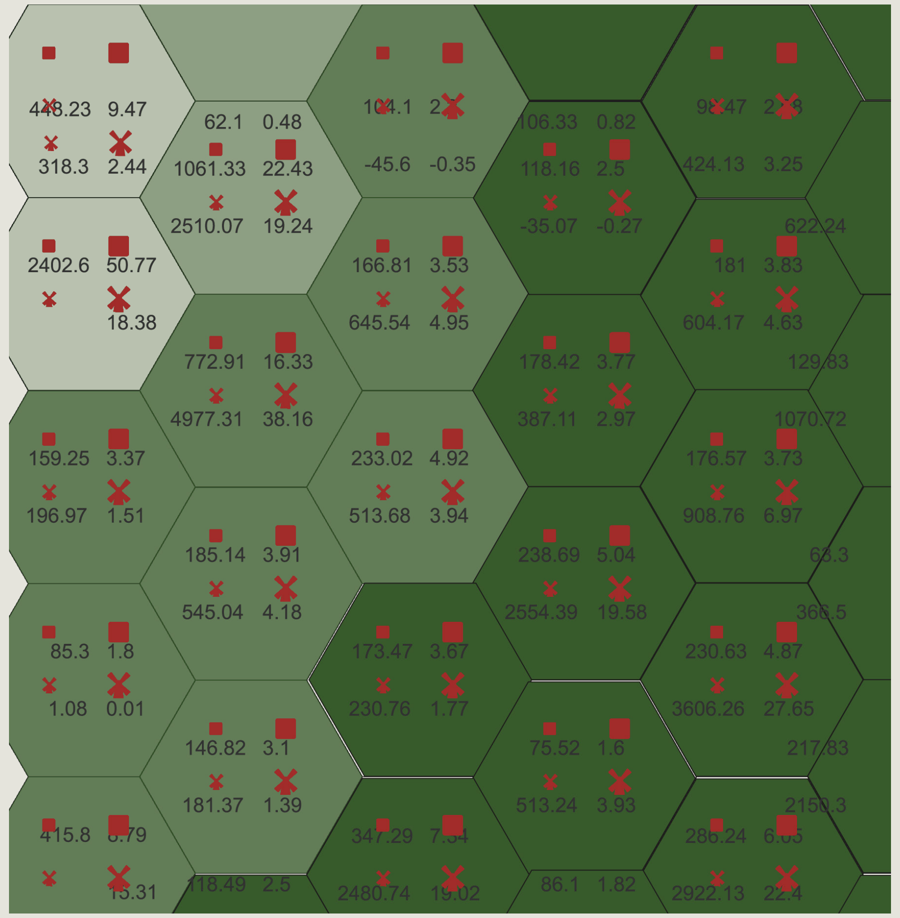
MEURTHE-ET-MOSELLE

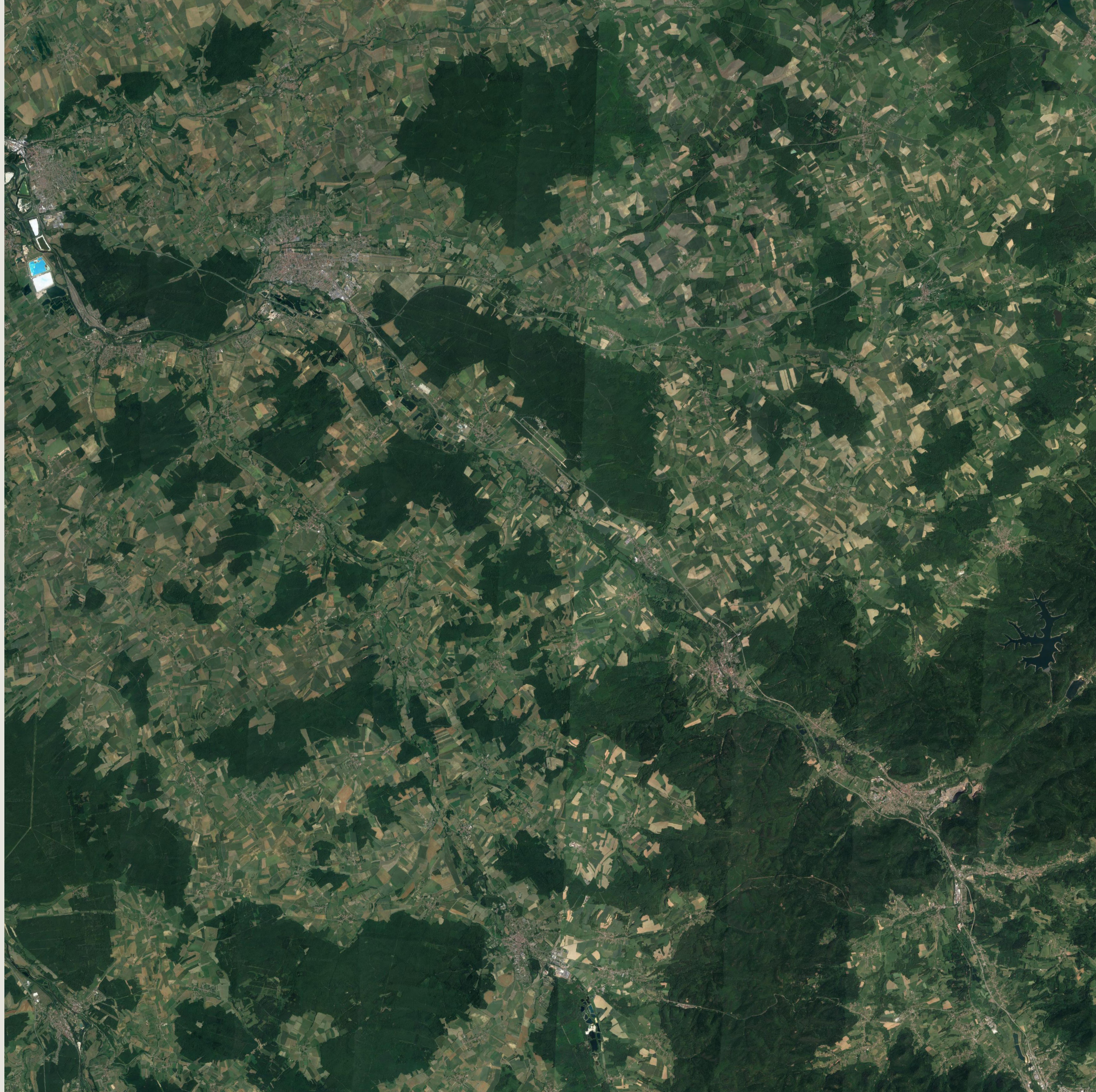
To illustrate the application of the decentralized and in-between networks in the real landscape, a site in the inland of France is chosen. the outskirts of the city of Nancy are still visible at the far left side of the frame. This area is sparsely populated and is located far away from the centralized network. The landscape of this area is characterised by endless agricultural fields and forestry. A small river that is not suitable for the transportation of heavy goods like hydrogen, crosses the area. The majority of the towns are located on the banks of this waterway. The population that is settled in the hinterland can be characterised by tiny one-street villages that usually occur at the crossing of two roads.

This area contains towns that will work with the decentralized system, but it also contains in-between areas with 25%, 50% and 75% centralized systems. The gradient in the landscape between decentralized and centralized networks can be shown and clarified in this exemplary frame.

The mathematical model can be directly applied to this site, resulting in the amount of storages and wind turbines needed to provide the area with a sufficient amount of energy. There is a distinction made between small (private) storages and windmills and large (collective) storages and windmills. These numbers can be compared to the land use to help decide which ones will be applied in which areas.





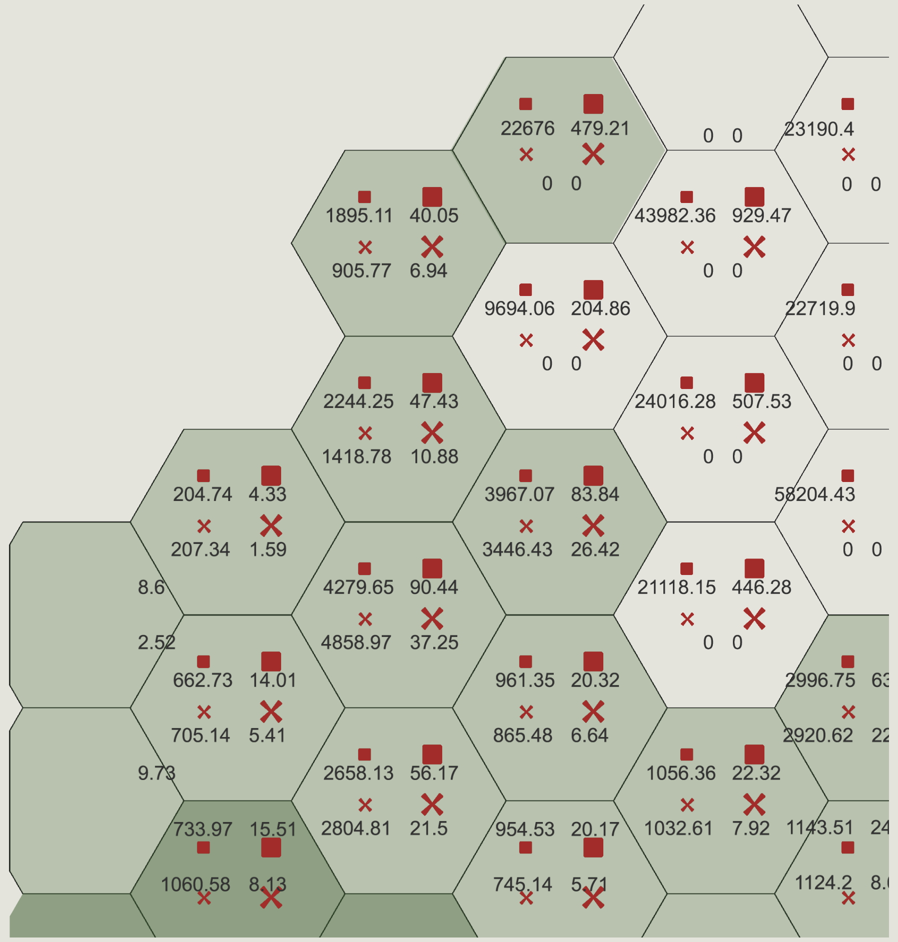


SOUTH-HOLLAND

To illustrate the application of the centralized and in-between networks in the real landscape, a site at the coast of South-Holland is chosen. This area contains the Rotterdam harbour, the largest harbour in Europe. This area is densely populated and is located close to the centralized network. The landscape of this area is characterised by the industrial and energy-dominated landscape of the harbour. This frame includes large-scale cities like Rotterdam, but also includes small rural towns that are characterised by their agriculture. The river that plays a large role in the transportation of heavy goods like hydrogen, crosses the area. The majority of the towns area located on the banks of this waterway. The population that is settled in the hinterland is a bit less dense, but has a close proximity to the centralized network.

This area contains cities that will work with the centralized system, but it also contains in-between areas with 50% and 75% centralized systems. The gradient in the landscape between decentralized and centralized networks can be shown and clarified in this exemplary frame.

The mathematical model can be directly applied to this site, resulting in the amount of storages and wind turbines needed to provide the area with a sufficient amount of energy. The centralized area does not contain any wind turbines, as its energy comes from the wind turbines on the North sea. There is a distinction made between small (private) storages and windmills and large (collective) storages and windmills. These numbers can be compared to the land use to help decide which ones will be applied in which areas.



centralized area

75% centralized area

50% centralized area

CONNECTING THE VALUES TO THE LANDSCAPE

PRESERVATION

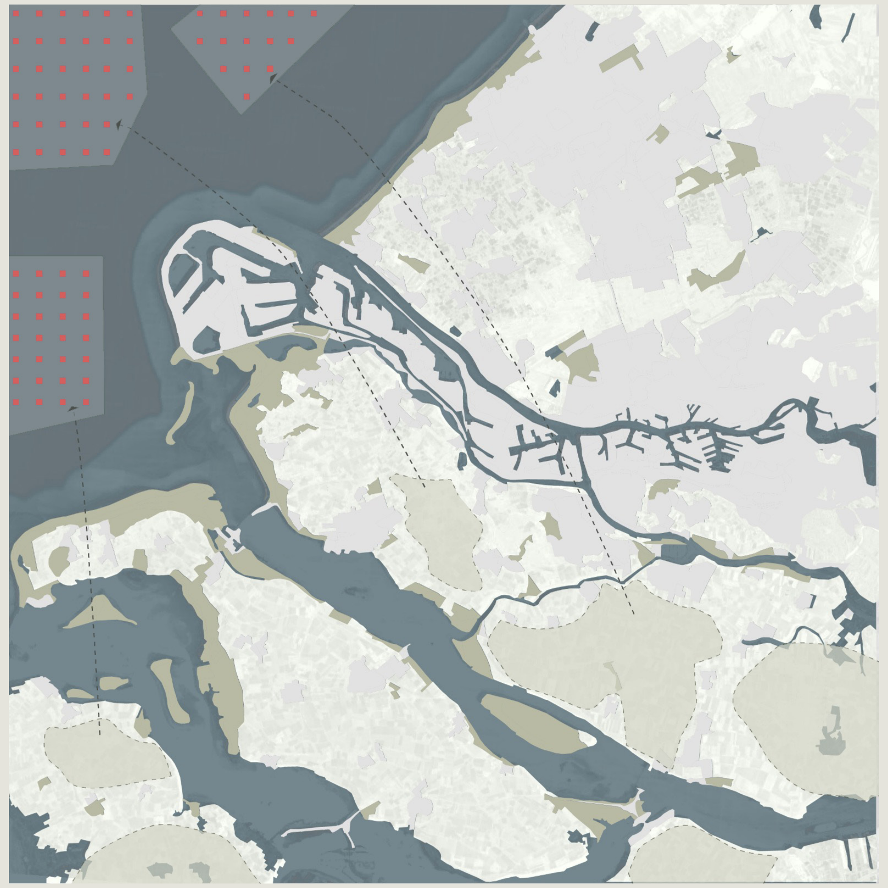
Clean energy production will require more land than fossil energy production. However, an excessive amount of windmills on land could seriously harm the landscape. By placing wind turbines at sea, large amounts of land could be preserved. At the same time, this minimises protest from residents, while it simultaneously preserve the integrity of the landscape to the greatest extent possible. Additionally, natural areas will be thoroughly protected and expanded if possible. In South Holland, the original natural areas of meadows, forests, and marshes will be protected. These are primarily situated along the waterfront in Zeeland. These areas will expand inland in the future. These emerging natural landscapes will be connected to the green corridors along the waterfront, facilitating migration of species and maintenance of landscape integrity.

hydrogen storage tanks

natural areas

water

0 5 10 km

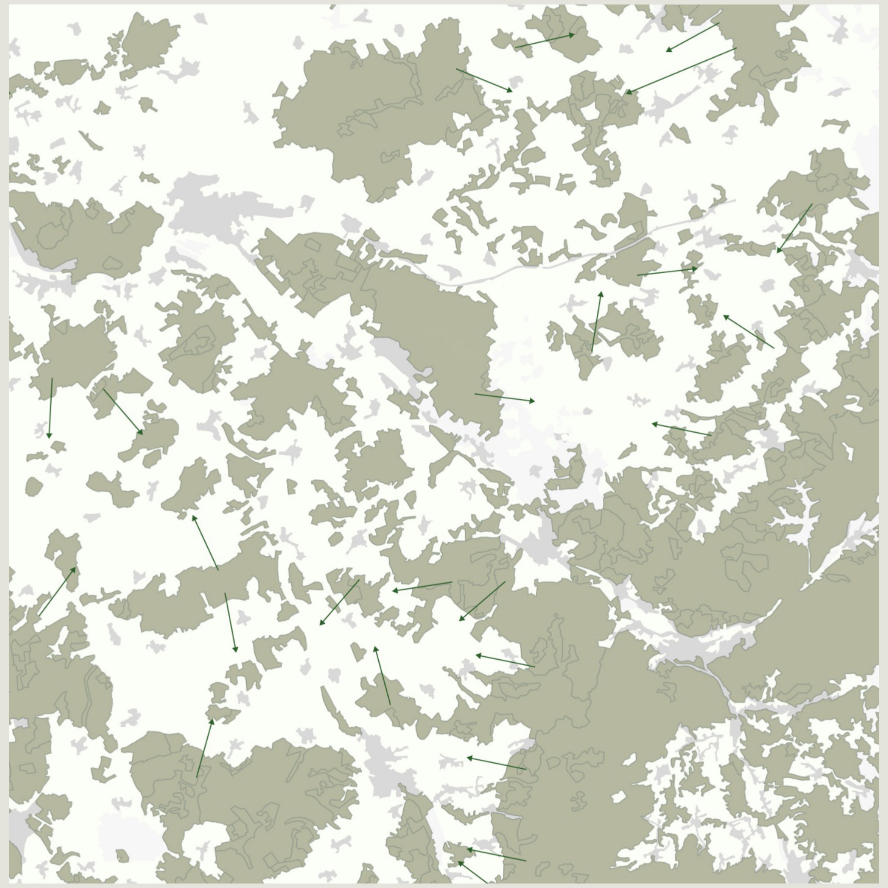


In France, there are numerous natural reserves that must both be preserved and strategically expanded. The locations suitable for expansion are typically located in areas/hexagons that already contain a substantial amount of nature. Additionally, in regions with a small amount of inhabitants and natural habitats, natural expansion is intentionally stimulated to create green corridors between different areas.

natural area

village

0 5 10 km



JUSTICE

In order to facilitate just access to energy to all, it is crucial to ensure that there is enough locally produced energy in areas where energy cannot always be delivered in a top-down way. Thus, wind turbines are needed in the in-between area to sustain a reliable energy flow. In some cases, wind turbines can be moved to a neighbouring area/hexagon to preserve the local landscape. These wind turbines need to be built on land outside of nature reserves and are usually built in clusters. The energy produced by these wind turbines can provide clean energy to nearby villages and towns.

wind turbine

natural area

wwater

0 5 10 km

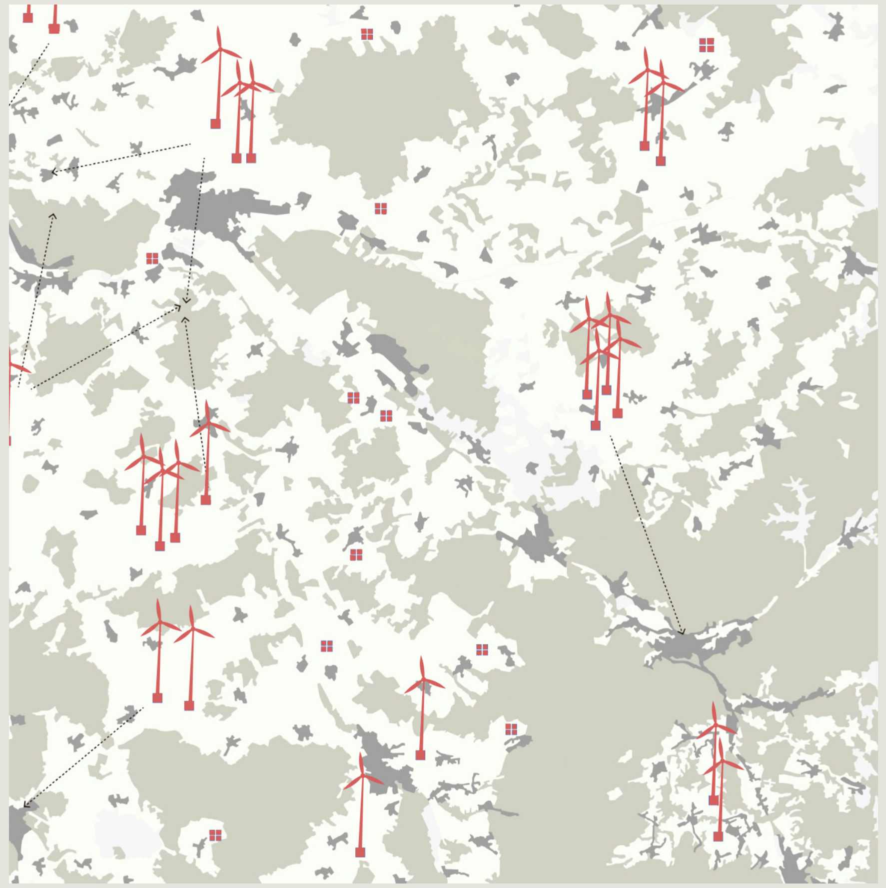
In the decentralized and 25% centralized areas, the vast majority of the energy is generated locally, and therefore a greater number of wind turbines is needed to ensure a sufficient amount of energy for the local population. However, in densely populated and natural areas, there is a lack of space to build wind turbines. Thus, they need to be constructed in neighbouring hexagons/areas with fewer people and fewer natural reserves. When multiple neighbouring hexagons need to build their own wind turbines, it is more efficient to cluster them together in an open space. For smaller villages, small wooden windmills can be constructed, which have a smaller footprint and are less expensive. Although they have lower capacity, they are sufficient for personal use and have less impact on the landscape, resulting in a more pleasing overall aesthetic.

wind turbine

natural area

village

0 5 10 km



RESILIENCE

As extreme weather conditions become more frequent, energy scarcity is likely to arise. The current number of storages could be unsuccessful in meeting the energy demand of urban areas, which means the existing energy storage area should be expanded to ensure an adequate energy supply during periods when the wind turbines on the North Sea cannot produce enough energy. Currently, the existing energy storage area in South Holland is concentrated mainly in the Rotterdam harbour, where many existing storage tanks can be converted into hydrogen tanks. However, additional hydrogen storage tanks will be necessary. Rotterdam will become the most significant battery in South Holland, as well as on the Rhine waterway.

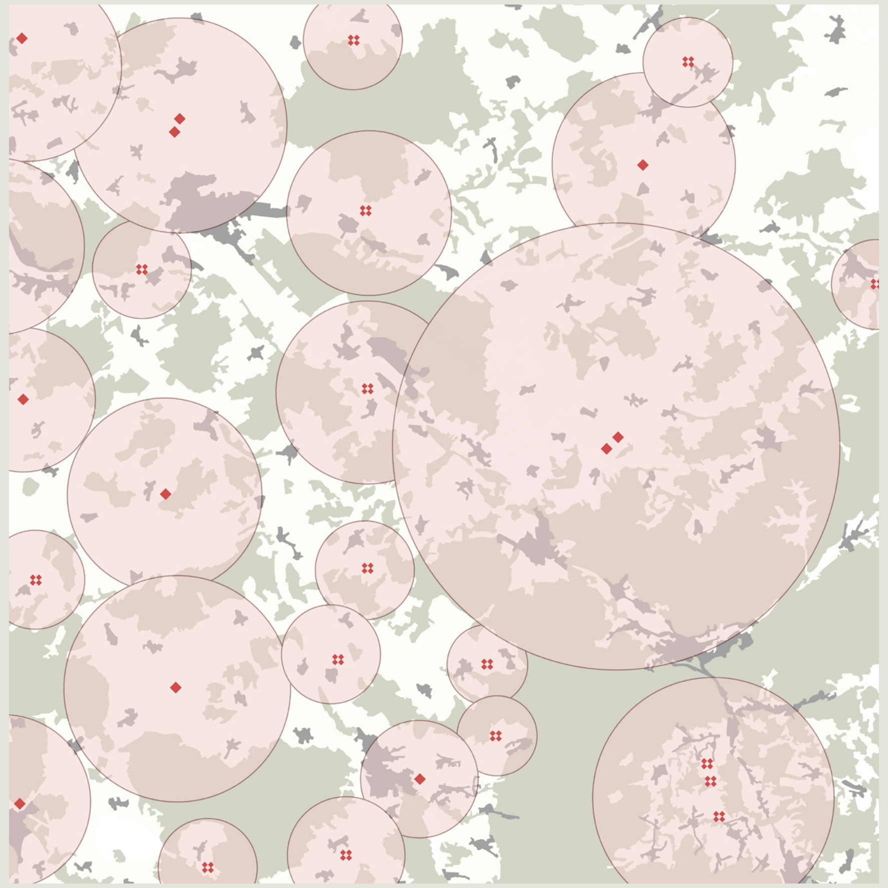
- hydrogen storage tanks
- hydrogen storage sites
- natural areas
- water

0 5 10 km

Storages are typically located near windmills or near towns. The size of the battery determines its service area. Larger batteries are able to provide energy not only to the local area but also to several neighbouring hexagons. Conversely, small batteries are typically located in natural and sparsely populated areas. They are more convenient, they are ideal to be used in areas with low population densities. For example, households can each have their own small hydrogen storage.

- battery service range
- hydrogen storage tanks
- natural areas
- villages

0 5 10 km



AVAILABILITY

To ensure local energy security, new storages need to be constructed in areas that currently lack them. Once suitable locations have been identified, the current hydrogen transport pipelines can be enhanced and connected. This way, the hydrogen that is generated and stored in Rotterdam can be transported to all towns that require it, resulting in an efficient hydrogen transport system and improved hydrogen availability in the future. This extension would not only facilitate hydrogen transport but also provide infrastructure for private energy trading between locations in certain circumstances.

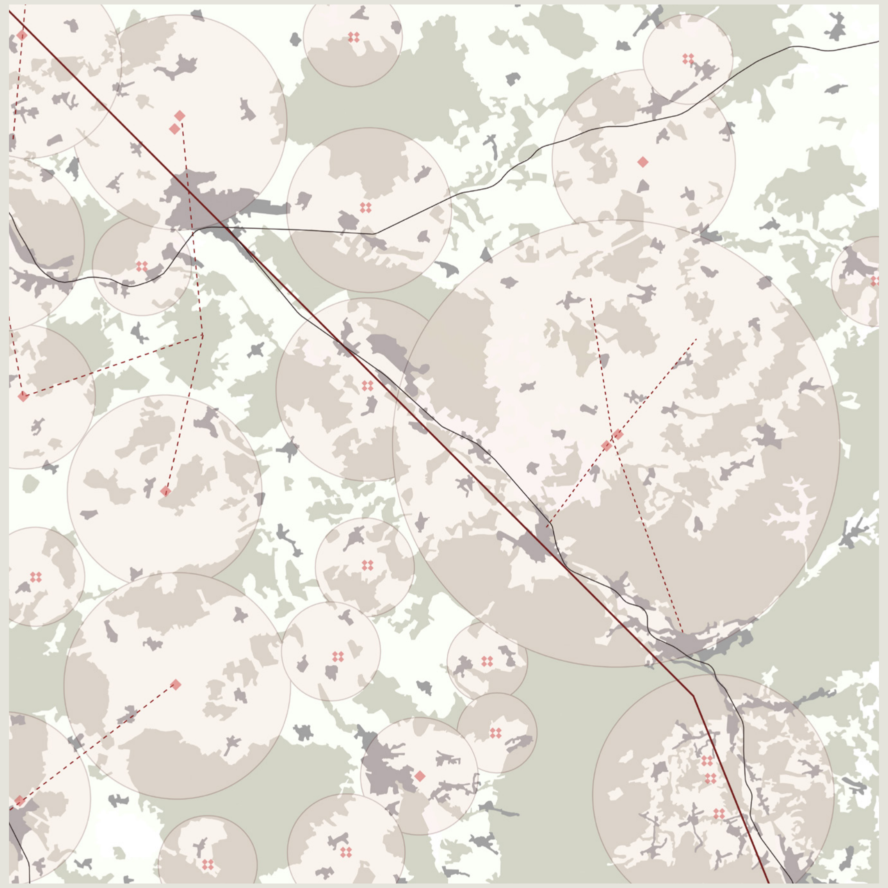
- hydrogen storage tanks
- pipelines
- natural areas
- water

0 5 10 km

In the 25% in-between areas, a portion of the storages will be linked to the hydrogen pipeline system which is connected to the bigger centralized network. Conversely, in the decentralized areas, the local pipeline network is not directly connected to the central pipeline that runs through the centralized area. Rather, it is linked to the local storages through a smaller pipeline, enabling the provision of sufficient energy to villages and towns without batteries or windmills.

- railway
- pipelines
- battery service range
- hydrogen storage tanks
- natural areas
- villages

0 5 10 km



RULES AND RECOMMENDATION AS A TOOLBOX

The *centralized* areas only consist of areas with a large population and a small amount of nature.

- The majority of energy in the centralized areas is generated from wind turbines at sea, however, suitable roofs are required to host solar panels.
- Buffer zones between residential areas and storage areas are required. It is encouraged to move storages/batteries to harbours and former gas plant locations.

The *in-between* areas are classified according to population, proximity to the centralized network and the amount of nature.

- The amount of energy that needs to be locally produced in the in-between area can differ from 25% to 75%. This requires suitable roofs to host solar panels. The rest of the energy that is needed will be generated by wind turbines (either tall ones of private ones) on land.
- Highly populated areas with a lot of nature are motivated to move energy elements like wind turbines and hydrogen storages to the harbour, sea or neighbouring areas.
- Highly populated areas with a little amount of nature are recommended to take windmills and batteries from neighbouring areas, if needed. These elements should be placed considering a buffer zone between the elements and the towns. If they do not have to take energy elements from surrounding areas, the natural area can be increased.
- Towns with a small number of inhabitants which are surrounded by a large amounts of nature are stimulated to preserve nature.
- For the smaller towns, which have a small amount of nature, protecting nature and taking over the wind power production and storages from neighbouring areas is recommended. If this is not needed, the natural area can be increased.
- If an area houses any energy infrastructure from neighbouring areas, the area can be compensated by improving the local public transport, generating job opportunities in the area, and creating more energy stability.

The *decentralized* areas are classified according to population and proximity to the amount of nature.

- For a small population with a large amount of nature, placing small windmills and storages is recommended. This contributes to having a as little as possible impact on the surroundings.
- Areas with a little amount of nature and a small amount of inhabitants should apply small windmills and increase and protect their nature.
- A rule of thumb that can be applied when deciding between tall or small wind turbines is that towns with a population over 500 people can generally take large wind turbines, because of efficiency.
- For large populations with a lot of nature, the operation is to move the windmills to neighbouring areas. If this isn't possible, areas should shrink in their energy use, therefore shrink in population. This is the result of the spatial claim of the energy elements being too big for the scarce space there is.
- Large populations with a small amount of nature will be stimulated to put windmills and storages in clusters.
- If an area houses any energy infrastructure from neighbouring areas, the area can be compensated by improving the local public transport, generating job opportunities in the area, and creating more energy stability.

In conclusion, recurring rules for the spatial operation are:

1. Energy production in a decentralized area should be organized in a bottom-up way.
2. Energy production in a centralized area should be organized in a top-down way.
3. Natural areas should always be protected.
4. Energy can only be transported within a certain distance from the production site. This distance differs among different modes of transport.
5. Buffer zones are required between the storage and production area and residential area, as hydrogen is a highly inflammable substance.
6. Quantity and sizes of the batteries and windmills should correspond with the population and location.

If an area takes in energy infrastructure from a neighbouring town, they can be compensated. These compensations are derived from actual problems that occur in remote areas like these nowadays. A few suggestions for compensations are as follows:

- Job opportunities // Rural areas often have fewer job opportunities and lower wages than urban areas, which can make it difficult to attract and retain a skilled workforce. By placing energy infrastructure in these areas, jobs can be created and this can give the rural areas a boost in new and attract younger inhabitants.

- Transportation // Limited public transportation in rural areas can make it difficult for residents to access employment opportunities, healthcare, and other services. When a rural area offers space to put energy/hydrogen infrastructure, they can get better public transport in return. This improves the connectivity of these areas.

- Social services // Residents of rural areas have limited access to healthcare, education, and other essential services due to a lack of infrastructure and resources. By placing energy elements, infrastructure can be improved, contributing to a better connection to surrounding areas which do have these services.

- Digital transformation // Many rural areas have limited access to high-speed internet and other digital technologies, which can limit economic opportunities and access to information. With placing new infrastructure for the hydrogen and energy elements the digital infrastructure can also be improved. This contributes to making the rural areas more appealing to live.

- Environmental improvement // Some rural areas face environmental challenges such as soil erosion, water pollution, and loss of biodiversity, which can impact agriculture and natural resources. In return for placing windmills and storages in the areas biodiversity can be improved by adding more nature . These improvements can also be made around the energy infrastructure to make a buffer or hide the elements.

- Social improvement // Rural areas can be socially isolating, particularly for elderly people or those without access to transportation, which can lead to mental health problems and social exclusion. By accommodating more social functions this can be improved. A better connectivity and attracting more people also contribute to social improvement.

- Benefit costs & ownership // Rural areas often have limited economic opportunities. Energy infrastructure can bring new ways to earn money for people in these areas. By placing small/big windmills on their property people can sell energy to the network, this gives them ownership of energy. For example farmers in rural areas can also use their land more efficiently by placing windmills on their agricultural ground.

TYPOLOGIES & VISUALISATION

Based on the ratio between nature and population in the three determined energy systems, nine different typologies emerge. Each typology can be connected to one or multiple recommendations from the toolbox. This way, the way the landscape will behave in the future can already be predicted. Problems can arise when the landscape offers too little variety in typologies. These actions should be taken as recommendations, not as binding advice.

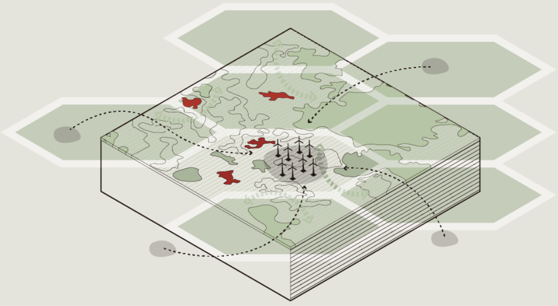
IN-BETWEEN AREA

SMALL POPULATION

LARGE NATURE AREA

PRESERVATION

LESS NATURE AREA

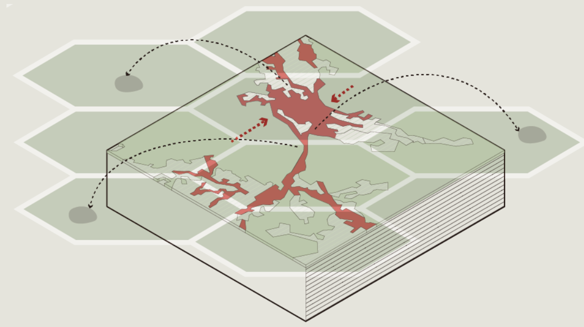


MORE WINDMILLS AND MORE BATTERIES

DECENTRALIZED

LARGE POPULATION

LARGE NATURE AREA



1.MOVE THE WINDMILLS AND BATTERIES TO NEIGHBORHOOD
(OR)
2.SHRINK THE VILLAGE

LESS NATURE AREA

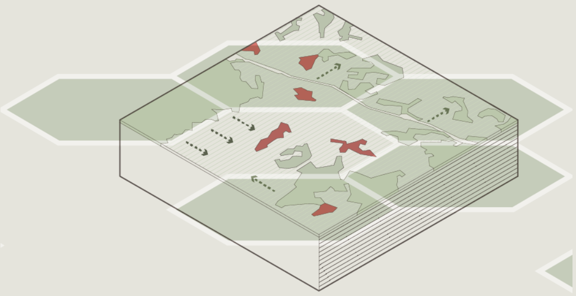
PUT BIG WINDMILLS AND LARGE BATTERIES IN THE CLUSTER

SMALL POPULATION

LARGE NATURE AREA

SMALL WINDMILLS AND SMALL BATTERIES

LESS NATURE AREA

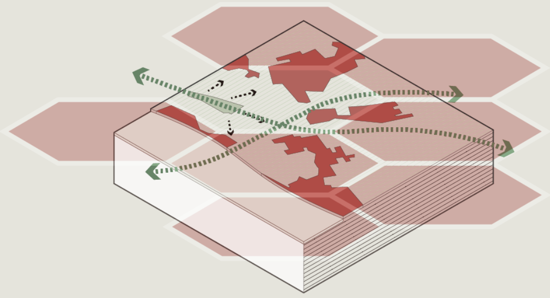


MORE NATURE AREA

CENTRALIZED

LARGE POPULATION

LESS NATURE AREA

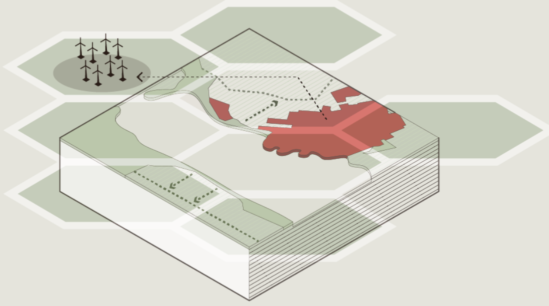


BUFFER ZONES BETWEEN RESIDENCE AND STORAGE AREA

MOVE THE BATTERIES TO THE HARBOR

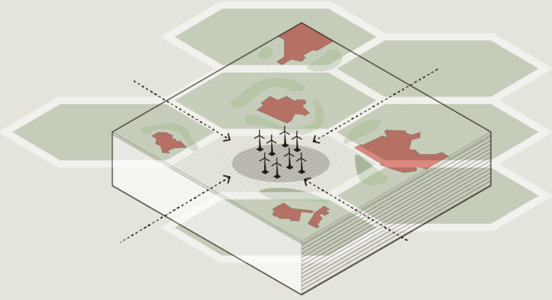
LARGE POPULATION

LARGE NATURE AREA



MOVE THE WINDMILLS AND BATTERIES TO HARBOR OR SEA

LESS NATURE AREA



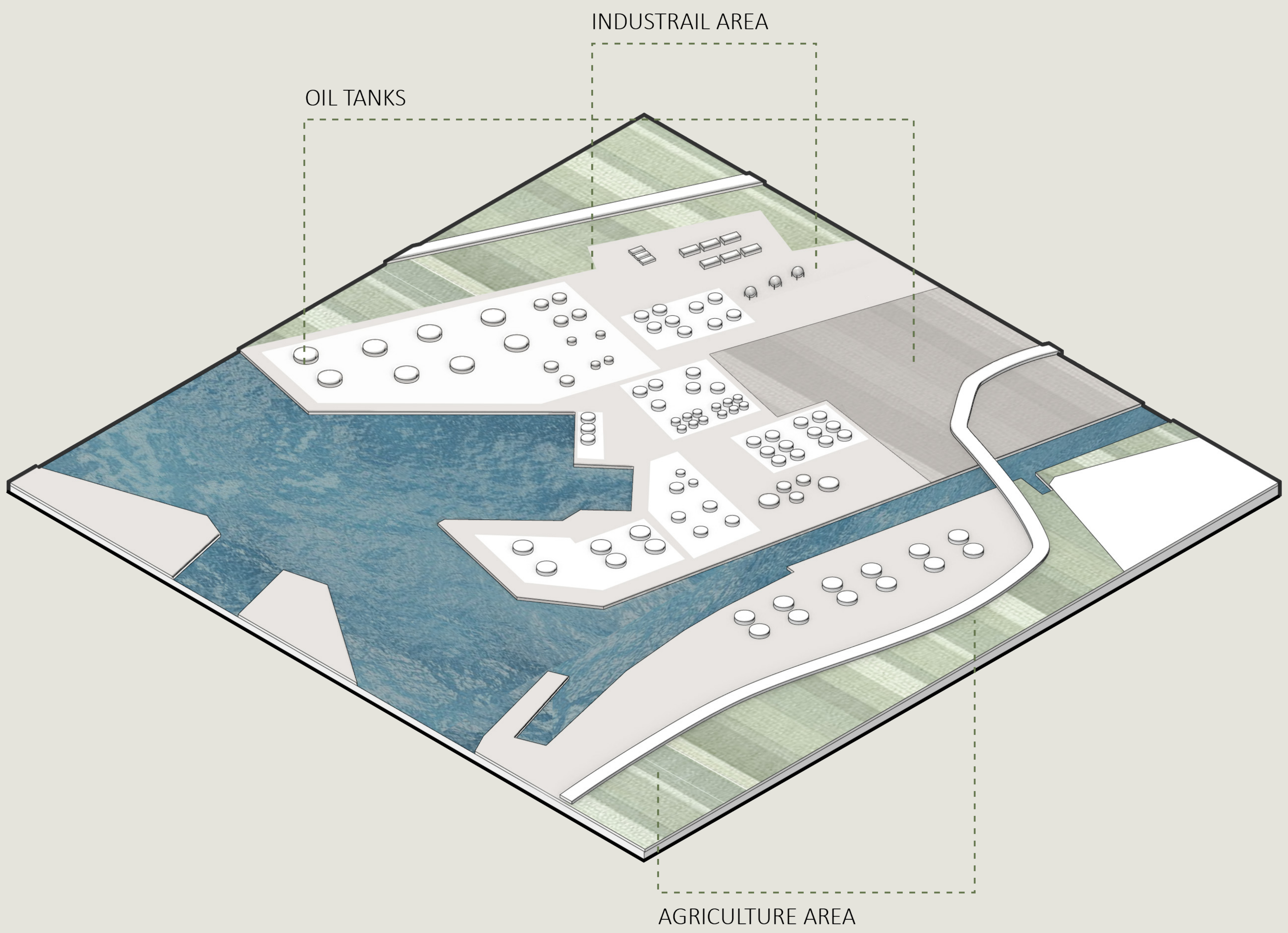
MORE BATTERIES AND WINDMILLS

BUFFER FROM THE TOWN

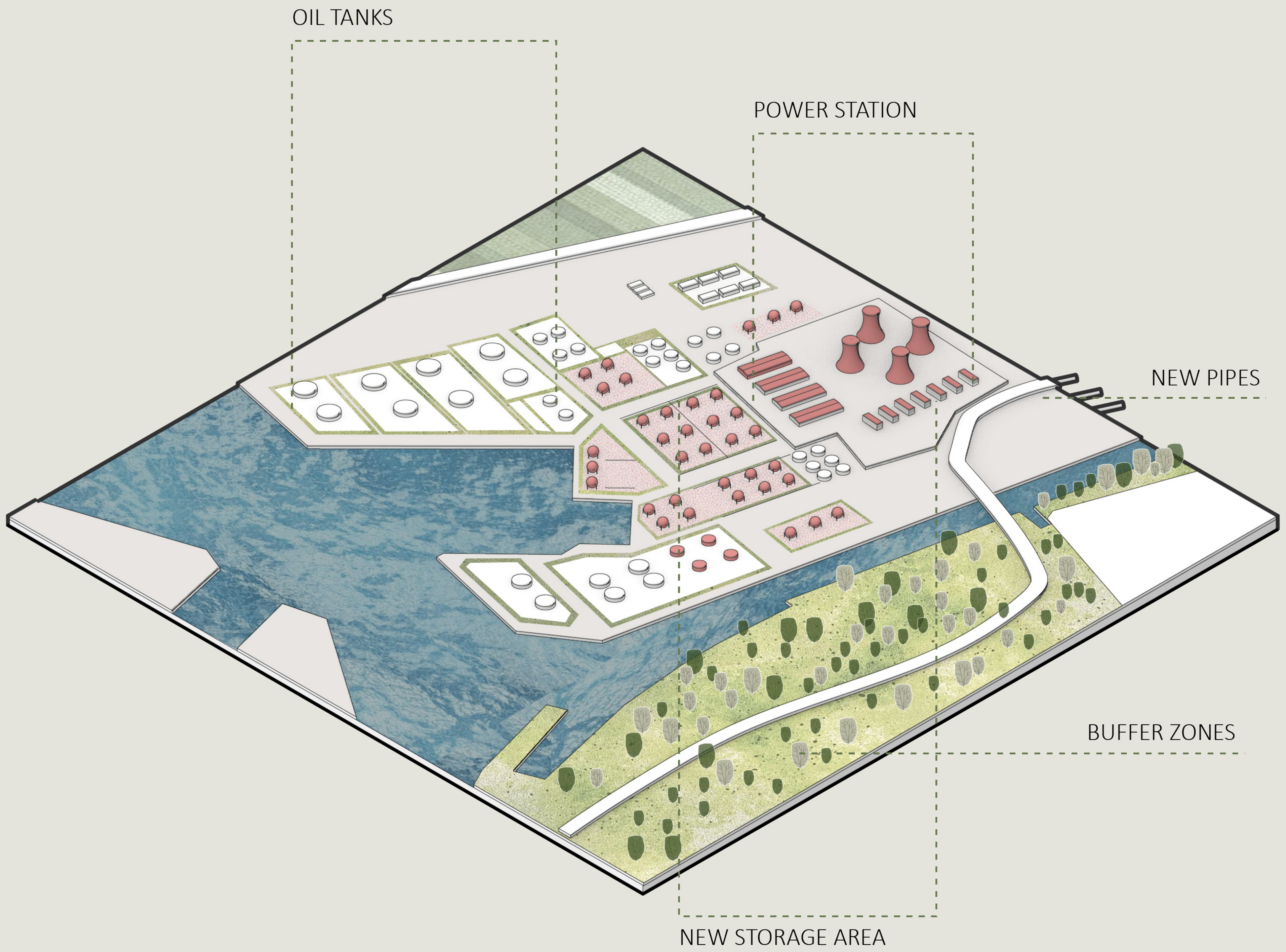
GRADIENT IN THE LANDSCAPE

The different types of energy systems are paired with types of landscapes. The urbanised areas are more likely to be more centralized, whilst the rural areas are more likely to be decentralized. The plot sizes are bigger in the decentralized area, giving residents more space to generate their own energy. The different types of infrastrucure change along the gradient. The centralized areas are more focused on the storages, the in-between areas are dominated by larger wind turbines and the decentralized areas are matched with the small windmills. These elements are visible in the following sequence.

A significant proportion of the windmills will be constructed on the sea, making use of offshore wind energy. The harbour will serve as the most important and largest hydrogen battery, facilitating energy storage and distribution. The areas that are currently occupied by oil tanks and traditional energy generation industries will be repurposed into hydrogen storage facilities, resulting in the transformation of the energy landscape.



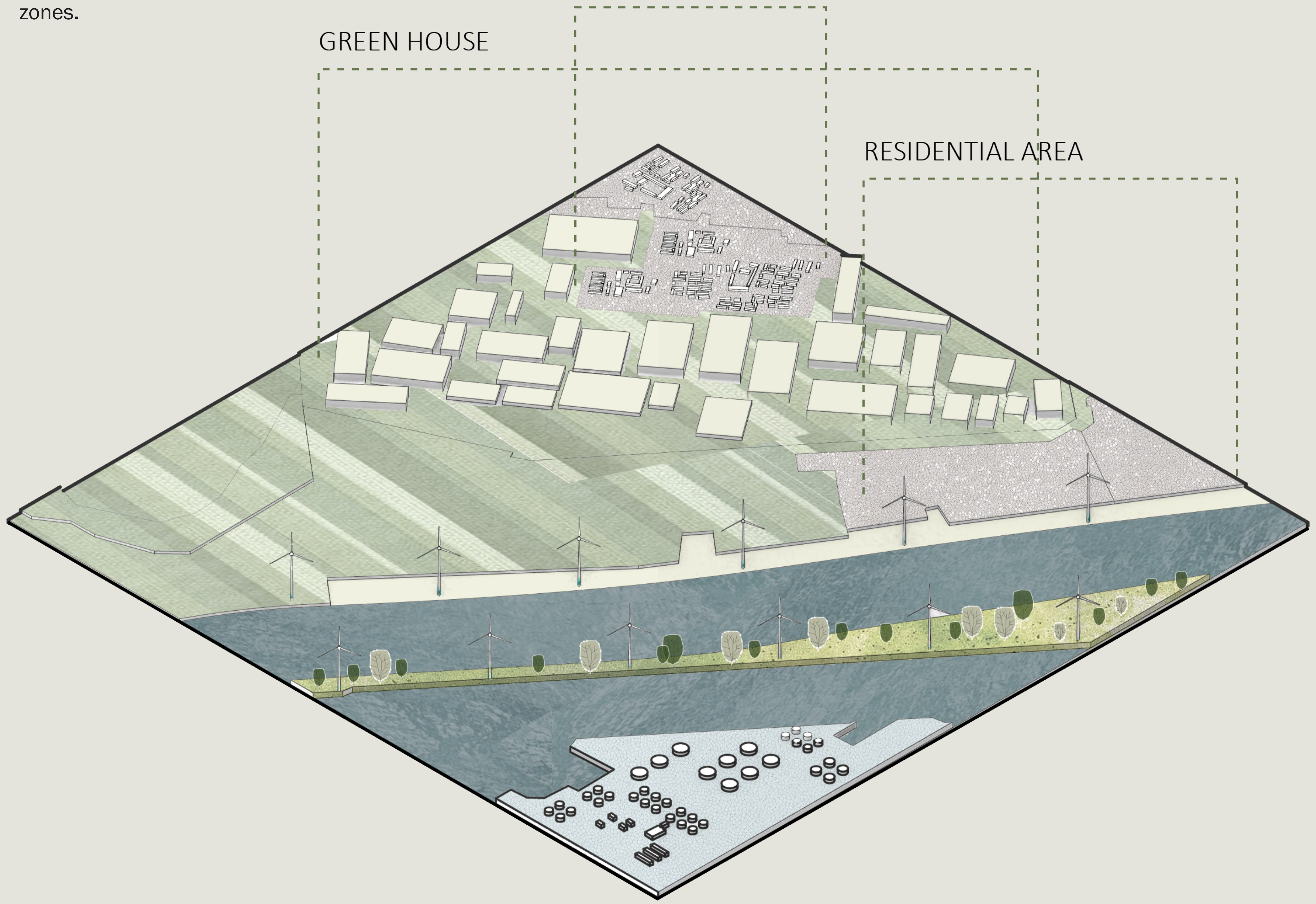
before



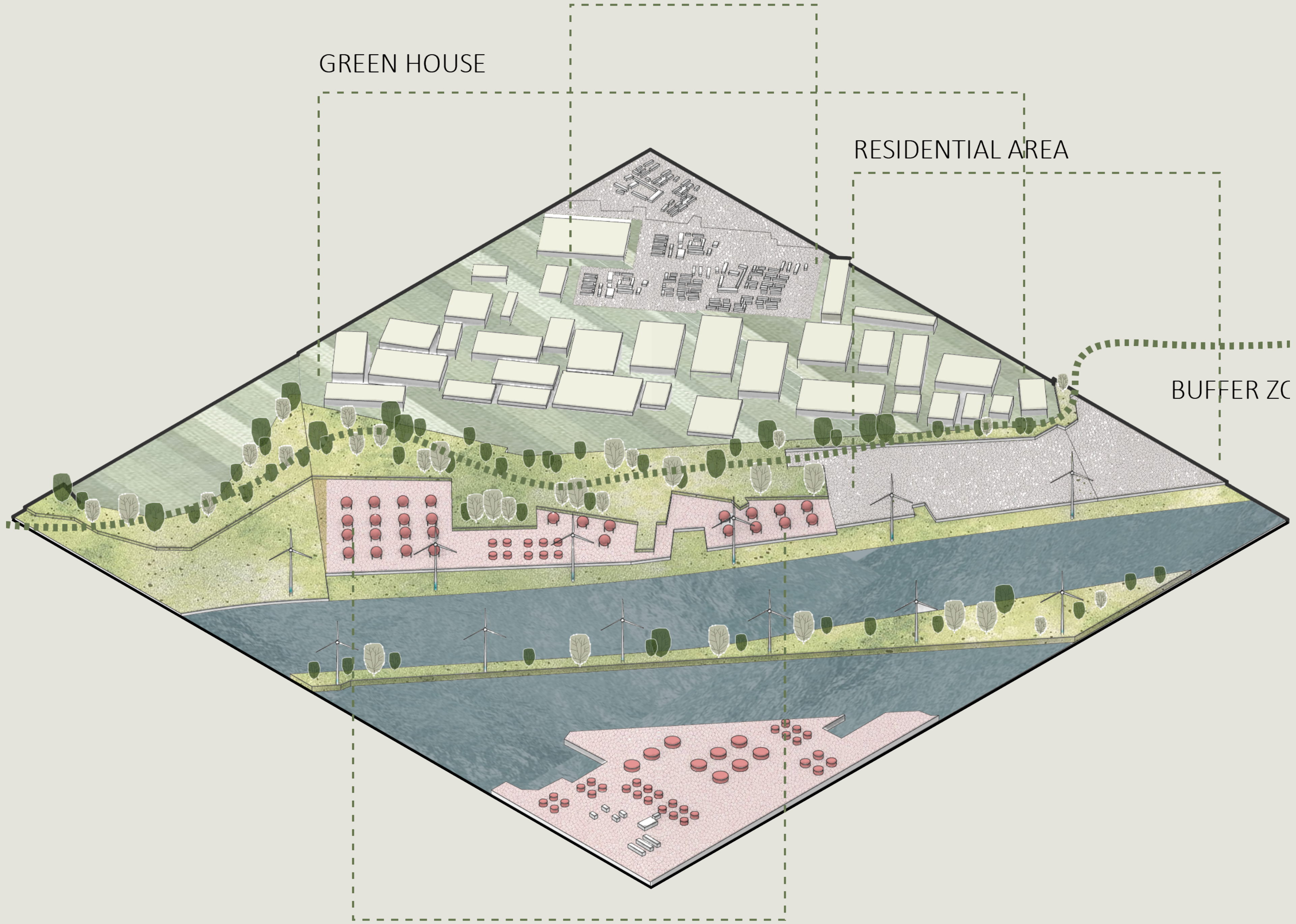
after


M S C
H2
H2
H2

In centralized areas, a substantial amount of energy is required. However, to balance the conflict between energy needs and the impact of energy production on the environment (of inhabitants), buffer zones will be established between the energy storage and residential areas. This approach will lead to the creation of a new type of landscape, one that integrates energy production and storage facilities, with a buffer, in the environment of residential zones.

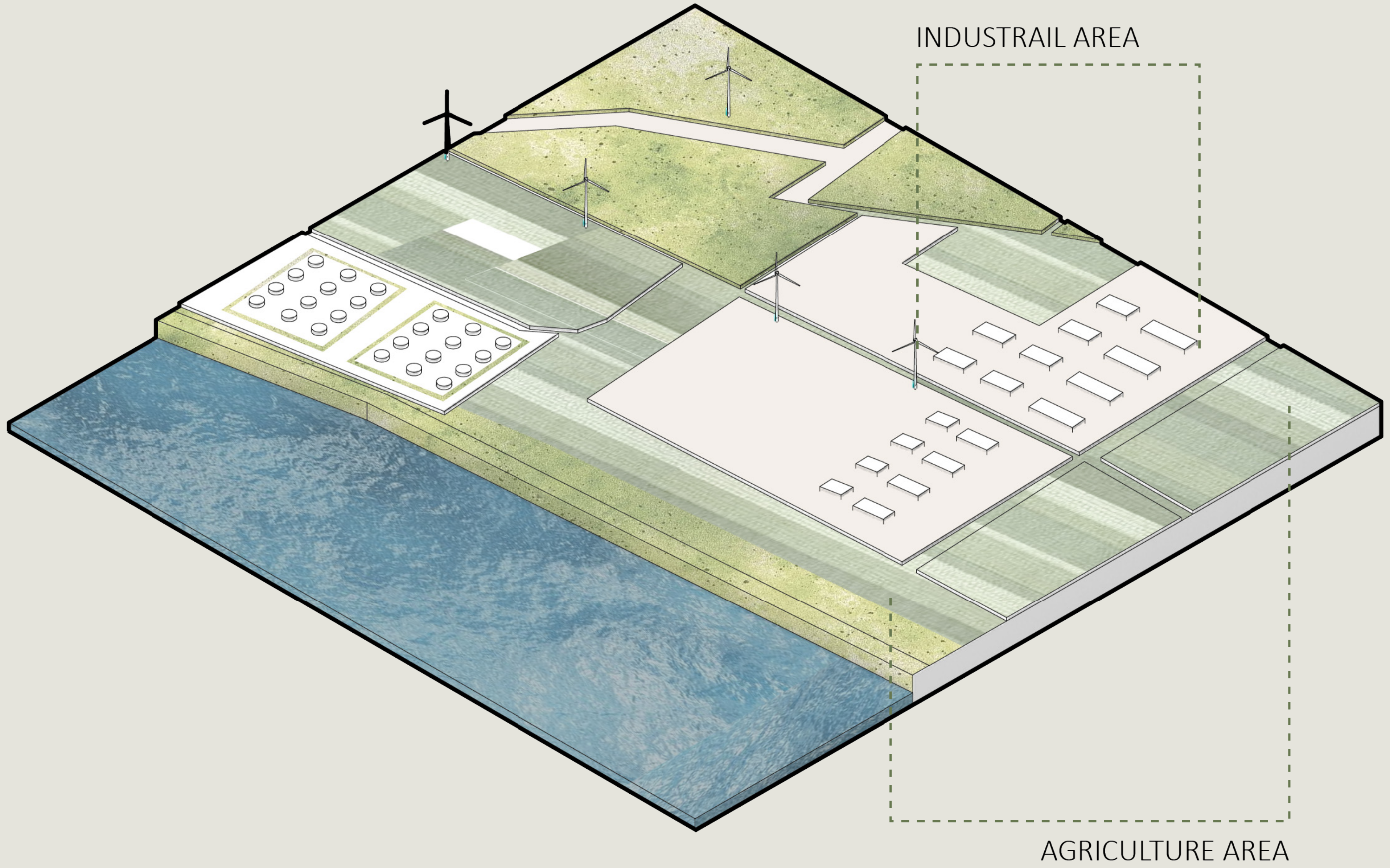


before

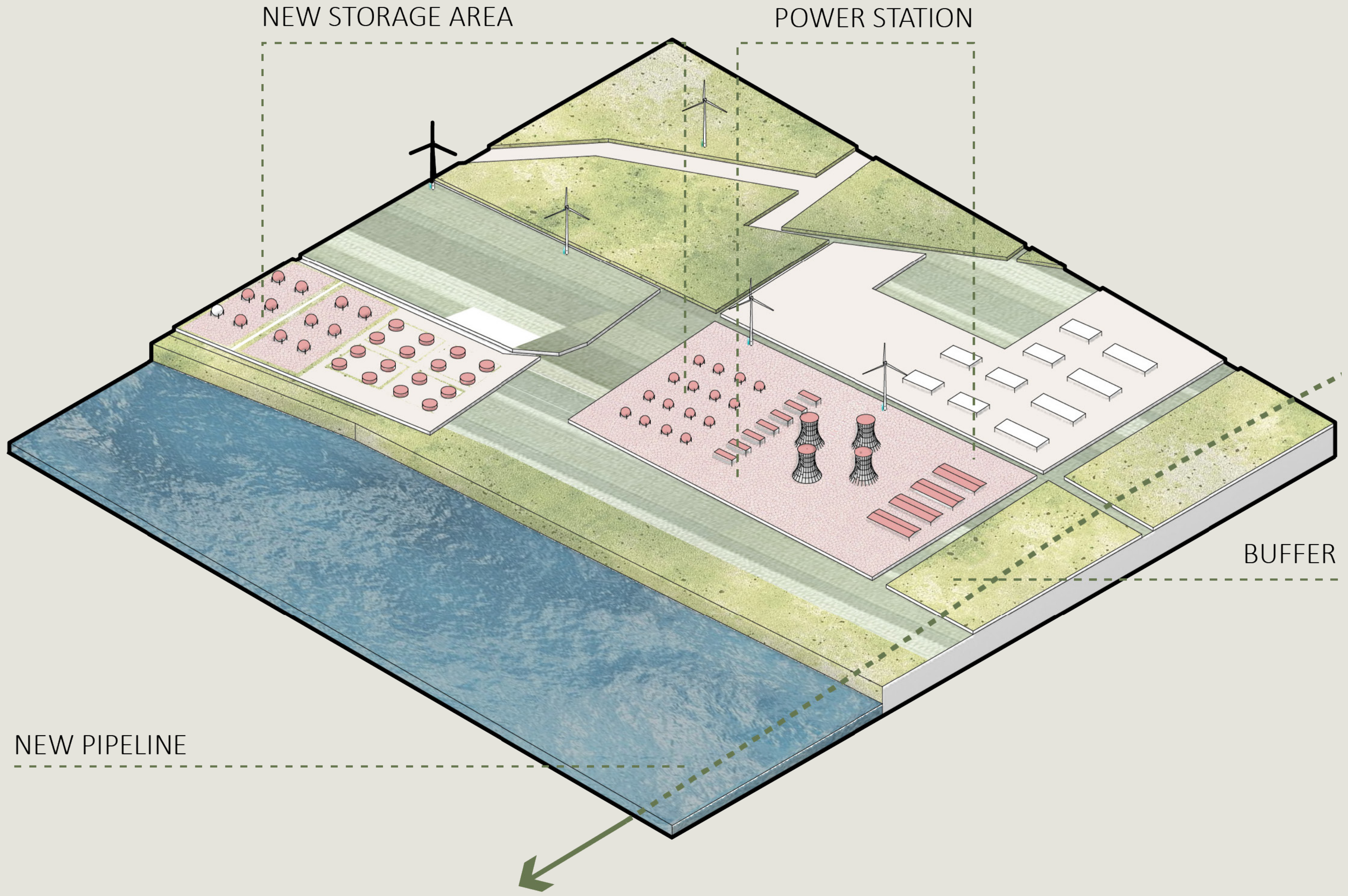


after

For small cities, new infrastructure in the form of pipelines and storage are needed, acting like batteries to provide energy for the necessary usage. New networks will be built beneath open areas for future repair and maintenance. Oil tanks will be transformed into hydrogen storage tanks and windmills will be built outside of natural areas.



before



after

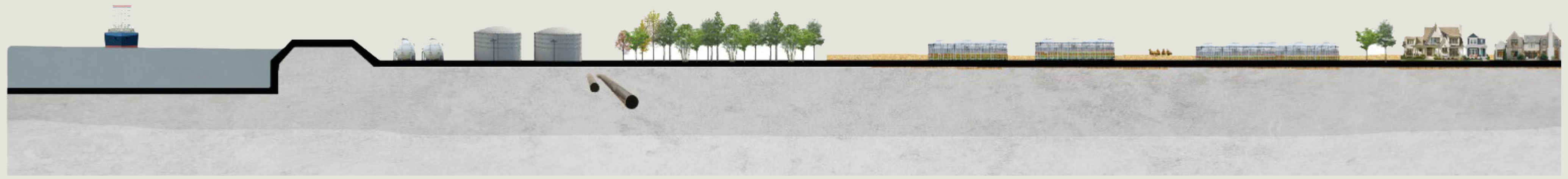
THE HARBOUR AS A TEST CASE

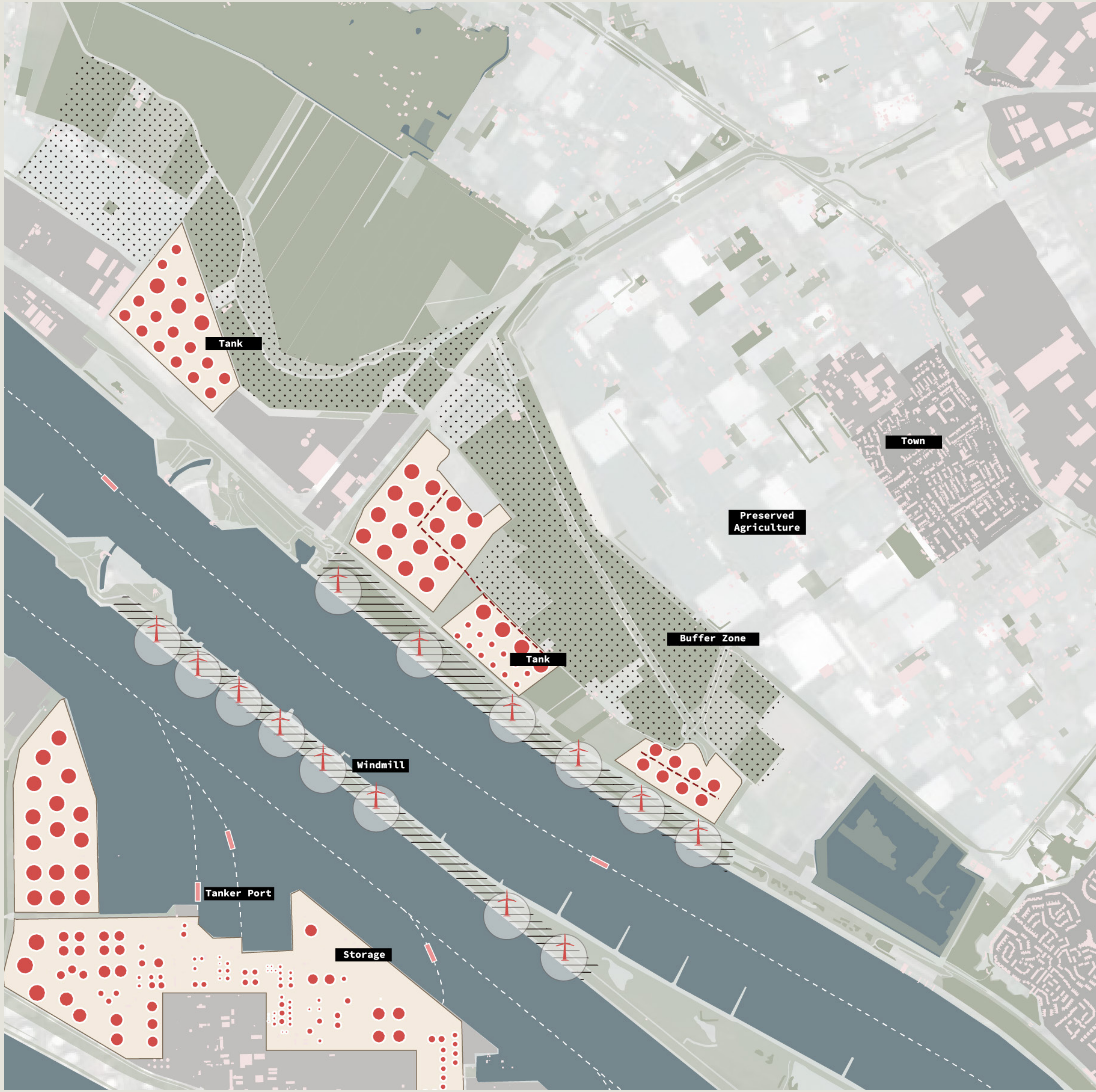
The harbour area is the central hub of South Holland, functioning as the key location for converting the electricity coming from offshore windmills into hydrogen, which is then stored in large tanks. To reduce the cost of hydrogen production, the hydrogen plant is situated as close to a water source as possible, allowing direct use of water as a raw material for the production process. In addition, several batteries are needed in the vicinity of the plant. As the largest battery on the entire hydrogen route, the harbour area stores vast amounts of hydrogen for subsequent distribution to other towns via different types of infrastructure. The original oil tanks in the harbour will be replaced with new liquid hydrogen storage tanks that can store more hydrogen in less space, enabling the harbour area to better manage energy shortages. The tank sites are strategically located at the water's edge for fire safety purposes.

To separate the port from the town, a large natural green belt on the south side of the harbour will be preserved and utilised. Overall, the harbour area serves as a crucial element of the plan, ensuring efficient and effective energy production and distribution.

THE CITY AS A TEST CASE

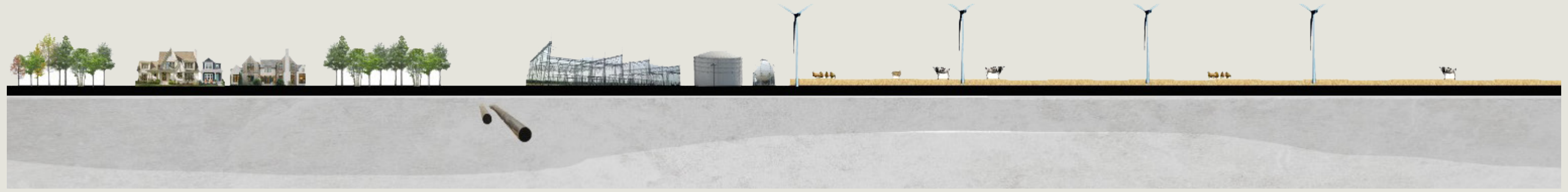
The storage space in the centralized area is located by the water to meet firefighting requirements and facilitate the unloading of hydrogen from ships. Since the centralized area is more populated, more land is needed for storage, which is usually derived from agricultural areas along the waterfront. A wide buffer zone is required along the outside of the storage area, usually consisting of natural greenery to ensure a safe distance and help hide the energy landscape behind it. Beyond the buffer zone, there is usually a large agricultural area to minimise the visual impact and safety threat of the hydrogen storage tanks. The large windmills on the original waterfront will be retained to continue supplying electricity to the local area.

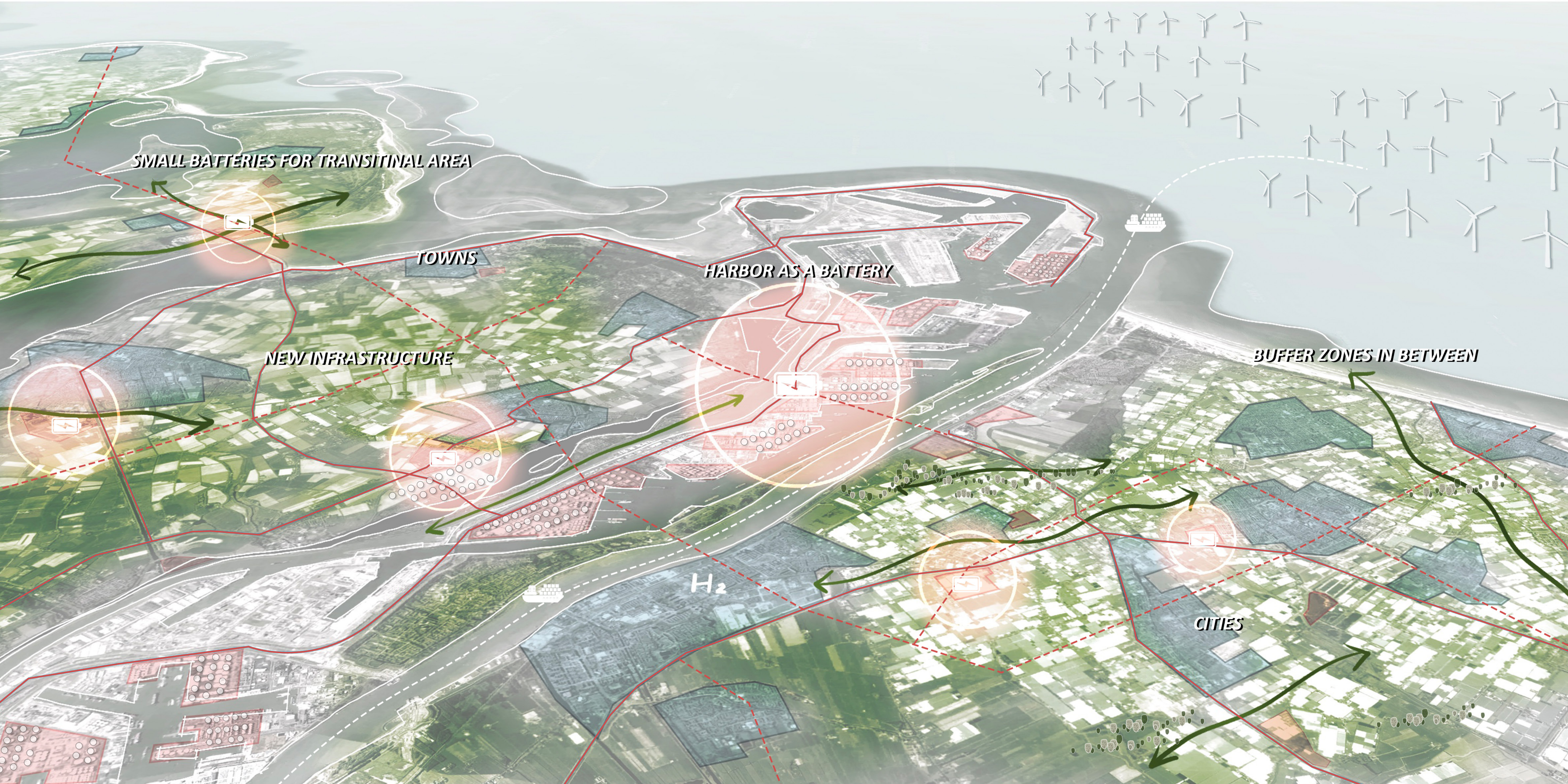




THE IN-BETWEEN AREA AS A TEST CASE

In this in-between area, the main form of energy is hydrogen from large batteries, supplemented by locally produced energy, primarily wind power. This particular in-between area is located fairly close to the centralized network. Power stations in this area are usually situated near larger surrounding towns to facilitate the energy demand of a larger population. Similar to the centralized area, the location of hydrogen storage tanks in the in-between area is preferably close to the waterfront. However, the number of storage tanks required here is relatively small, resulting in a smaller land requirement to meet the energy needs of the local population. The location of large windmills is often at the edge of agricultural areas to preserve the integrity of the agricultural land, while also being situated near the power station for efficient energy transmission. Hydrogen pipelines in this area generally run along the edge of large green belts close to towns and power stations, providing easy access and maintaining a safe distance from the town.




SMALL BATTERIES FOR TRANSITINAL AREA
TOWNS
HARBOR AS A BATTERY
NEW INFRASTRUCTURE
BUFFER ZONES IN BETWEEN
H_2
CITIES

CONCLUSION

A FUTURE FOR EUROPE WITH RENEWABLE ENERGY

WEAVING ENERGYSCAPES ASSESSMENT

Energy is everything. It shapes us and the way we live. How it shaped the past, it will also shape the future. This project shows that this future, with renewable energy sources, will face some major challenges, especially on the subject of energy reliability. To get a grip on what maintaining a reliable energy system will look like, the current system has been analysed and tested to overcome the challenges the energy transition will bring. The utilisation of hydrogen, as a means to store and transport renewable energy, is a key element in the project. It is a solution to the challenge of bringing reliability into our future energy system. Hydrogen's suitability for integration into the current energy infrastructure makes it a sustainable choice.

Coming back to the research question of this report: How can the network of existing infrastructure contribute to solve the spatial implications of the energy transition by introducing hydrogen as a sustainable energy carrier?

With the research and design finished, this main question can be answered using the posed sub questions.

Fairly early on in the project it was clear that the transition to renewable energy will leave no type of landscape untouched. The challenge is to make changes in the right place at the right time, and especially, in the right way. This way of changing was defined partially by using a self made model to characterize different energy landscapes. The three types of energy landscapes, centralized, decentralized and in-between, show what kind of energy system is needed. Therefore, explaining what is demanded from an area. Existing infrastructure is used to make the transformation not only sustainable, but also to preserve the current identity. The transition will bring situations where preserving is not possible, the project shows how to make the best weighted option in these circumstances.

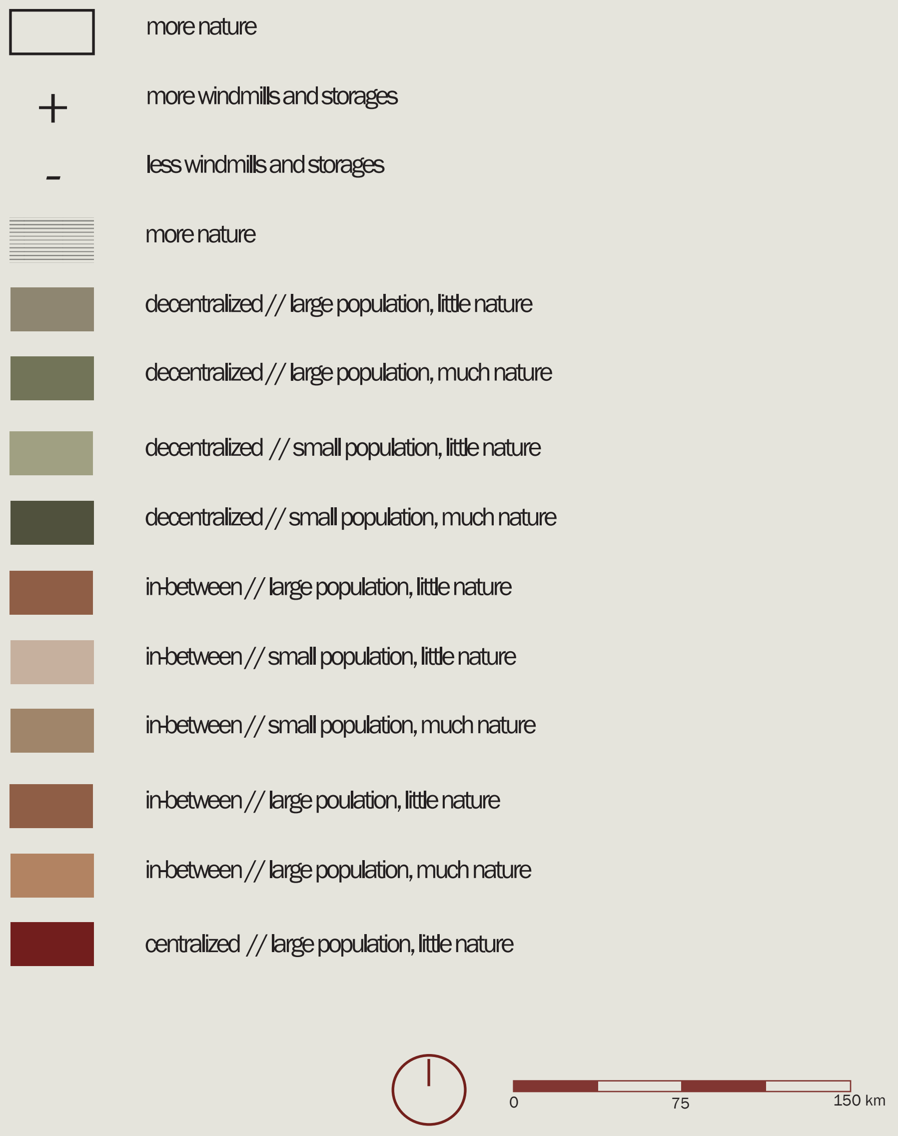
Spatial implications play a big role in the transition. Using an algorithm, the actual amount of energy elements are calculated for every area. This translates the spatial implications of the transitions to actual numbers, which facilitate an even more detailed view of the collision between space and energy needs. Working with these collisions is guided by recommendations that show how to work with the dilemmas that the energy transition brings along. These solutions are closely connected to the values of the project. Justice, resilience, availability and preservation are values that are guiding in the decisions that are prescribed for these challenges. With these recommendations hydrogen can function as an element that contributes to the energy transition in a positive way on multiple levels. It brings stability to the energy systems, making the whole future of renewable energy production more stable. The diversity in energy systems contributes to making diverse areas that build up resilience to future challenges.

The results of the project show interesting findings that can tell a lot about our future energy systems. At the same time they may feel hard to grasp because of the big differences to how we are living now. While this can be seen as a weakness, it can also be a wake-up call to show that we are on the verge of a big event. Giving a more detailed impression on how this transition will develop over time can be an interesting addition for a future project. At the same time, the complexity of the project makes it hard to make exact decisions on how certain events will fold out in the future. In a time where developments are going faster than ever, this only gets harder to predict.

The final product of the project is a good representation of the ending of the project. The map shows how the made up recommendations will unfold on a bigger scale. It shows that different areas will face other transformations and challenges. It is a map that tells a lot of stories, and therefore asks a lot of new questions. Questions that will not be answered in this project, but will be given to the reader to take with them to contemplate and consider, leaving open the endless possibilities for (de)growth and transformation in the future.

The outcome shows how energy weaves itself through urbanism, or the other way around, and takes us to a future where new and extreme transformations are bound to happen. Just as our relation with energy changed from pre industrial to industrial eras, the transformations that are ahead of us will question our current way of living and lead us to living environments we never had imagined otherwise. Do not be worried, just as energy, urbanism never gets lost, it just changes its shape.

“Energy cannot be created or destroyed, it can only be changed from one form to another.” – Albert Einstein



REFLECTION

THE PROCESS

INDIVUDUAL REFLECTION YINGXING

It was a great group work collaboration! What I was most happy about was that the group defined our vision at the beginning, which gave us a clear goal for all the work that followed.

There were many interesting lectures this semester, and some of the content discussed before each class was something I had never considered when I was in China, such as some political topics and the complex game of interested parties involved. As a Chinese student, I got to see a completely different approach to planning here, which is to fully consider the interests and demands of all parties, such as how to make large fossil energy companies step by step out of the history stage through precise compensation.

The values made me realize that different values can lead to completely different spatial solutions. First we need to determine what are our most important values, then assume different futures oriented by different values, and finally strike a balance among these different solutions. How to get this balance is the focus of the whole spatial solution, which better shows the main values promoted by this solution.

The vision guides our future direction, and this large scale, high completion vision is very clear about the values we want to achieve, and from the values we derive a series of strategies and spatial design solutions that follow. The vision clearly articulates how this future system will work, which allows us to define what kind of space these systems will require.

First, in our planning scenario, governance is reflected in the way people in different areas of the new hydrogen energy system access energy. Through the development of new policies, people in different regions have the ability to obtain enough energy for their needs from large networks or locally. Although the construction of the energy network relies mainly on the government, residents can still trade energy in a limited way through the public energy network.

Energy is the blood of human society. All countries want to ensure their own energy self-sufficiency nowadays. However, in a densely populated and small area like the Netherlands, there is very little land available, so a complete hydrogen energy system is not only for the Netherlands, but also for Northwest Europe and the North Sea. New energy is a very promising public good for the planet in the coming decades. Almost all regions are pushing for an energy transition. Now when I look at news related to new energy technologies, such as photovoltaic energy storage, flywheel energy storage and a variety of other news, I realize that green hydrogen is only a small part of new energy. I am heartened by the fact that many different new energy sources will eventually form a new energy system for the planet in a few decades, and the benefits will be felt in a thousand years, which may be a good thing for all of humanity.

INDIVIDUAL REFLECTION XINYI

Reflection of Xinyi Wu: My knowledge of the topic has gradually increased. At the beginning, throughout the excursion we saw a significant amount of the energy landscape and identified the various types of energy that are currently produced in the Rotterdam harbor. We concentrated on renewable energy when it came to the energy transition. In order to attain energy stability and self-sufficiency in non-urban areas while also supplying energy to urban areas, our group project set out to design a system. We have to do a lot of research on different energy technologies, systems, and governance frameworks to achieve this goal. Besides, the interaction between research and design was essential since the knowledge we learned from research immediately informed our design choices. After researching on the hydrogen production flow we designed the new flow through three different networks base on the infrastructures exist.

Research on various energy technologies and systems, including hydrogen batteries, solar panels, wind turbines, and centralized vs. decentralized systems, took up a large amount of our work during the project's early stages. We were able to build a design plan that could successfully address the energy needs of both urban and non-urban areas thanks to the study that assisted us in identifying the technologies and systems that were most appropriate for our project.

The role of a vision in our planning and design proposal was also essential. We developed a clear vision for our project that focused on achieving energy self-sufficiency and stability in decentralized areas while also promoting energy justice and safety. This vision influenced our development strategy by guiding our decision-making process and helping us to stay focused on our project's primary goals.

The governance aspect was also embedded in the planning and design proposal of our project. We recognized that effective governance structures were necessary to ensure the successful implementation and operation of our system. We included governance elements such as stakeholder engagement, policy development, and regulatory frameworks in our design proposal to ensure that our project could operate in a sustainable and equitable manner. The reasons for embedding governance aspects in our proposal were to ensure that our system was socially acceptable, environmentally sustainable, and economically viable. In order to understand how the power and benefits are distributed among the parties in the energy system, we made a matrix about the stakeholders. During this process we brainstormed together and had a nice outcome.

Overall, our group project required a close relationship between research and design, a clear vision, and an embedded governance structure to achieve our goals of energy self-sufficiency, stability, justice, and safety. Through this project, we gained valuable insights into the complexities of energy systems and the importance of considering various factors such as technology, governance, and social justice in energy planning and design. It is vital to emphasize that I truly like how this quarter is set out. The combining of theoretical lectures with design courses is quite logical and consistent, and it tremendously benefited our group. Besides, our regular cooperation allowed us to work effectively. And I really value each group member since we can all learn from one another and work together effectively. This quarter, I honestly learned a lot of knowledge.

INDIVIDUAL REFLECTION ISAMU

Before the project started, I already looked forward to working on a big scale. It was something I have never done before, but actually see myself working with in the future. Researching and designing on this scale brought new challenges that I didn't face before. Already quite early in the project I noticed that data will be an important element in our research and design process. This was something I really enjoyed. I personally see data in urban planning as something essential, because it helps in understanding the current situation and identifying patterns and trends in urban development, especially on the big scale that we are working on. I also got the possibility to design with data in this project, by making algorithms that composed a model which was one of the core elements of our vision. This balance between the evidence-based decision-making with the data, and the more conceptual design thinking came to an inspiring outcome. The strategy that resulted from the vision held on strong to the ideas of the vision, but at the same time there was a lot of room to come with interesting results and ways of working. Translating the values we created into an algorithm was a big challenge for me, but this meant I was even more proud of the outcome. Values, recommendations and rules are the outcome of long group discussions and going backwards and forwards in implementing and seeing what it results in. Being able to translate these elements that we implemented on the small scale to a big scale, gives an extra dimension to the decisions we make. In the end I think it has been a good decision to never fully let go of the scale of Northwest Europe. This has resulted in an integrated outcome of the project, nicely connecting to our title "Weaving Energyscapes".

Our group consist of different characters with different skills. During the project we found out how to utilise our skills in the right way, I focused primarily on the technical part. With my background in urban design and data science, my personal goal was to work with these elements in a synergetic way. I really enjoyed showing and discussing my findings with the group and tutors. The tutors pushed me to keep working in the way I was doing, which in the moment sometimes felt like I was drifting away too much from urban planning. In the end I am actually really happy this happened, because I now realize that this way of working is essential for future urban planners. In general, I look back to an interesting and fun project where I gained a lot of new insights and skills.

INDIVIDUAL REFLECTION MEREL

As the quarter is coming to an end, I will take the time to reflect on the project that we indulged in the past nine weeks. Designing on a regional or continental scale was something I personally had never done before, which made me curious as to how things would play out at such an ungraspable scale. What type of stakeholders would be influential? How to deal with policies that differ from nation to nation? How is it even possible to set up a framework that can be applied in such different environments and circumstances? All of these questions (and more) were addressed over the last weeks, and I learned a lot of things from the answers.

The balance between research and design in this project is clearly visible. A lot of research needed to be done to find out how the system of storing energy as hydrogen actually works and how it could be applied on a larger scale. A lot of developments regarding hydrogen are now in the initiation phase, so there was no working example available for us to get inspired by. The eventual design is very much based on research and data, as we composed an algorithm to determine the landscape types, I feel that this adds to the futuristic character of a future with hydrogen.

The very first idea of the vision was already born in the first week, 'the harbour as the battery of the future' is the idea from which the whole project originated. The vision has been a tool to guide us towards the strategy. The strategy was also greatly influenced by the data-driven model but then applied to physical situations. The strategy was not only influenced by impersonal maths but also contained social aspects, such as information from relevant news articles about the problems in certain towns in our project area. This has led to a vision that is both human and scientific.

The governance in our group flowed in a very natural way. Personally, I had a moment in which everything was becoming unclear, so I took the leading task upon myself to gain clarity and understanding of what we were actually all doing. Naturally, this leadership role stayed with me until the very end. To stay focused, it is crucial for me to understand what is going on in a group project, which is why the leadership role seems to fall upon me on a regular basis. However, I despise the 'management' side that comes with having the overview. I do not like to tell others what to do, I just like having a nice organized overview. We had a very broad variety of complementary talents in our group, which was essential in achieving these results!

BIBLIOGRAPHY

Ace. (2019). Prescriptive Requirements for Photovoltaic System. energy code ace. https://energycodeace.com/site/custom/public/reference-ace-2019/index.html#!Documents/72prescriptiverequirementsforphotovoltaicsystem.htm

Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Capetillo, N. Å., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters, 9(3), 034012. https://doi.org/10.1088/1748-9326/9/3/034012

Bilfinger Tebodin - Bilfinger Tebodin B.V. (2023, 9 februari). Bilfinger Tebodin B.V. https://www.tebodin.bilfinger.com/

Change, N. G. C. (z.d.). Carbon Dioxide Concentration | NASA Global Climate Change. Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/vital-signs/carbon-dioxide/#:~:text=Key%20Takeaway%3A,in%20less%20than%20200%20years

EAZ wind. (z.d.). Onze windmolen | EAZ wind. EAZ wind NL. https://www.eazwind.nl/onzewindmolen

Energietransitie. (z.d.). Port of Rotterdam. https://www.portofrotterdam.com/nl/haven-van-de-toekomst/energietransitie

Energy use per person. (z.d.). Our World in Data. https://ourworldindata.org/grapher/per-capita-energy-use?region=Europe

Europe population 2021 - StatisticsTimes.com. (z.d.). https://statisticstimes.com/demographics/europe-population.php

European Commission. (z.d.). The EU and the United Nations – common goals for a sustainable future. https://commission.europa.eu/strategy-and-policy/international-strategies/sustainable-development-goals/eu-and-united-nations-common-goals-sustainable-future_en

European Commission, official website. (z.d.). European Commission. https://commission.europa.eu/index_en
Gebouwd, D. & Duurzaam Gebouwd. (2022, 1 december). Gasmonteurs opgeleid voor werken met waterstof. Duurzaam Gebouwd. https://www.duurzaamgebouwd.nl/artikel/20220909-gasmonteurs-opgeleid-voor-werken-met-waterstof#:~:text=Een%20bijkomend%20voordeel%20is%20dat,al%20in%20de%20grond%20liggen.

Good Energy. (2023, 6 januari). How do wind turbines work? | Good Energy. https://www.goodenergy.co.uk/how-do-wind-turbines-work/#:~:text=Most%20onshore%20wind%20turbines%20have,of%20around%201%2C500%20average%20households

How do wind turbines work? | Good Energy. (2023, 6 januari). Good Energy. https://www.goodenergy.co.uk/how-do-wind-turbines-work/#:~:text=Most%20onshore%20wind%20turbines%20have,of%20around%201%2C500%20average%20households

Howell, B. (2023, 26 januari). What's The Best Angle and Direction for Solar Panels? | The Eco Experts. The Eco Experts. https://www.theecoexperts.co.uk/solar-panels/best-angle-and-direction

IEA. (z.d.). Monthly Electricity Statistics [Dataset]. https://www.iea.org/data-and-statistics

ISO | ISO Tanks Worldwide | US/China. (z.d.). isotanks. https://www.isotanks.com/iso

J, M. (z.d.). Swedish Public Housing project goes Off-Grid with Solar, Hydrogen and fuel cells. www.linkedin.com. https://www.linkedin.com/pulse/swedish-public-housing-project-goes-off-grid-solar-h2-michael-jensen/

K-Means Clustering Algorithm - Javatpoint. (z.d.). www.javatpoint.com. https://www.javatpoint.com/k-means-clustering-algorithm-in-machine-learning
Ltd, S. U. R. E. C. (z.d.). How are UCO or UCOME shipped to overseas market for large orders from China. www.linkedin.com. https://www.linkedin.com/pulse/how-uco-ucome-shipped-overseas-market-/?published=t

MAHB. (2021, 10 december). When Fossil Fuels Run Out, What Then? - MAHB. https://mahb.stanford.edu/library-item/fossil-fuels-run/

NASA hydrogen tank. (z.d.). NASA. https://ntrs.nasa.gov/api/citations/20220004276/downloads/Cold%20Facts_LH2%20Sphere%20Update.pdf

National Institute for Occupational Safety & Health | NIOSH | CDC. (z.d.). https://www.cdc.gov/niosh/index.htm

Net Zero Carbon Emissions | PETRONAS Global. (z.d.). https://www.petronas.com/sustainability/net-zero-carbon-emissions?gclid=CjwKCAjwrdmhBhBBEiwA4Hx5g-0zfjWpPkFdsS_HKMabf2-E-8aNaYGwch9CzqRutRtN0B64vt30VhoCaJQQAvD_BwE

Onze windmolen | EAZ wind. (z.d.). EAZ wind NL. https://www.eazwind.nl/onzewindmolen

Our World in Data. (z.d.). Energy use per person. https://ourworldindata.org/grapher/per-capita-energy-use?region=Europe

Port of Rotterdam. (z.d.). Energietransitie. https://www.portofrotterdam.com/nl/haven-van-de-toekomst/energietransitie

Primary Energy Consumption : 2050 Forecasting | Enerdata. (z.d.). https://eneroutlook.enerdata.net/forecast-world-energy-primary-consumption.html<i>
Prospects for using hydrogen in gas power plants are becoming tangible. (z.d.). <span>https://press.siemens-energy.com/global/en/pressrelease/prospects-using-hydrogen-gas-power-plants-are-becoming-tangible

Rocky Mountain Institute. (2023, 6 april). RMI. RMI. https://rmi.org/

Schröder, T. (2022, 29 september). Waterstof niet geschikt voor verwarmen huizen, zegt studie. Maar klopt dat wel? Change Inc. https://www.change.inc/energie/waterstof-is-niet-geschikt-voor-het-verwarmen-van-huizen-38960

Sustainable Development Goals - UN Global Compact NL. (2023, 26 januari). UN Global Compact Network Netherlands. https://gcnetherlands.nl/en/sustainable-development-goals/

THE 17 GOALS | Sustainable Development. (z.d.). https://sdgs.un.org/goals

The EU and the United Nations – common goals for a sustainable future. (z.d.). European Commission. https://commission.europa.eu/strategy-and-policy/international-strategies/sustainable-development-goals/eu-and-united-nations-common-goals-sustainable-future_en

The International Association for Energy Economics. (z.d.). https://www.iaee.org/

United Nations. (z.d.). THE 17 GOALS | Sustainable Development. https://sdgs.un.org/goals

United Nations Development Programme. (z.d.). UNDP. https://www.undp.org/

Ustolin, F., Paltrinieri, N., & Berto, F. (2020). Loss of integrity of hydrogen technologies: A critical review. International Journal of Hydrogen Energy, 45(43), 23809–23840. https://doi.org/10.1016/j.ijhydene.2020.06.021

Vattenfall. (z.d.). Opbrengst zonnepanelen per m<sup>2 | Vattenfall. Vattenfall.nl. <span>https://www.vattenfall.nl/kennis/opbrengst-zonnepanelen-per-m2/

Wikipedia contributors. (2023, 5 april). Tank container. Wikipedia. https://en.wikipedia.org/wiki/Tank_container

World Bank Group - International Development, Poverty, & Sustainability. (z.d.). World Bank. https://www.worldbank.org/en/home html#!Documents/72prescriptiverequirementsforphotovoltaicsystem.htm

APPENDIX

How was the final map made

1. Overlay the raster with the landuse

2. Overlay the raster with the landuse

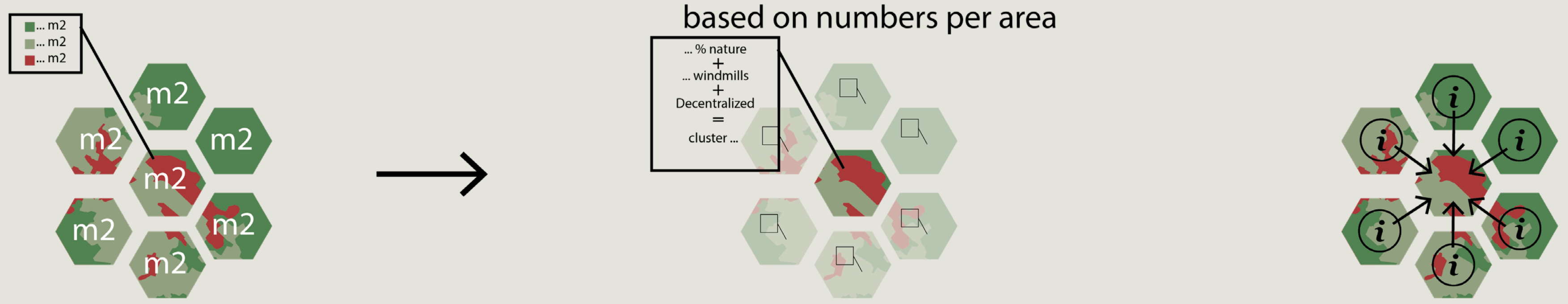
3. Clip the layers

To find out how much nature, agriculture and artificial area every area has by overlaying it with the hexagon raster. The landuse is clipped into every hexagon.

4. Calculate the landuse of the hexagons seperately

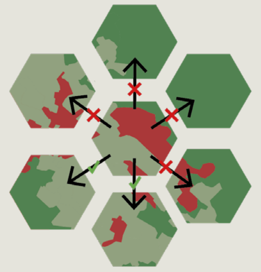
5. Apply the made up typologies to the hexagons by making clusters based on numbers per area

6. Give the information about surrounding hexagons to hexagon



7. Check if needed action for hexagon is possible

The center hexagon needs to move his windmills, it checks if it is possible to move it to the surrounding hexagons



8. Doing this gives a map that shows a scenario where hexagons are based on its cluster and surroundings