RESILIENT ENERGY, ENERGETIC CITY

Adaptive strategies for coastal regions in transition

COLOPHON

Resilient Energy, Energetic City

P5 Report of MSc Urbanism thesis

AUTHORS:
Jie Wang
Student ID: 4578546
wj1250431@gmail.com

KEYWORDS:
Climate change
Energy transition
Urban transformation
Evolutionary resilience

MENTOR TEAM:
Dr.ir. Diego Sepulveda Carmona - Section Spatial Planning & Strategy
Dr.ir. Hamed Khosravi - Section Urban Design

Faculty of Architecture, Delft university of Technology
MSc Architecture, Urbanism and Building science
MSc track Urbanism
Delta Urbanism Research Group / Delta Interventions Studio 2017–2018
Dr.ir./ Arch. Taneha Kuzniecow Bacchin, graduation Delta Interventions Studio leader

Delft, Netherlands, 2017 - 2018

Resilient Energy, Energetic City

Adaptive strategies for coastal regions in transition

P5 Report

Jie Wang

Delft, Netherlands
2017 - 2018

0 INTRODUCTION

0.1 Motivation of the study

0.2 Context of project

0.3 Problem field

0.4 Problem analysis, Problem statement

0.5 Hypothesis

0.6 Research question. Subquestions.

Research framework

0.7 Methods & Methodology

0.8 Theoritical framework

0.9 Goals of the project, Intended products

1 RESEARCH

1.1 Climate change impact

1.2 Transitional energy system

1.3 Urban structure and urban system

1.4 Synergies

1.4.1 Climate change and energy system

1.4.2 Climate change and urban system

1.4.3 Energy system and urban system

1.5 From risks to opportunities

4 PHASING

4.1 Short term development - 2020

4.2 Short-medium term development - 2025

4.3 Medium-long term development - 2040

4.4 Long term development 2050

4.5 Conclusion and benefits

2 SCENARIO

2.1 Defining trends

2.2 Building exploratory scenarios

2.3 Evaluation of current situation

2.4 Design & planning challenges

2.4.1 Challenges of climate changes in months and years

2.4.2 Challenges of energy system in energy generation and consumption

2.4.3 Challenges of future development in population and infrastructure

2.5 Recommendation and proposal

3 DESIGN

3.1 Climate consensus - scientific views on climate change

3.2 Vulnerability assessment - recognization of risks in local scale

3.3 Resilience initiatives strategies

3.3.1 To be safe

3.3.2 To be energetic

3.3.3 To be climatic

3.3.4 To be dynamic

3.4 Interlinking synergetic systems to improve the urban structure

3.5 Participatory urban regeneration

3.6 Implementation roadmap & synergies between different projects

3.7 Conclusion of design strategies

5 CONCLUSION & REFLECTION

5.1 Conclusion

5.2 Upscaling to the North Sea

5.3 Reflection

5.4 Societal and scientific relevance

ANNEX

- Timeframe
- Reference

0 INTRODUCTION

0.1
MOTIVATION OF STUDY

The dynamics of the deltas and the relation between dynamic natural process and societal development have a strong fascination for me, which was the trigger point for choosing Delta Intervention as my graduation studio.

In the human civilisation, deltas plays an important role on population agglomeration and economic production, which then lead to the development of major urban centres (Anthony, 2015). Different urbanisation processes and urban patterns happened on deltaic regions. People regarded the nature as the resources, in particular for energy. Though delta environment is quite attractive, it is meanwhile vulnerable to flooding, soil subsidence and salinization. Especially under the impacts of climate change, there are more risks and threats caused by sea level rise, increasing discharges of the rivers, intensity rainstorms.

The North Sea is facing such challenges. On account of the rich sources of offshore and convenient site for port, many energy infrastructure was built on the coastal regions. Energy was getting along with high emission of greenhouse gas. The consequence of that is frequent risk of climate change. Even though the transition towards renewal energy is happening to reduce greenhouse gas, this cannot stop the climate change immediately. Indeed, renewal energy infrastructure is more vulnerable.

The disruption of the energy system will have an influence beyond the physical level, which will also change the socio-economic system and even the urban systems. Also, it is not a unique case of the North Sea, but also the global challenge. Thus, it is urgent to search for sustainable transition from carbon-based energy to green energy under the condition of the impact of changing climate, which helps to improve the urban structure and increase the resilience to change situation.

More than that, the knowledge imputed and outputted in the graduation project is able to be transferred to other relevant research and design, for instance, the transition of energy system, transformation of redundant infrastructure, climate change on coastal region, resilience of complex urban system.

Fig. 1. Risk of North Sea infrastructure
Source: Platts, 2015. *http://www.platts.com/latest-news/oil/london/risk-of-north-sea-infrastructure-shutdown-rising-26201938*

Fig. 2. Wind turbines fall in extrem wether
Source: Seth Stapleton, Huron Daily Tribune via AP. *http://www.washingtontimes.com/multimedia/image/ap_wind_turbine_fallsjpeg/*



1



2

0.2
CONTEXT OF PROJECT

The North Sea is part of the North Atlantic Ocean, which is situated between Great Britain, Scandinavian Peninsula and the north of the European continent.

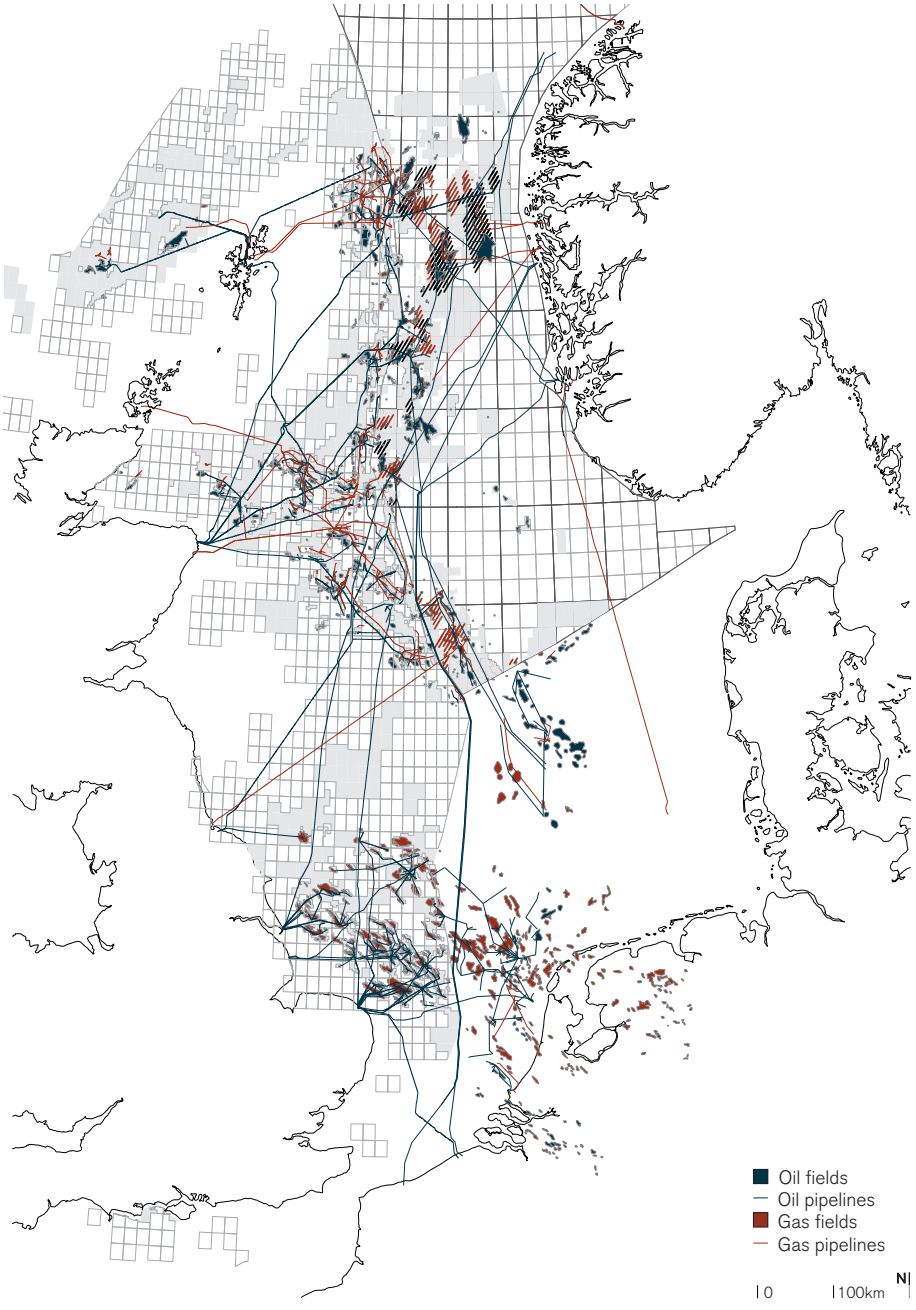
On account of the rich ecosystem, it has long time was a major fishery and was substantially expanded in the 19th Century (Holt and Raicevich, 2017). The source of energy resource such as oil and gas was discovered in 1959 and 1910, which now becomes the most important oil field and the largest natural gas field in western Europe (Glennie, 1998; Noreng, 1980).

It is easy to come into conflict without the constitutional status of the economic share. Thus the countries border the North Sea has exclusive fishing rights within 12 miles of territorial waters, and divided country rights of mineral resource based on the Convention on the Continental Shelf (Barry, Elema and van Der Molen, 2006).

Consequently, frequent human activities in the North Sea promoted to develop the discontinuous and diverse infrastructure at the border of the land as well as urban settlements (OSPAR, 2000).

In recent decades, climate change has put more pressure on the coastal development, in particular sea level rise, floods and erosion risk (Safecoast, 2008). Not only the landscape and coastal infrastructure will be influenced but also the social-economic aspects. Depending on the data from the Corine Land Cover 2000 database, more than 14 million people will be influenced who lived in the flood risk area accounting to 38,000 square kilometres.

Fig. 3. Oil and gas fields in the North Sea
Source: the Norway group II, D-i



3

Norway is situated in east north of the North Sea, which also connected with the Norwegian Sea and the Barents Sea.

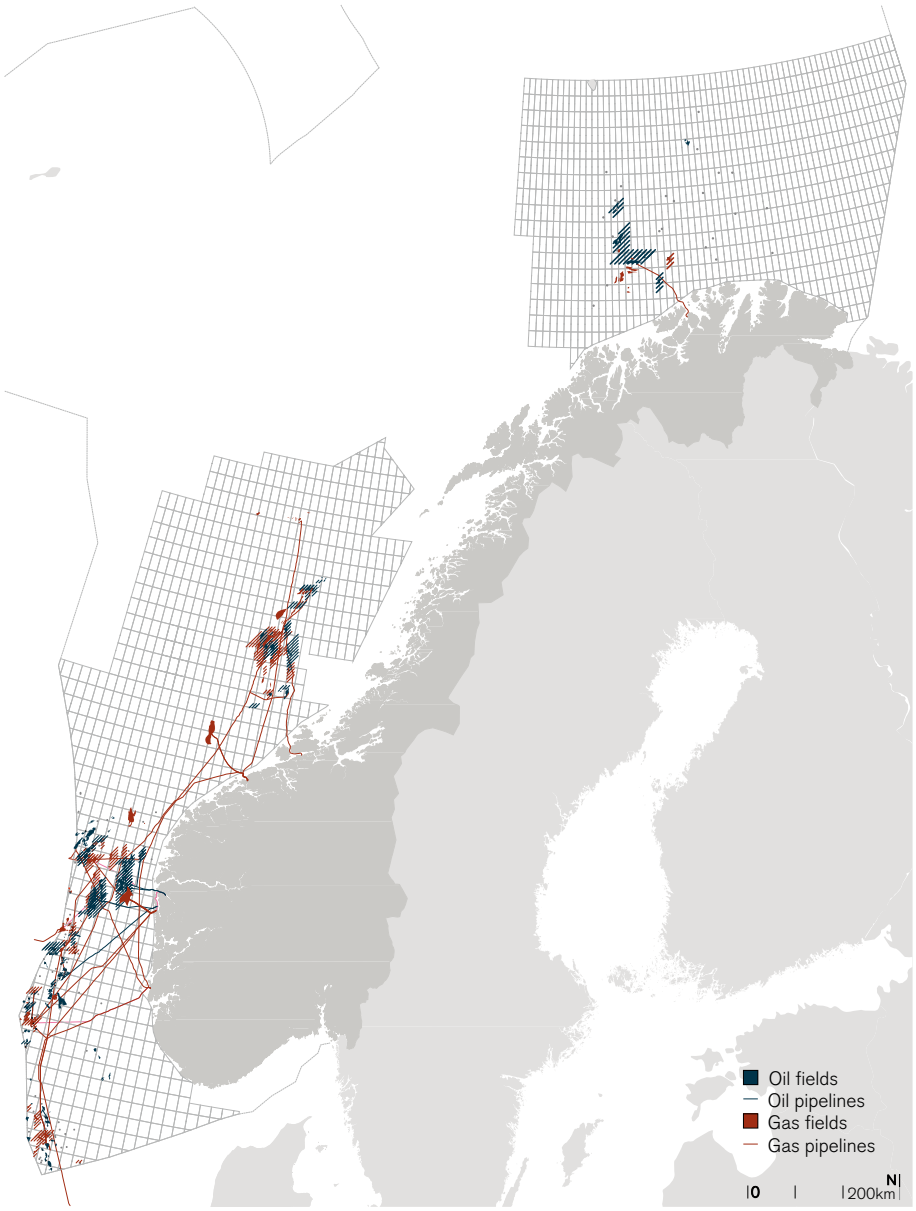
This excellent geographic advantage brings welfare to Norway since the 12th century. Before the oil and gas were found in the sea, Norway largely depends on the fishing culture and export of wood. And recent decades, Norway is known as a prosperous country in the world relying on the exploitation of natural resources in particular in the energy resource in the North Sea. The extraction of oil and gas and the related industries provides the job opportunity for almost 52,000 people (Bjørnland, 1998; Statistics Norway, 2017).

After the offshore oil and gas were first discovered in 1959, more suspicion aroused of the resource in the North Sea (Stauble & Milius, 1970). The first natural gas field was found in 1965, but because of lack of the usual technologies for bad weather, the platform collapsed and sank soon after (Ferrier & Bamberg, 1982). Then, oil was discovered in the northern part between UK and Norway. However, due to the high cost of modernising technologies and the low oil price, the oil was not considered as a profitable economy (Kemp, 2013). After 1990's, the industry reaches the peak.

Nowadays, the oil and gas sector becomes more mature and contributes as the most important exports. However, considering the rate of exploration and the remaining reserves (without regard to under trained resources), the era of petroleum will end in a few decades (CIA, 2017).

Although Norway is trying to use renewal energy to support national demand instead of the conventional energy, this transition cannot help Norway maintain state revenue and. More than that, this will provoke significant changes both offshore and onshore. The platforms in the sea might be removed, sank or transformed according to the demanding policy. Meanwhile, most of the industrial area, harbours, the urban patterns and the social-economic system will be greatly influenced.

Fig. 4. Offshore oil and gas fields - Norway
Source: the Norway group II, D-i



4

0.3
PROBLEM FIELD

The problem field includes five parts. 1. Climate change, 2. Delta Urbanism, 3. Energy transition, 4. Complex urban system, 5. Vulnerability & Resilience

1. Climate change

Climate change is becoming more acute today. The climate factors change dramatically which has greatly influenced eco-system, social-economy and health of human and animals. Moreover, changes in climate parameters like temperature and precipitation will lead to social and economic vulnerability.

The influence of climate change is a global phenomenon. However, different areas are suffering differently. Climate change may be beneficial for some regions or sectors, while most of the effects are adverse, for example the floods, storms, extreme events and shifting land which has a large environment, economic and human cost.

To control the increase of the global warming, UN climate summit in Paris in 2015 proposed that all the members should take action on reducing greenhouse gas.

2. Delta Urbanism

The delta is an alluvial plain created by the sediment in rivers when meeting the seawater in the estuary, gulf and ocean (Meyer and Nijhuis, 2014). These deltas possess characteristics of fertile soil, dynamic ecosystem, rich resource of food and energy, and advantageous positions for transfer and trade. This provides attractive conditions for urban development.

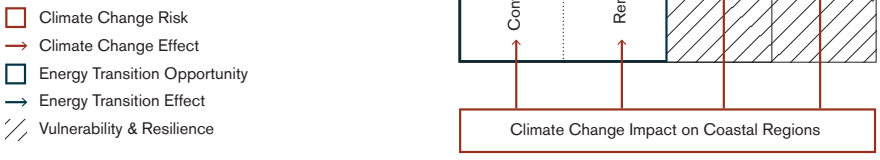
Urbanised deltas are regions gathered dynamic natural environments, economic values, human settlements and exploitation (Meyer and Nijhuis, 2014). A large construction of flood defence, drainage along with port and harbours transformed the basic ground of the delta region. This kind of action resulted in the land erosion, soil degradation, distributaries narrowed rapidly, sharp separation of water, which resulted in reducing the adaptive capacity and inducing vulnerability (Overeem and Brakenridge, 2009).

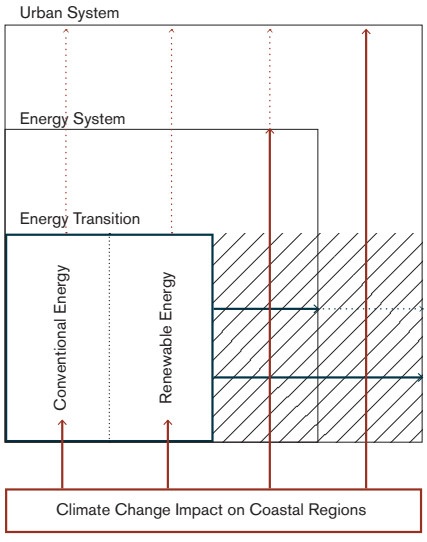
Fig. 5. The relation of problem fields
Source: Author

However, the vulnerability of urbanised deltas is the joint effect of the climate change and urbanisation process, industrialisation process and defence strategies. The specific conditions forms particularity of deltas, which needs a new type of urban planning (Meyer and Nijhuis, 2013). Delta Urbanism is started by the research group of the Delft University of Technology with the ambition to find out the solution of the process of transition in urbanised deltas by rethinking the relation between urban system and the natural environment in the delta region.

3. Energy transition

Energy transition is happening mainly based on two reasons. One is to reduce the greenhouse gas in order to mitigate climate change, which conventional energy is largely responsible for. Thus, the replacement of the conventional can definitely serve as the main contributor to climate change impact. Another reason is the finite resource of fossil fuel. Take the North Sea as the example, the oil and gas might be used up in the near





decades (based on the data on Statistics Norway in yearly exploration amount and the known remaining reserves). It is necessary and urgent to decrease carbon-based economy and use substitutes for the conventional energy in order to change the current situation and achieve carbon neutral by 2050 according to the COP21 conference.

The appearance of renewable energy seems an opportunity to turn the tables, which collect energy from renewable resources. According to the report of REN21 in 2016, the renewable energy contributed 23.7% to the global energy consumption in 2015 and increased by 4.5% comparing with the data in 2014. Many countries also set the goal of 100% renewable energy in the future. Though renewable energy provides the foreseeable future, it is still a challenge for energy system to completely transformed into zero-emission system, especially given the predictable increased population and the ongoing climate change.

4. Complex urban system

According to Michell (2009), a complex system consists of massive characteristic and dynamic subsystems. These subsystems are under the influence of each other and the external force as well.

Similarly, the urban system consists of a lot subsystems. Based on the layered system theories of McHarg (1969) and Meyer and Nijhuis (2013), the urban system is made up by the substratum of the nature, soil and water, the networks of infrastructure and the human development layer of urban patterns, transport and economy. These sublayers enjoy its own characteristics and dynamics, and meanwhile are interacted on each other. Considering the complexity of the urban system, even a small transition inner of outside the system will lead to intractable consequence.Thus, the complex urban system is a key element in this project.

Urban systems as the human system involves 'spatial product of the flow of social, economic, infrastructural and ecological systems' (Gleeson, 2008), which is the primary causes of climate change. Meanwhile, it is quite vulnerable when facing the impact

of climate change which will influence the health of human, the value of property and the organisation of urban structure. In addition to this, the energy transition as the internal factor will directly change the energy system and have effects on the urban system. The combination of these two will definitely make a big difference in the operation and function of the whole urban structure and urban system.

5. Vulnerability and Resilience

When the systems, sectors or regions in the city cannot fit the changing environment, they might suffer the risks. The influence will beyond the physical aspects, not only happen in the spatial aspect but also affect the socio-economic system.

According to Birkmann (2013), vulnerability consists of conditions, the exposure, susceptibility and the response capacities. The '**exposure**' is the frequency and intensity of a system exposed to the hazards, '**susceptibility**' is the extent and degree of the system be affected or respond to the changes, and the '**capacities**' is decided by physical, social, economical and environment aspects. This means, the vulnerability is not simply decided by the hazards arising from the climate change, but also responsible for the internal variables. It must be considered as an interaction of these factors and includes three elements: exposure, sensitivity and capacity to adapt. (Ionescu et al., 2009).

Vulnerability does not need to be regarded as negatives. Conversely, it can be seen as the opportunity for the necessary development. 'In the disaster context, resilience is often treated as the simple inverse of fragility.' (Proag, 2014). Since resilience comprises of absorbing the disturbance, recovering from the damage and adapting to the change, vulnerability will be reduced by the high flexibility of resilience when facing a risk.

Enormous quantity of literature has been studying the concept of resilience, while there is no unified definition of resilience (Sharifi and Yamagata, 2014). Resilience is originated in the physics which means the ability of the object to return to the origin after an exoteric force and in psychology field

that means the ability to recover from a shock and then can bring itself in balance in a timely manner (Barata-Salgueiro and Erkip, 2013). The emphasis was put on which 'balance' the system can return to after a shock. This can be regarded as resistant to change. Then, in 1973, the resilience concept was introduced into ecology domain by Holling as the ability of a system to absorb disturbance and still keep the system functions as before the shock.

In the sociology, resilience is communities to adapt to the changing environment (Adger, 2000).

This project adopted the ecological approach. Here, resilience is supposed to be a process for reducing vulnerabilities. When a system or a region suffered the impact of external influence, it needs the time to respond or recover from. In this case, the speed of removing can namely represent the resilience level. The faster is speed, the higher resilience it is (Holling, 1973), that can be interpreted as lower vulnerability level (Brooks, 2003).

0.4
PROBLEM ANALYSIS. PROBLEM STATEMENT

1. Impacts of climate change

Due to continued greenhouse gas emission, climate change is happening globally. Rising temptation as the fundamental consequence, accompanied by other changes in the climate system, leading to the impacts in the natural and human system. Influences differ from the according to different scales, locations and conditions. Though someone might benefit from the change of climate, for example the boost of agriculture and fishery in the cold area under the condition of global warming, most of the impacts are irreversible and undesirable. The possibility of extreme weather, floods, droughts are increased, which will threat the nature, infrastructure, buildings, industries and people.

- Climate change impact in Europe's & Norway's coastal areas

Coastal regions are the most susceptible area under global warming. In the coastal region of Europe, the likelihood of the risk of river and coastal flooding is estimated to increase and the river flow will increase. In winter, the precipitation will increase. The species will move to the norther area. And the energy demand for heating will decrease considering the cold weather under a global warming scenario.

In Norway, considering the dynamic landscape, the impacts are quite different. The western part of the coastal Norway is similar to the situation of the general coastal region in Europe. In mountain areas, the temperature will rise larger than average. Thus, the glacier volume and extent and mountain permafrost areas will decrease. Not only the species in Alpine regions will be threatened, but also the ski tourism will be reduced. In south-east area of Norway, temperature will rise more than global average. Agriculture and summer tourism is likely to benefit. While the snow and ice cover will be decreased, more river flows will occur, which might facilitate the hydropower potential. The energy demand for heating is likely to reduce but the winter storm will be more frequent and intensive.

- Climate change impact on coastal energy infrastructure

Due to rich natural resource and advantageous conditions for transportation, energy facilities tend to be clustered in coastal regions. Also, to meet the increasing energy demand, more renewable energy infrastructures as the supplementary are placed. However, there will be increased risks of damage to energy infrastructure due to climate change. More like the 'central nervous system of our economy' (European Commission, 2011), the local damage of energy system will have global ramifications (Kopytko and Perkins, 2012), for example the disruption of supply chains (Emmerson and Stevens, 2012) and temporary prices rise. Also, as energy facilities usually have long design lives, high set-up costs (Wilby et al. 2011), prospection on future climate change and environmental conditions is essential for the design.

- Climate change impact on energy system

Extreme weather will increase the likelihood of energy infrastructure damage in exploration, generation and transfer process. The energy system will break down once the component is damaged. Meanwhile, energy demand will change. Though energy demand might decrease due to the rising temptation, the magnitude and frequency of heat or cooling in extreme weather is unknown. The damage of the energy system will definitely cause the influence of related service system and jobs will be lost.

- Climate change impact on urban system

Because of the increased possibility of more frequent and intensive floods, the flood defence and water management will be altered, or the city will at the risk of loosing a lot of infrastructure, industries, buildings and people. The change of precipitation pattern influences the lifestyle. Furthermore, in terms of the predicted population growth and ageing trend, more vulnerable groups will be harmed. The heat island will happen in the city due to heat storage of artificial surface. The agriculture, tourism and other systems will also be influenced.

Fig. 6. The relation between climate change impacts and others
Source: Author

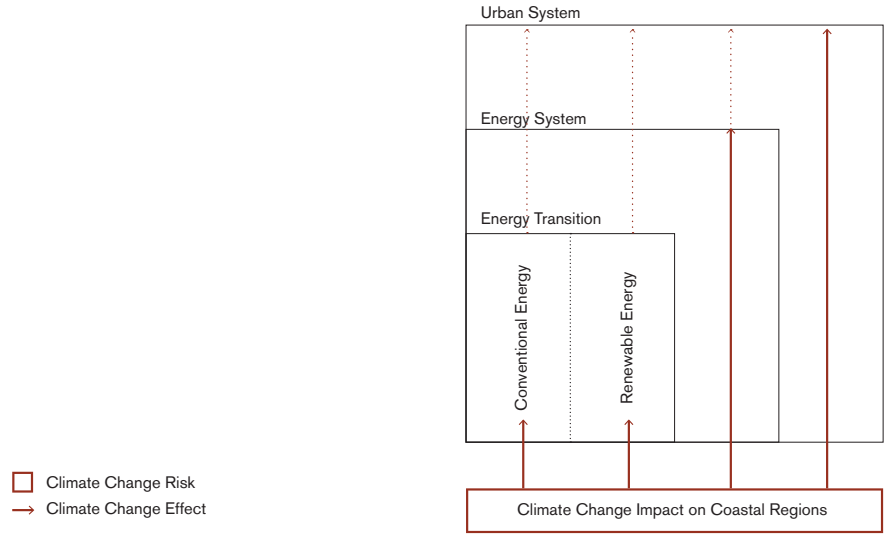
2. Opportunity of Energy transition

- Energy transition opportunity to energy system

To control the increase of the global warming, UN climate summit in Paris in 2015 proposed that all the members should take actions. This is a challenge for the energy system which is mainly responsible for the climate warming. Carbon-based economy and GHG emission need to be reduced so to achieve carbon neutral by 2050. It is necessary to use new and clean energy to instead of conventional energy.

- Energy transition opportunity to urban system

As a primary factor in the urban system, the energy system is embedded in the urban structure and interrelated with social-economic, spatial and environmental systems. Take Norway as an example that Petroleum



sector accounts for 12% GDP and 36% total exports of whole Norway excluded the service and supply industry in 2017 (according to National Accounts, Revised National Budget). It is measured as the largest sector with respect to the added value, state revenues, investments and exports. Also, the petroleum sector and related industries proved the job opportunity for 185300 people in 2016. But due to the energy transition, employment decreased 20% than in 2013. The change in the urban system is closely related to other aspects.

Also, this transformation needs the time. Geography and region to some extent influence the transition of product and speed. Meanwhile, demand for energy will correspondingly increase according to the increasing population all over the world. Only under the circumstances that the quantity demanded for energy are met and the price is affordable can society become thriving and prosperous.

3. Climate change impact x Energy transition opportunity = Transformation

The impact of climate change will lead to a complex urban system in transition. So will the ongoing energy transition process. We can regard the climate change impact as the external driven factor and energy transition opportunity as the internal factor because of the subordination of the urban system. Anyone will result in the transformation of urban system and more over, the joint effort will make this transformation even more complicated and unpredictable.

- Vulnerability + Transition = Risk

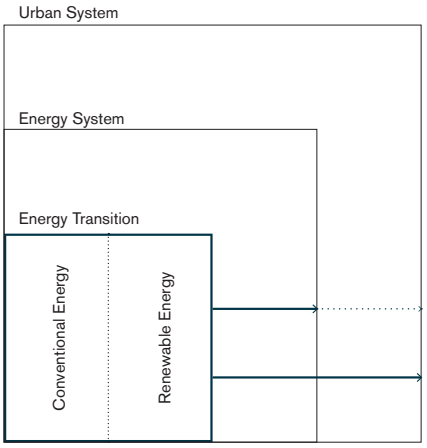
Given the rich resources of energy in the delta area and the convenient geography for trade, a vast of energy infrastructure was built on the coastal region. Take petroleum system as the example, offshore platform was placed on the sea to explore oil and gas. Then, oil and gas was stored in the onshore terminals through pipeline and shipping before local distribution to deport or to end-use. Thus, the vulnerability of the coastal energy infrastructure will cause the breakage of the energy system and collapse in the whole urban system.

Fig. 7. The relation between energy transition opportunity and others
Source: Author

- More Risk + Less Resilience = No Future

When the city is facing with more risks but do not possess the capacity to adapt or return to the equilibration, the city might get into trouble. Though adaptation and mitigation measures have been put on a high priority, lacking of time, money, technology, resources, uncertainties of climate change and undefined responsibility of different countries becomes the barrier to take action towards resilience and sustainable future.

Nevertheless, in the historic extreme weather events, the lessons were taught that not adapting to climate change will cost a lot, not only on physical aspects, but also on social labour force, transition time. This is not a long-range plan for the future.



Energy Transition Opportunity
Energy Transition Opportunity

Climate Change Impact on Coastal Regions

Problem Statement.

Due to the dynamic ecosystem and plentiful sources of energy, vast of energy infrastructure were built on the coastal region. Under the circumstances of the changing climate, the coastal energy infrastructure is more possible to suffer from the hazards, like floods, storms and soil erosion than before. Meanwhile, the energy system is on a large scale in the transition, with the considering of the use up of fossil fuel in the near future and the emission of greenhouse gas which contribute to climate change. While, on account of the dependence of renewable energy on the climate and environment, the transitional energy system is even more vulnerable. Lack of attention on improving resilience of vulnerability will lead to a vast cost when facing to hazards, which is not a viable option and long-term plan for future development.

As a primary factor in the urban system, the energy system is embedded in the urban structure and interrelated with social-economic, spatial and environmental system. Thus, the combination of climate change impact and transitional energy system threats the whole urban system on its operation and function. The economy depends on the energy system will collapse and the energy structure and urban structure need reconstructing. The people in the changing urban system also suffered from this influence. Especially, the susceptible groups are harder to adapt to the environment. Considering the trend in the increase of population and the ageing effect, more people will be the victims under the climate change impact.

Fig. 8. Scope of Vulnerability & Resilience
Source: Author

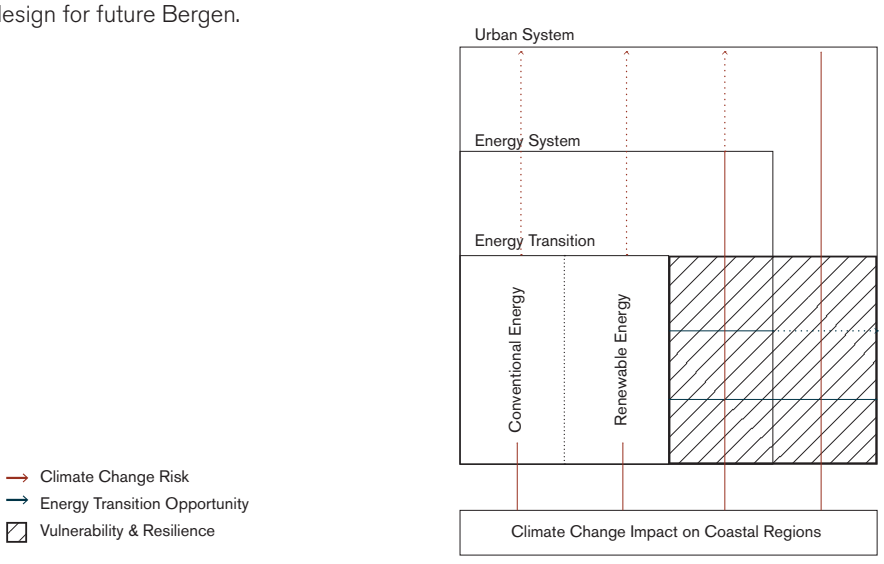
0.5
HYPOTHESIS

Based on the problem statement, the hypothesis of the proposal is proposed that the potential risks of climate change impact and energy transition on urban systems can be mitigated and are even turned into opportunities for further development.

This hypothesis guides the subsequent methodology under the conditions of changing climate and energy transition.But considering the uncertainties of the future, challenges are brought to design and planning. The result can be seen as exploratory design for future Bergen.

Thus, in this proposal, scenarios are built to deal with the great uncertainties.

In the process of research and design, the complex urban system can hardly be recognised. So this proposal will try to integrate complex systems through multi-scale, time, layers. In addition, this proposal adopted open-ended design, which can be updated as the progress of time and technology.



0.6
RESEARCH QUESTION. SUBQUESTIONS. RESEARCH FRAMEWORK.

" When a system is able to protect itself against sudden extreme events, we call it a robust system. When a system is temporarily disordered by a sudden extreme event, but able to recover relatively quickly, we call it a resilient system. When a system is able to adapt to a changing context, we call it a complex adaptive system. "

(Meyer and Nijhuis, 2014)

So, can we seize the opportunity by increasing resilience level, from transition to chance, instead of risk.

- Resilience + Transition = Opportunity?

Research Question:

Which integrated resilience strategies can be applied in the coastal system of Norway assessing the climate change impact within the process of energy transition goals?

Subquestions:

- How does the transition of energy systems contribute to climate change?

- Which are the effects of climate change impacts in the coastal region?

- How does climate change affect coastal energy system?

- How the urban system and the urban structure are affected by climate change effects and the energy transition?

- Which systems are at risk in the coastal region?

- How to mitigate the climate change impact and how to adapt to these effects through time?

- What kinds of resilience measures can be applied and which governance bodies need to be aligned to do so?

	SUBQUESTION	APPROACH	OBJECTIVES
What will be changed?	How does the transition on energy systems contribute to climate change?	**Scope**	- Know 'What is the goal' - Know 'Who was involved' - Know 'What is the policy' - Know 'What is the timeframe'
Which systems are at stake?	Which are the effects of climate change impact in coastal region?	Estimate general consequences of **Climate Change Impacts**	- Know 'What are the hazards' - Choose climate projections
	How does climate change affect coastal energy system?	Develop inputs for vulnerability assessment	- Know 'What is vulnerability' - Know 'What consists of vulnerability'
		Determine exposure of assets and operations	- Identify methods for assessing vulnerability
		Identify **Urban Structure & Urban System** Assess **Vulnerabilities**	- Apply inputs gathered in prior - Determine the likelihood/ severity damage / disruption given a cliamte event
What needs to be adapted?	How the urban system and the urban structures are affected by climate change effects and the energy transition?	Estimate consequences of climate change impacts	- Identify direct, indirect and induced costs of climate change
	Which systems are at risk in the coastal region?	Assess **Risks**	- Apply inputs, define and anchor categories for consequence and likelihood - Develop a likelihood- consequence matrix
How to build resilience?		Build scenarios	- Filter risk (with greatest opportunity for resilience improvement) - Understand benefits and challengs
	How to mitigate the climate change effects and how to adapt to this effects through time?	Identify and assess resilience measure	- Know 'How to approach each risk' - Identify options for improving resilience
	What kinds of resilience measures can be applied and which governance bodies need to be aligned to do so?	Build portfolio of resilience measure	- Prioritize and select resilience measures - Eveluate resilience measures
		Develop **Resilience Pathway**	- Develop an action plan - Integrate resilience plans into desicion making

0.7
METHODS & METHODOLOGY

Literature review on stock of contemporary delta urbanism theories and practice, climate change vulnerability assessment, coastal adaptive strategic and spatial planning to climate change, the documents and government reports of energy transition towards less emission energy, case studies of other energy infrastructure system in coastal regions, achievements in low-emission energy and renewable energy source, transformation of redundancy.

Theory essay serves as a tool research on the meaning of climate change to coastal energy infrastructure system, by assessing the vulnerability to identify the key factors in adaptive measures in terms of spatial strategies in the coastal region.

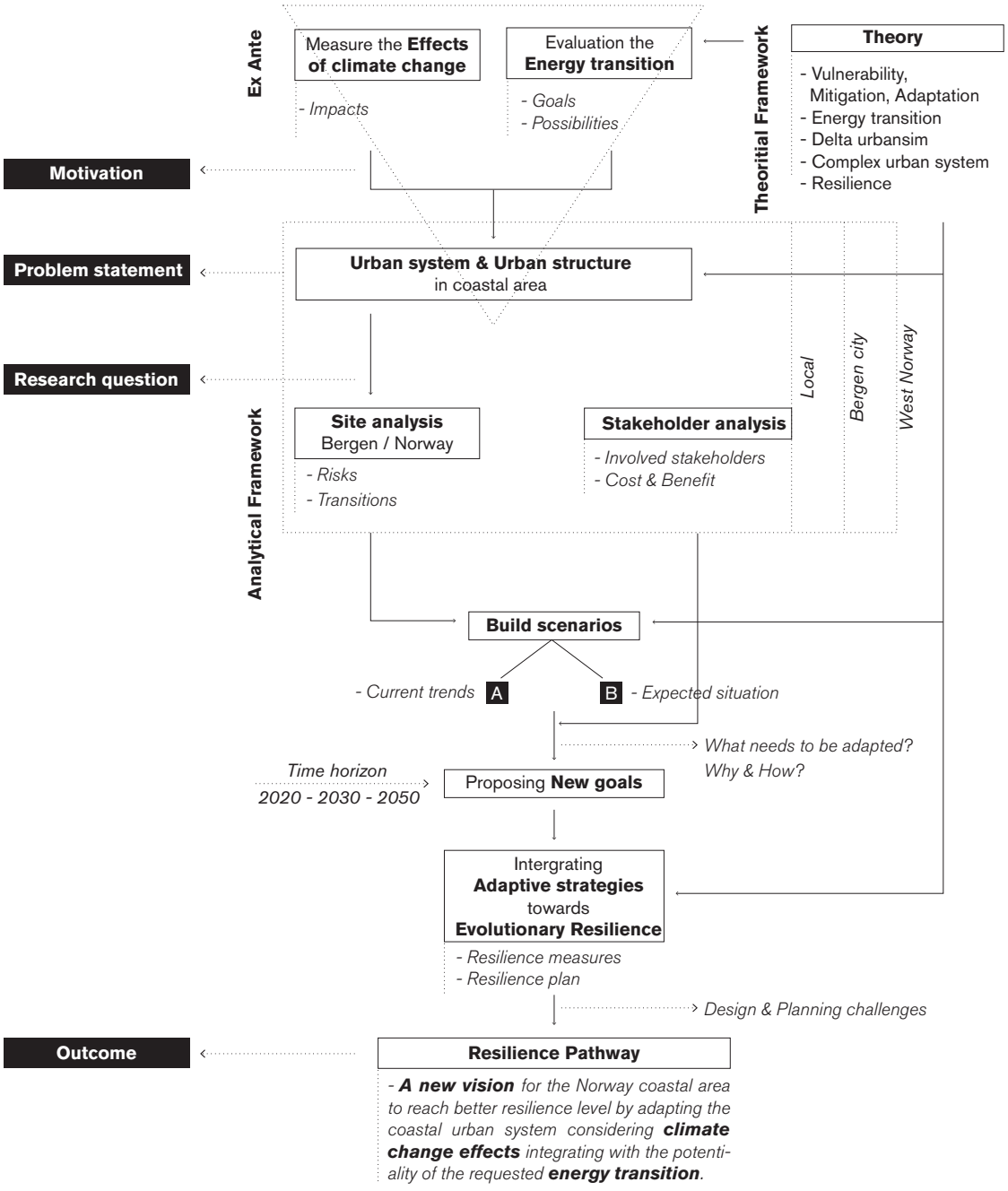
Working with layers, times, scales (Courtesy of TU Delft – Nijhuis, Pouderoijen) is a way to analyse complex delta through different layers, periods and scales. The layers can be interpreted as the 'substratum' system with nature, e.g. soil, rock & water, the networks of infrastructures, and the occupation of urban patterns, e.g. settlements and transportation (Meyer, 2016). Also, it is important to identify some crucial episodes of the spatial form, which might tell the story of the evolution of dynamic systems. By transfer scale, the interrelation and interaction can be unscrambled better. This analysis approach serves to decompose the complex delta system and explore the problems and opportunities.

Drawing the Delta is not only used to represent the natural structure, topography, geomorphology, urban patterns, resources, elements of Norway but also as an instrument to connect a generic context based on research and potential spatial interventions developed on intrinsic quality of space.

Exploratory scenarios for development opportunities due to several uncertainties of future climate change, impacts of climate change, future demographic, economic and urban development.

Design as a way of research cannot only propose possible spatial interventions but also provide the strategic framework of potential future planning and reframe current approaches.

Fig. 9. Methodology chart
Source: Author


Ex Ante
Measure the **Effects of climate change**
- *Impacts*
Evaluation the **Energy transition**
- *Goals*
- *Possibilities*
Theoritial Framework
Theory
- Vulnerability, Mitigation, Adaptation
- Energy transition
- Delta urbansim
- Complex urban system
- Resilience
Motivation
Problem statement
Urban system & Urban structure in coastal area
Research question
Analytical Framework
Site analysis Bergen / Norway
- *Risks*
- *Transitions*
Stakeholder analysis
- *Involved stakeholders*
- *Cost & Benefit*
Local
Bergen city
West Norway
Build scenarios
- *Current trends* A
B - *Expected situation*
What needs to be adapted? Why & How?
Time horizon
2020 - 2030 - 2050
Proposing **New goals**
Intergrating **Adaptive strategies** towards **Evolutionary Resilience**
- *Resilience measures*
- *Resilience plan*
Design & Planning challenges
Outcome
Resilience Pathway
- ***A new vision*** *for the Norway coastal area to reach better resilience level by adapting the coastal urban system considering* ***climate change effects*** *integrating with the potentiality of the requested* ***energy transition***.

Problem statement

1. Coastal infrastructure under risk
2. Energy system in transition
3. The changing urban system
4. People as victims

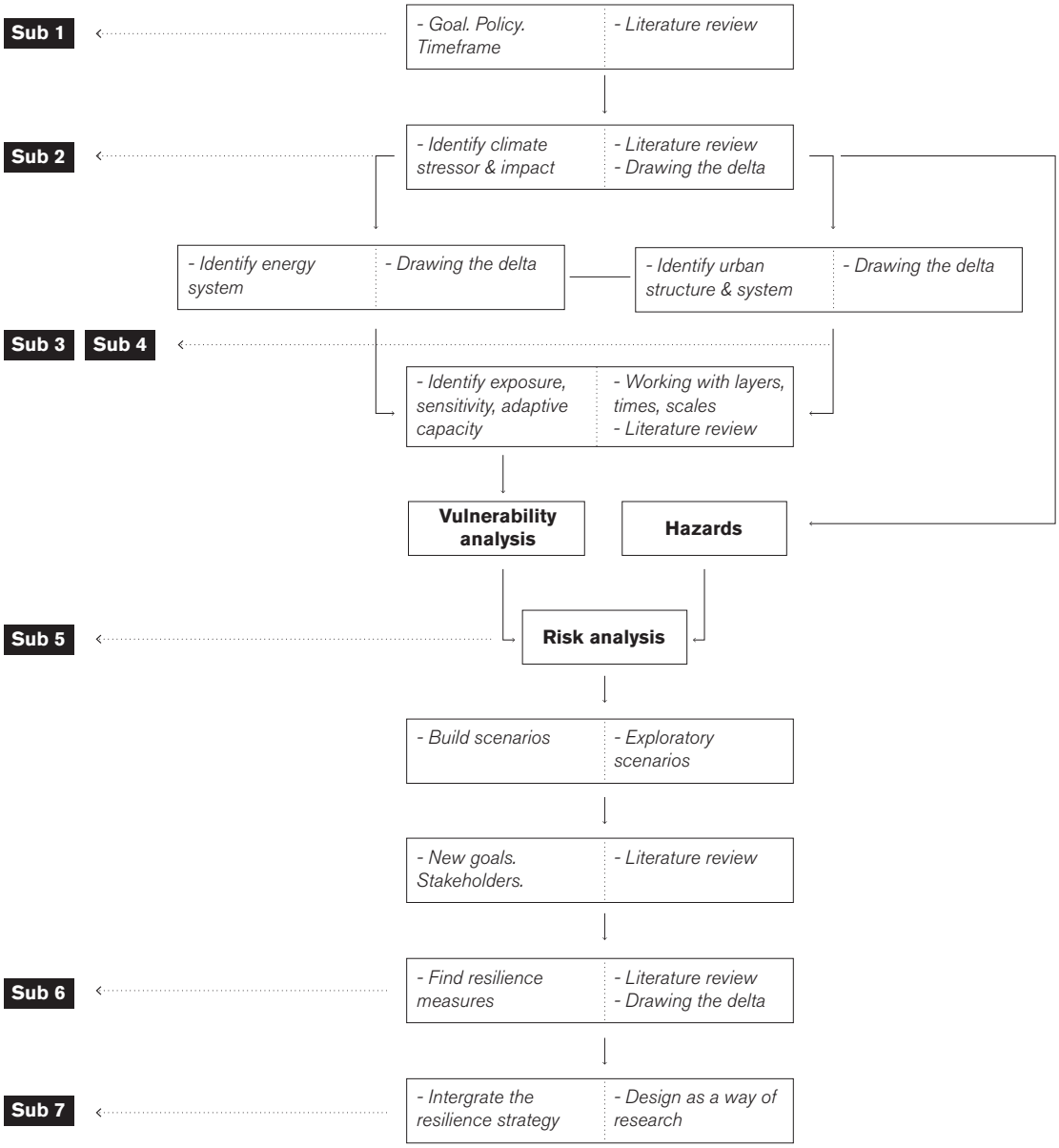
Research question

Which integrated resilience strategies can be applied in the coastal system of Norway assessing the climate change impact within the process of energy transition goals?

Outcome

A new vision for the Norway coastal area to reach better resilience level by adapting the coastal urban system considering climate change effects integrating with the potentiality of the requested energy transition.

1. How does the transition on energy systems contribute to climate change?
2. Which are the effects of climate change impact in the coastal region?
3. How does climate change affect the coastal energy system?
4. How the urban system and the urban structures are affected by climate change effects and the energy transition?
5. Which systems are at risk in the coastal region?
6. How to mitigate the climate change effects and how to adapt to these effects through time?
7. What kinds of resilience measures can be applied and which governance bodies need to be aligned to do so?


Sub 1
- Goal. Policy. Timeframe
- Literature review
Sub 2
- Identify climate stressor & impact
- Literature review
- Drawing the delta
- Identify energy system
- Drawing the delta
- Identify urban structure & system
- Drawing the delta
Sub 3
Sub 4
- Identify exposure, sensitivity, adaptive capacity
- Working with layers, times, scales
- Literature review
Vulnerability analysis
Hazards
Sub 5
Risk analysis
- Build scenarios
- Exploratory scenarios
- New goals. Stakeholders.
- Literature review
Sub 6
- Find resilience measures
- Literature review
- Drawing the delta
Sub 7
- Intergrate the resilience strategy
- Design as a way of research

0.8
THEORITICAL FRAMEWORK

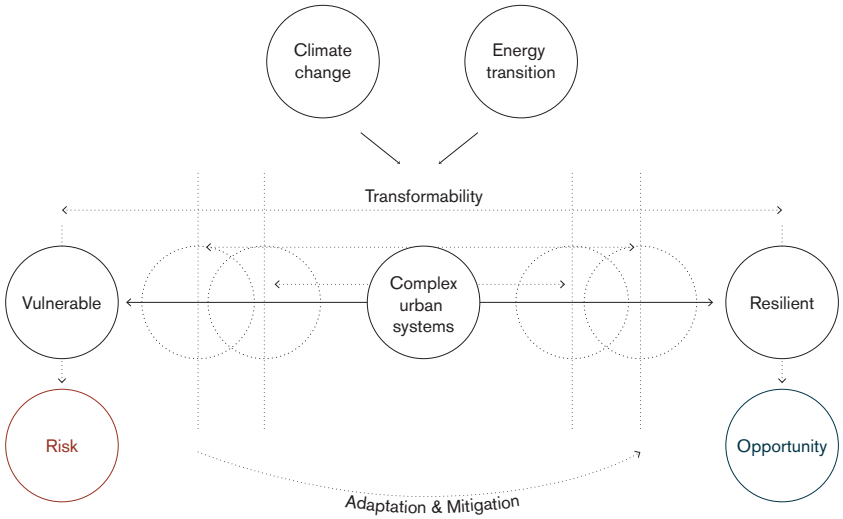
Theoretical framework is structured to support the whole research-based design, mainly by five main topics:

1. Vulnerability and Risk theories and relevance to climate change. One of the primary purpose is to identify the climate change impact on energy infrastructure, energy system and complex urban system in the coastal region. The vulnerability theory provides the knowledge to learn further how and to what extent does the climate change impact threats these systems. Combining the assessment of vulnerability and hazards, the risk might happen in the short-term and long-term future can be estimated, which can provide a comprehensive understanding of emerging risks. The research on vulnerability and predication of risks is the precondition for resilience strategy by helping understand and build up undesirable conditions.

2. Transformability including transition theory, serves as part of the resilience thinking. It related with the adaptive capacity by changing the fundamental attributes in a system to shift the direction of urban development. In defining and evaluating the time and resource, transformation happens in social, economic, environmental system, embedded in the complex urban system. Thus, transformability goes together with complexity theory. In terms of energy system, transformability provides both the knowledge for energy resources to mitigate climate change impact and energy infrastructure for example the drilling platform offshore and petroleum plants onshore. Constantly updated knowledge of transformability helps to prepare and adapt in case of the change in city.

3. Delta urbanism theories are new approaches to planning urban environment for spatial plans and management while respecting the dynamics of the ecosystems. Due to the particular features of the deltaic region, the interventions are quite different from the ones for the landlocked cities. Emphasis is put on the relation between natural and human system. Although Norway is not a delta region, by means of delta urbanism theories, the basic principles of dealing with the natural environment and urban development in a harmony way can be developed, which is the headstone of integrated strategies for resilient cities in coastal regions.

Fig. 10. Theoritical framework
Source: Author



10

4. Complex urban system theories provide a comprehensive understanding of the influence when facing the transition. Understanding the composition, the operation and function of the urban system are the preliminary for risk assessment. And meanwhile, the new equilibrium of the subsystems in the complex urban system is the evaluation of the resilient city after a critical transition.

5. Resilience is an extended concept of **mitigation**, **adaptation** towards sustainable development. Adaptation as an adjustment in both natural and human systems, provides the basic knowledge to respond to the expected climatic impact in order to acclimatise the changing impact and moderates the disaster. Mitigation affords the strategies to reduce the anthropogenic pressure in the climate change, including reducing the greenhouse gas emission. Resilience persists in a harmony relationship between natural and human system and puts the focus on the synergies and interactions of social-ecological, environmental, spatial, ecology systems, which provide a more advanced thinking for sustainable development.

Turning risks into opportunities

- Building urban energy resilience in the context of climate change and energy transition process in Norway

Jie Wang,
Student, 4578546, Urbanism, Delft University of Technology, Delft, Netherlands

Keywords: Climate change / Vulnerability / Resilience / Energy transition

In order to reduce greenhouse gas emission and mitigate climate change, the energy system is in the great transition from conventional energy to renewable energy. But meanwhile, the energy system is suffering from the effects of climate change which will not stop immediately and is becoming more vulnerable, especially the renewable energy that relies on climate and environment. Challenges were brought to the energy resource, networks and energy demands. Under the combined action of energy transition and changing climate, a series of impacts will happen in the city, affecting the ecosystem, basic infrastructure, related services and the built environment. Moreover, given the projection of increased population in the city, new challenges are brought.

The aim is to convert the potential risks of disruption in energy supply deriving from the climate change impact and other threats into opportunities which mean having spare and continuous energy and even promote the development of the energy system and other sectors. To approach this, the emphasis was put on fostering energy resilience which can prepare, absorb, recover and transform to the climate change impacts. By recognising the quantification of energy system, in terms of energy production, distribution and end-use, a set of indicators of resilience criteria was built as the final goal. Meanwhile, the key factors that determine the vulnerability of the energy system will be assessed on the basis of literature review of vulnerability theories and evaluation methods. With a detailed assessment of vulnerability and resilience, a conclusion was made to reveal the practical strategies of reverting risks by exploration of the relevance between constructed vulnerabilities and resilience assessment.

Introduction

Countries establish energy transition goals and policies in order to support the mitigation of climate change. In the COP21 conference in Paris, in 2017, it is proposed that the carbon-based economy should be decreased by using substitutes in order to change the current situation and achieve carbon neutral by 2050. Although mitigation and adaptation measures are taken, the climate change is still happening and will continue. The extreme weather like flood, storm will increase the risk of energy infrastructure damage in exploration, generation and transfer process. Considering that more weather-dependence renewables are replacing the carbon-based energy to support urban system, there is more possibility of a power failure. The damage of the energy system will definitely influence the related service system, social-economy system and other sectors.

As the primary factor in the urban system, energy system in transition will be used as the tool to explore how to diminish the impact of climate change and invert the climate change risks into resilient development opportunity. To shed light on this perspective, this paper addresses two primary thinking, vulnerability and resilience of the transitional energy system to climate change impact.

The first step is to recognise the existing energy system and build the energy resilience assessment as the criteria based on literature review. Then, according to the climate change impacts in Bergen, key driven factors of vulnerability in the energy system will be identified. Thus, the dimension and elements for vulnerability assessment to the energy sector will be introduced. Finally, improve the

vulnerability factors according to the identified resilience target by exploring the associations between the components of vulnerability and resilience assessment. The results will be presented as the strategies for resilience enhancement.

The challenge of climate change and energy transition

1. Impact of Climate change

Due to continued greenhouse gas emission, climate change is happening globally. Rising temptation as the fundamental consequence, accompanied by other changes in the climate system, leading to the impacts on the ecosystem, social-economy and health of humans. The climate factors change dramatically like temperature, precipitation and sea level. Meanwhile, the impacts also differ in location, scale and conditions. Though someone might benefit from this, for example the boost of agriculture and fishery in the cold area under the condition of global warming, most of the impacts are irreversible and undesirable. The possibility of extreme weather, floods, droughts are increased, which will threaten the nature, infrastructure, buildings, industries and people.

As one of the coastal regions, Norway is susceptible under global warming. In the west, the likelihood of the risk of river and coastal flooding is estimated to increase and the river flow will increase. In mountain areas, the temperature will rise more than average. Thus, the glacier volume and extent and mountain permafrost areas will decrease. Not only the species in Alpine regions will be threatened, but also the ski tourism will be reduced. The temperature will rise more than global average. Agriculture and summer tourism is likely to benefit. While the snow and ice cover will be decreased, more river flows will occur, which might facilitate the hydropower potential. In winter, the precipitation will increase. The energy demand for heating is likely to reduce but the winter storm will be more frequent and intensive.

2. Transition to sustainable energy system

Energy transition is required mainly based on two reasons. One is to mitigate the climate change. Following consideration of the more severe and more frequent climate change impacts, the replacement of carbon-based energy is quite urgent, which is the main contributor to greenhouse gas. Another reason is the finite resource of fossil fuel. Take the North Sea as the example, the oil and gas might be used up in the near decades (based on the data on Statistics Norway in yearly exploration amount and the known remaining reserves).

35

As a leader in Europe and even in the world, Norway has set a target of 67.5% renewable energy of total energy consumption by 2020 and 80% in 2050(Ministry of Petroleum and Energy, 2012). In particular, according to Grønn strategi (Bergen commune, 2016), Bergen will reduce 30% direct greenhouse gas emission in 2012 compared with in 1991, become fossil-free by 2030, which means no oil, coal or gas used for transportation and building and finally keep the temperature increase below 1.5 degree.

3. Challenges in the urban system

Actually, Norway has already reached the target of renewables' share for 2020, which is dependent on hydropower. Although Norway has abundant petroleum source, most of them are used to export Thanks to the dynamic geography, Norway features extensive coastlines surrounded by the Barents Sea, the Norwegian Sea and the North Sea and several huge fjords, which are suitable to develop hydropower. In 2016, the share of hydropower in electricity production is 96.3, whose production is 143,417 GWh alone. Thermal power and wind power contributed comparatively less, 3,456 GWh and 2,116GWh separately (Statistics Norway, 2016).

Because of the small population, the total energy consumption is low. While the energy consumption per capital is extremely high when comparing to the surrounding countries (Eurostat, 2015). It is estimated that annual energy use is mostly used for space heating due to the cold weather in Norway. But warmer climate and more precipitation recently have led to less energy consumption in the household and more electricity export than before.

Thus, the combination of climate change impact and transitional energy system threats the whole urban system on its operation and function. The economy depends on the energy system will collapse and the energy structure and urban structure need reconstructing. The people in the changing urban system also suffered from this impact. Especially, the vulnerable groups are harder to adapt to the environment. Considering the trend in the increase of population and the ageing effect, more people will be the victims under the climate change impact.

Table 1. Electricity balance (GWh)

	2016	Share	Per cent 2015 - 2016
Production, total	148989	100	3.1
Hydro power production	143417	96.3	3.6
Thermal power production	3456	2.3	-2.5
Wind power production	2116	1.4	-15.9
Imports	5741		-22.5
Exports	22151		0.5
Gross consumption	132579		2.1
Pump storage use and other own consumption	1435		-37.7
Loss and statistical difference	7697		2.2
Net consumption	123447	100	2.8
Mining and manufacturing etc.	54761	44.4	2.4
Services etc.	26539	21.5	2.7
Private households and agriculture	42147	34.1	3.5

* Note: Electricity balance (GWh) in 2016, Data based on Statistics Norway.

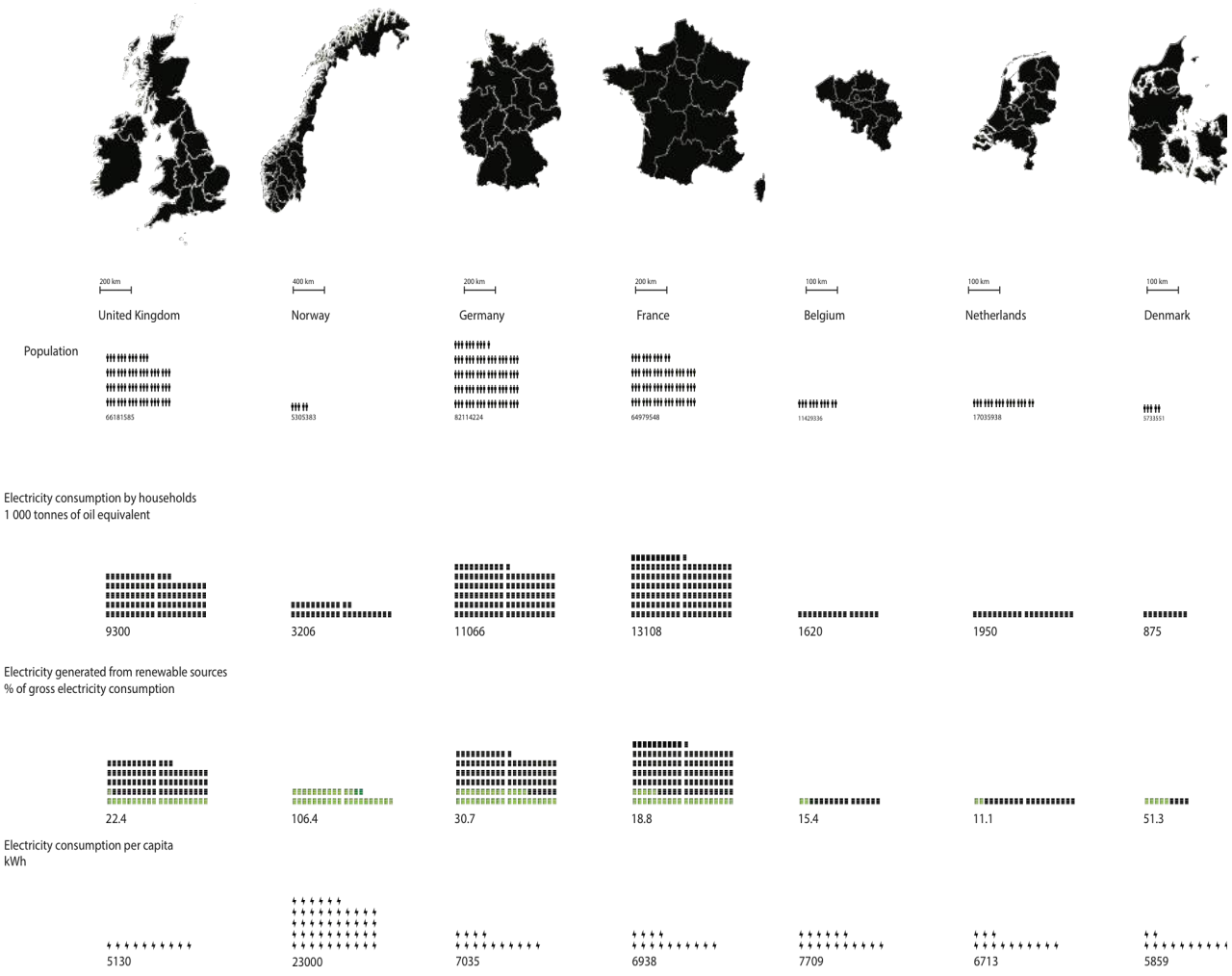


Figure 1. Comparison of energy balance in the North Sea region. Drawn by author. Data based on Statistics Norway

Methods and materials

Considering the associated impact of climate change and energy transition, the energy system and other urban systems have a high potential to be at stake. Under this circumstance, the transitional energy system can be seen as the key intermediate in this relationship. It is needed to enhance the resilience of energy system. Thereby the potential risks of climate change impact might be mitigated and even utilise this change as the opportunity to achieve a better socio-economic status.

1. Reducing risks through improving the vulnerability

To reverse the risks, the first step is to understand what are the risks. Risk is commonly defined as "probability of hazard occurrence" and a series of potential consequences leading to "expected loss"(UNDHA, 1992; Stenchion, 1997; Downing et al., 2001) Here, risk is the potential shocks in terms of energy system when facing extreme weather, which is conceptualised as a combined function of hazards which means potential threats triggered by climate change and vulnerability that result in expected losses, namely "risk=hazard x vulnerability".

In this relationship, it is supposed that as long as improving one of the variables, either reducing the possibility of hazard or enhance the vulnerability to have less expected losses can reduce risks (assume another variable will not change much when one changes). Considering that the hazards are quite unsure and minimising the possibility of hazard is closely related to the technology of forecast, thus this paper only discusses risk reduction by vulnerability enhancement.

Vulnerability is a dynamic and comprehensive concept to measure expected harmful impacts to people, assets or systems (McCarthy et al.,2001). According to the latest version of IPCC (2014), vulnerability is defined as "susceptibility to harm", which is made up by three dimensions, including exposure, sensitivity and adaptive capacity (Downing et al., 2001; Polsky et al., 2007).

Exposure means "the nature and degree to which a system is exposed to significant climatic variations", relating to the climatic variability and systems' character and location. Sensitivity is "the degree to which a system will respond, either positively or negatively". And adaptive capacity is "the ability of a system to adjust to climate change … to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (McCarthy et al.,2001; Füssel and Klein, 2006). These three dimensions have come together to determine the vulnerability, which means if the exposure and sensitivity are high, a system can still be less vulnerable with a strong adaptability to cope with the shock and adapt to the environment, and vice versa.

In the relation of risk and vulnerability, the latter is more like a dose, responding to the external influence on the system. The equation can be revised as "risk= hazard x (exposure x sensitivity x adaptive capacity)".

2. Capitalising opportunities through enhancing the resilience

When we talking about risk reduction, we mitigate the hazards and improve the vulnerability to make the system have a better durability and adaptively so the system can come back to the balance situation after a shock or a disaster. This concept is very like the initial definition of resilience in physics and ecology. The former focused on the ability to recover from the shock in a timely manner (Barata-Salgueiro and Erkip, 2013) and the latter was by Holling in 1973 which is designated as the ability of a system to absorb disturbance and still keep the system functions as before the shocks. Then, this concept was introduced into many fields and has been studied by a great quantity of literature.

This paper adopted the definition of evolutionary resilience which can not only "recovery from shocks" but also have the ability to prepare and seize "transformability opportunities that emerge from change" (Davoudi et al., 2016) It puts the emphasis on the better equilibrium point after the hazards, achieving the development in social-economic system, ecosystem and environment.

3. Setting resilience criteria as the goal

Resilience is the same kind of concept to vulnerability, whose driving factors are often overlapped (O'brien et al., 2006) Thus, vulnerability and resilience can be regarded as two different states at the two ends of the axis. On the side of vulnerability, the system is susceptible and hard to recover, while on the other side of resilience, it is easier to get to the equilibrium state and advance to a more desirable state. But to what extent means can be regarded as reaching the evolutionary resilience goal?

There are four dimensions constitute the framework of evolutionary resilience, including preparation, persistence, recovery and transformability (Holling, 1973; Barata-Salgueiro and Erkip, 2013; Sharifi et al, 2016; Davoudi et al., 2016). Preparation means human interventions like predicting and preparing for minimizing potential energy disruption driving from climate-related hazards. Persistence carries on the definition of resilience in ecology and physics which stands for the ability of absorbing and withstand the shock, which enables the energy system to continually functions without a great deterioration. Recovery is related to flexibility and resourcefulness, which provide an alternative resource, networks and a good management to re-operate if the system collapse. Transformability represents that the system is able to adapt the new conditions and probably advance to a positive development.

Viewed from temporality, these four dimensions are organised as a cycle of resilience. Prevention actions and measures are firstly taken to prepare and protect the energy infrastructure from climate change impacts. After the occurrence of hazards, the first phase of an energy system is to persistence, in which the characteristic of robustness will retain the function as much as possible. If the system failed to persist, it will go through the next phase of recovery to the new condition by recovering from the hazards. If risk management is good, the process of restoration and recovery will be accelerated. Then seizing the opportunity of evaluating and modifying the system to move forward to a more flexible and better development. By learning lessons from the events, next preparation will be more robust and innovative.

The resilience criteria are built based on these four dimensions. This paper extracts the most relevant criteria according to the review paper of energy resilience criteria by Sharifi and Yamagata (2016), which concludes all the indicators mentioned in 238 published studies between 1973 and 2016. These papers refer to a wide range of domain, from urban planning to engineering, from energy policy to social policy. Thus, these indicators are relatively multidisciplinary and trustful.

Built on the stage of the energy system, resilience criteria are classified into energy production, distribution and end-use.

In terms of energy source, diversification is the most important property to build resilience, which could prepare alternatives before hazards, and become flexible and robust after the shock. In Norway, almost all the electricity generation comes from hydropower. On one hand, the high share of renewables contributes to less emission of greenhouse gas. On the other hand, this high dependence on hydropower and the large consumption on electricity, will amplify the risk effects if the hazards happen, especially on the current trends that more severe climate change like rising sea levels and frequent extreme events might occur. The risks of damage to energy infrastructure and system will be increased. Thus, it is essential to have alternative power that can provide sufficient electricity for such large electricity consumption after a shock. All the promising energy resources like sun, wind, geo-thermal, bio fuel and waste are listed here to further elaborate the detailed criteria. The imported energy is also regarded as a kind of source, but the dependence on the condition of exported country will make it become more uncertain and incredible, including the labile energy price. When energy can balance by self production and even have ability to export reserve energy, it can be seen as more resilient. In distribution, the age, the type, efficiency will influence the persistence of networks. So, regular maintenance and phasing out is listed in the preparation to help enhance resilience.

From the perspective of the distribution mode, the combination of centralised and distributed system can increase the efficiency and flexibility of energy production and distribution. And in the end-use process, energy storage and energy consumption in a building are considered. Because backup and energy storage can alleviate the pressure of shut down, it is considered as the important part of resilience assessing. Meanwhile, it is also a kind of energy production and enjoys its own distribution system.

For energy consumption, the type of district energy system, multi-function space and co-relation of buildings influence the demand of energy and reduce the need for distribution. In addition, energy demand is related to demography in city, including the density of population, the age, income, social-class of people. Development pattern which is decided by density pattern and infrastructure system can contribute to energy resilience by moderate centralised and urbanisation to reduce energy consumption on communication.

Category			Resilience dimension			
			Preparation	Persistence	Adaptation	Transformability
Production	Oil and gas	Diversification of energy supply (fuel mix, multisourcing, type of generation)	x	x		x
		Energy/Carbon intensity of generation	x			
		Reliance on imports	x	x		x
		Energy price	x	x		x
	Water	Rainwater harvesting, decentralized water harvesting systems	x	x		x
		Water conservation	x	x		x
		Reducing water footprint of energy production and transmission	x			x
		Energy generation from sewage	x	x		x
	Sun	Large solar thermal collectors	x	x	x	
	Wind	Large wind turbines located outside the built-up area	x	x	x	
	Geo-thermal	Ground source heat pumps	x	x	x	x
	Bio fuel	Biofuel energy	x	x		x
	Waste	Waste heat or biomass-fueled combined heat and power plants	x	x		
Distribution	Power networks	Energy production near point of use (colocation of supply and demand)	x	x	x	
		Spatially distributed generation (and critical facilities)	x	x	x	
		Fortification and robustness (physical security) and operational system protection (system relief)	x	x		
		Smart micro-girds fed by micro-turbines and solar panels and storage facilities	x	x	x	x
		Regular maintenance	x			
		Age of infrastructure	x	x		
		Generation, transmission and distribution efficiency	x	x		x
		Phasing out and introducing new technologies	x	x		
		Type of feeder lines	x	x	x	
		Natural gas distribution	x	x	x	x
		Number and configuration of node	x		x	
End-use	Backup and storage	Back-up energy sources and stocks of energy	x	x	x	
		Energy storage facilities	x	x	x	
		Distributed storage and connectivity with generation	x	x	x	
		"Spare capacity and reserve margins"	x	x		x
		Vehicle to Grid (selling surplus power)	x	x		x
	Energy demand	Type of district energy systems	x	x	x	x
		Energy self sufficiency	x	x	x	x
		Energy cycling	x	x		x
		Multi-Functional and mixed use	x	x	x	
		Co-location of enterprises and others	x	x	x	
		Development pattern (sprawl, compact, suburbanization, infill, brownfield, greenfield, etc.)	x	x	x	x
		Density (housing and population)	x	x	x	x
		Income	x	x	x	x
		Connectivity and street system	x	x		

39

Building Vulnerability assessment and resilience strategies through association of components

1. Building vulnerability assessment based on existing conditions

According to three dimensions of vulnerability, efforts are made to classify the criteria extracted from the papers into exposure, sensitivity and adaptive capacity. Though the concept of vulnerability and resilience is generic, the indicators are not exactly the same. It is not possible and unnecessary to sort out all the criteria into these three dimensions of vulnerability. Therefore, the indicators are selected again in line with the existing situation of Norway.

By definition, exposure is related to the degree of impact on people, asset and systems. Therefore, power generation, distribution networks and energy storage facilities are determined. Under the condition of more precipitation, more extreme weather in Norway, these infrastructures are more likely to be damaged. Once the energy system blackouts, it will influence the energy consumer and the urban system. So, the location of people and population density are listed as the exposed population under the expected changes. Another dimension, sensitivity means the degree a system will respond to. The reliance on imports and energy price is quite fluctuating once facing some changes, which is related with affordability and accessibility. In the power networks, the distance of distribution, the age and type of infrastructure, the number and configuration of nodes as well as the condition of technology will determine the extent of damage. Similarly, distribution and networks of backup and storage will influence the connectivity with either generation. The demand of energy consumption will be affected by the type of district energy system, in addition to the demography pattern. If the demand is low and can be afforded, then the sensitivity might be low. It is worth to mention that adaptive capacity is different to exposure and sensitivity, which is closely associated with education level, technology and skills, access of information and management. At any given exposure and sensitivity, adaptive capacity can rewrite the situation.

Table 3. Vulnerability assessment of energy system

40

Category			Vulnerability dimension		
			Exposure	Sensitivity	Adaptive capacity
Production	Source	Diversification of energy supply (fuel mix, multisourcing, type of generation)			x
		Reliance on imports		x	
		Energy price		x	
Distribution	Power networks	Distance between energy production to point of use (colocation of supply and demand)		x	
		Spatially distributed generation (and critical facilities)	x		
		Fortification and robustness (physical security) and operational system protection (system relief)			x
		Regular maintenance			x
		Age of infrastructure		x	
		Generation, transmission and distribution efficiency			x
		Phasing out and introducing new technologies		x	
		Type of feeder lines		x	
		Natural gas distribution	x		
		Number and configuration of node		x	
		Cost for restoration of network			x
	Backup and storage	Back-up energy sources and stocks of energy		x	
		Energy storage facilities	x		
		Distributed storage and connectivity with generation		x	
End-use	Energy demand	Type of district energy systems		x	
		Energy self sufficiency		x	
		Density (housing and population)	x		
		Location of people	x		
		Education level			x
		Age of people		x	
		Income		x	
		Connectivity and street system		x	

2. Combining the components and establish resilience strategies

On the basis of vulnerability assessment, the resilience indicators are reexamined and reclassified. The basic principle of enhancing resilience of vulnerability is proposed which is reducing exposure, reducing sensitivity and increase adaptive capacity towards the goal of preparation, persistence, recovery and transformability. But as mentioned before, not all the resilience criteria can be allocated into the classification of vulnerability. Thus, it was divided into two tables, one is the relevance between vulnerability and resilience dimension and the other one is the association of indirect vulnerability and resilience, whose factors are integrated with the indicators in either exposure, sensitivity or adaptive capacity and will follow the same classification.

In of association between (indirect) vulnerability and resilience, it is obvious to see that all the indicators should have the character of preparation which can be learnt from reducing exposure magnitude, improving sensitive factors to reduce sensitivity of the energy system and enhance adaptive capacity on maintenance, management, adaptive actions.

Table 4. Association between vulnerability and resilience

Dimension		Category	Resilience dimension			
			Preparation	Persistence	Recovery	Transformability
Vulnerability	Exposure	Spatially distributed generation (and critical facilities)	x	x	x	
		Natural gas distribution	x	x	x	x
		Energy storage facilities	x	x	x	
		Density (housing and population)	x	x	x	x
		Location of people	x	x	x	x
	Sensitivity	Reliance on imports	x	x		x
		Energy price	x	x		x
		Distance between energy production to point of use (colocation of supply and demand)	x	x	x	
		Age of infrastructure	x	x		
		Phasing out and introducing new technologies	x	x		
		Type of feeder lines	x	x	x	
		Number and configuration of node	x		x	
		Back-up energy sources and stocks of energy	x	x	x	
		Distributed storage and connectivity with generation	x	x	x	
		Type of district energy systems	x	x	x	x
		Age of people	x	x		x
		Income	x	x	x	x
		Connectivity and street system	x	x		
	Adaptive capacity	Diversification of energy supply (fuel mix, multisourcing, type of generation)	x	x		x
		Fortification and robustness (physical security) and operational system protection (system relief)	x	x		
		Regular maintenance	x			
		Generation, transmission and distribution efficiency	x	x		x
		Cost for restoration of network	x	x		x
		Education level	x	x		x

41

Table 5. Association between indirect vulnerability and resilience

Dimension		Category	Resilience dimension			
			Preparation	Persistence	Recovery	Transformability
Other indirect vulnerability	Related with GHG emission **Adaptive capacity**	Energy/Carbon intensity of generation	x			
	Related with Diversification of energy supply **Adaptive capacity**	Rainwater harvesting, decentralized water harvesting systems	x	x		x
		Water conservation	x	x		x
		Reducing water footprint of energy production and transmission	x			x
		Energy generation from sewage	x	x		x
		Large solar thermal collectors	x	x	x	
		Large wind turbines located outside the built-up area	x	x	x	
		Ground source heat pumps	x	x	x	x
		Biofuel energy	x	x		x
		Waste heat or biomass-fueled combined heat and power plants	x	x		
	Related with new technology and distribution **Sensitivity**	Smart micro-girds fed by micro-turbines and solar panels and storage facilities	x	x	x	x
	Related with Natural gas distribution **Exposure**	Vehicle to Grid (selling surplus power)	x	x		x
	Related with energy self sufficiency **Sensitivity**	Energy cycling	x	x		x
		Multi-Functional and mixed use	x	x	x	
		Co-location of enterprises and others	x	x	x	
		"Spare capacity and reserve margins"	x	x		x
	Related with Demography **Exposure**	Development pattern (sprawl, compact, suburbanization, infill, brownfield, greenfield, etc.)	x	x	x	x

42

In the terms of exposure, distributed energy generation and energy storage facilities can be improved by minimising the number in the preparation stage and strengthen the resistivity and recovery capacity. Similar strategies can be applied to natural gas distribution, but on account of its dependence on road transportation, it has the potential to optimise. The people in the city are exposed to potential impacts reflecting on the location and density, which can be considered together with the development pattern to reduce exposure and find a better urban structure and form.

About sensitivity, the share of imports should be as low as possible under the precondition of meeting the energy demand. Once disaster occurs, less dependence on imports in fewer impacts, namely less sensitive. Similar to energy price. Moreover, these two provide the opportunities for the economy system to export reserve energy and contribute to GDP. The sensitivity of energy networks can be decreased by phasing out and introducing new technology, change the type of lines and systems according to build up resistance and some of them can be designed with recovery ability. On the social aspects, the older and the low-income are more sensitive. Thus more attention should be taken on them to protect and make them easier to shake down. Also, the demographic structure and income structure should be considered together with the development pattern.

Adaptive capacity in terms of diversity of energy resource, fortification and system protection, regular maintenance, generation and distribution efficiency is quite related with the development of technology. Maintenance can provide more comprehensive protection on infrastructure and the whole system and the others make further improvement on the robustness. Moreover, the energy system can be more

innovative and sustainable when conventional energy was replacing by diverse renewables and has high efficiency. On the side of planning and management, improve education and enhance social willing to cost for the establishment and restoration of networks are necessary to resilience enhancement.

Discussion and conclusion

Due to more intensive climate change and greatly energy transition, the energy system which embedded in the urban structure might face more risks and involve a transition in the whole system in the future. Thus, how to improve the two components of risks, hazards and the vulnerability, become important. Considering the inevitability and uncertainty of hazards, the paper focuses on the improvement of vulnerability. Through reviewing relevant papers, a concept of evolutionary resilience was put forward as the objective and criteria of vulnerability improvement, which is composed of preparation, persistence, recovery and transformability. In consideration of the unique characteristics of transformability in evolutionary resilience, the process of improvement of vulnerability towards resilience was alluded to "turning risks into opportunities".

Thus, this paper attempted to apply both vulnerability and resilience knowledge on energy system in Norway and achieve the goal of evolutionary resilience by: (1) establishing the method framework for enhancing the vulnerability to resilience; (2) setting the resilience goal and adopting reliable criteria; (3) finding vulnerability indicator in the resilience criteria; (4) associating the components and improving the vulnerability indicator and indirect vulnerability attributs according to resilience targets.

The main strategies for resilience enhancement are reducing the vulnerability from three dimensions, reducing exposure, reducing sensitivity and increase adaptive capacity. The extent of reducing or increasing depends on the resilience principle, according to the context of each criterion. Although some general strategies are proposed based on the criteria, it is important to add the dynamic environment to revise the assessment and objectives.

Among the four dimensions of resilience, it is clear that preparation is the most important resilience dimension for all the vulnerability elements in this association, which means all these measures should be considered in urban planning in the initial stage. Moreover, it is also revealed that one component is usually interrelated with others. Thus, the improvement of energy resilience is not a separate measure, which should be considered as an integrated approach, combining with social-economy, ecosystem, environment and other factors.

The result of this study can be regarded as guidelines for improving the vulnerability and assessing resilience of energy system in first step of urban planning. Using indicator to assess the vulnerability and resilience helps to simplify the complex system, which make the monitoring of performance and evaluation possible as well as guiding further decision making. However, on the other side, due to the selection of indicators based on related studies and the accessibility of data, the factors chosen here are not all-sided. This kind of parameter quantification method might hide some underlying problems when simplifying the complex state. Therefore, data accessibility and standardisation are the challenges for risk management.

References

1. Bergen commune (2016) *Grønn strategi, Klima - og energihandlingsplan for Bergen 2016*
2. COP21 (Conference of the Parties) (2015) GE.16-01194(E). *Adoption of the Paris Agreement.* Available online: https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf Retrieved 2017-10-31.
3. Davoudi, S.,Zaucha, J., and Brooks, E. (2016), Evolutionary Resilience and Complex Lagoon Systems, *Integrated Environmental Assessment and Management, 12*(4), pp. 711–718.
4. Downing, TE, Butterfield, R, Cohen, S, Huq, S, Moss, R, Rahman, A, Sokona, Y and Stephen, L (2001). *Vulnerability Indices: Climate Change Impacts and Adaptation,* UNEP Policy Series, UNEP, Nairobi.
5. European Commission (2009) Renewable Energy Directive (2009/28/EC) *Directive of the European Parliament and of the Council on the production of the use of energy from renewable sources 2009.*
6. European Commission, (2016) COM/2016/0767 final/2 - 2016/0382 (COD) *Proposal for a directive of the European parliament and of the council on the promotion of the use of energy from renewable sources (recast).*
7. Eurostate (2015). Environment and energy. http://ec.europa.eu/eurostat/data/database Retrieved 2017-11-10.
8. Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change, 75*(3), 301–329.
9. Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245
10. IPCC (2014), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
11. Kuznecova, T., Romagnoli, F., & Rochas, C. (2014). Energy Metabolism for Resilient Urban Environment: A Methodological Approach. *Procedia Economics and Finance*, *18*(Supplement C), 780–788. https://doi.org/10.1016/S2212-5671(14)01002-8
12. McCarthy, J. J., Canizani, O. F., Leary, N. A., Dokken, D. J., and White, K.S. (eds.) (2001), *Climate Chang 2001: Impacts, Adaptation and Vulnerability*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, Cambridge University Press, Cambridge.
13. Ministry of Petroleum and Energy (2012) Ares(2013)117932 - 30/01/2013. *National Renewable Energy Action Plan under Directive 2009/28/EC, Norway.* Inofficial translation of September 2012, based on NRAP in Norwegian of June 2012
14. O'brien, K., Sygna, L., & Haugen, J. E.(2004), Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change 64(102)*, Kluwer Academic Publishers, Netherlands, pp.193-225.
15. Polsky, C., Neff, R., Yarnal, B.(2007), Building comparable global change vulnerability assessments: The vulnerability scoping diagram, *Global Environmental Change,* 17 (3–4) (2007), pp. 472-485.
16. Sharifi, A., & Yamagata, Y. (2016), Principles and criteria for assessing urban energy resilience: A literature review. *Renewable and Sustainable Energy Reviews, 60*(Supplement C), 1654–1677.
17. Statistics Norway (2017). Electricity. https://www.ssb.no/en/energi-og-industri/statistikker/elektrisitet/aar Retrieved 2017-11-10.
18. Stenchion, P. (1997). Development and disaster management. *Australian Journal of Emergency Management 12*, 40–44.
19. UNDHA (1992). *Internationally Agreed Glossary of Basic Terms Related to Disaster Management*, United Nations Department of Humanitarian Affairs, Geneva.

0.9
GOALS OF THE PROJECT. INTENDED PRODUCTS

A revised perspective for the coastal development in Norway will be proposed as the expected outcomes for the graduation project, which considering the interrelation of the energy system and other urban systems.

By defining concrete adaptive guidelines for delta urbanism and forming into local adaptation strategies, this project aims to improve the urban structure and increase resilience capacity of existing climate vulnerability considering climate change effects and integrating with the potentiality of the requested energy transition.

Research goals:

- To assess the vulnerability of the energy system in transition of the coastal area in Norway and find out the key factors which have the possibility to be improved.

- To analyse the consequences in spatial, social, economic and environmental aspects in case of the disaster.

Sub goals:

- To question the temporality of fossil fuel related plants and analyze functions after redundancy.

- To weigh the opportunities and potential problems that renewable energy brought

Design goal and intended products:

- To develop resilience strategy and interventions including mitigation and adaptation measure for Bergen which could provide guidance for reframing current approach of energy system and exploring future potentials under climate change

1 RESEARCH

1.1
ASSESSING CLIMATE CHANGE IMPACT IN BERGEN, NORWAY

Climate change is intensified in recent decades in Norway. According to the report of Cliamte in Norway 2100, if the trend of greenhouse gas emissions continues, the annual temperature will increase by about 4.5 degrees at the end of this century. The sea level will increase between 15 and 55 cm, vary in different areas. Extreme weather will occur more frequently and more severely. The precipitation pattern will be changed. The rain-flows are getting bigger while the snowflakes are getting smaller. Fewer glaciers are left. In addition, the left ones are smaller.

As one of the western coastal cities facing directly to the North Sea, Bergen is more susceptible to the weather. Though the population in Bergen is used to the heavy precipitation, floods, wind and landslides, these challenges are very likely to intensify with the future climate change.

While, the good thing is that. Bergen is the only city in Norway who has its own Head of Climate section. Take into account of the loss of human and assess results from intensified climate change, a risk and vulnerability analysis (RAV) has been carried out as the preliminary of urban planning to reduce the risks of unforeseen incidents.

According to this report, future climate changes in Bergen are estimated to result in temperature change, sea-level rise and more extreme weather like storms. Due to the unpredictable of extreme weather, the data of wind and precipitation can be seen as the replacement. These will in turn increase the risk of floods, snow slides and land slides.

- The Norwegian Centre for Climate Services (NCCS), (2017), Cliamte in Norway 2100, NCCS report no. 1/2017, M-741.

- Bergen Kommune, (2014), Bergen ROS (overordnet risiko- og sårbarhetsanalyse for Bergen) 2014

- BaltCICA, http://www.baltcica.org/cases-tudies/bergen.html

Fig. 11. Flood risk
By author based on NVE

Fig. 12. Snow slide risk
By author based on NVE

- Temperature rise

The range of temperature in summer and winter is estimated to become narrower than before. But the average temperature has increased by about a half degree during the last 15 years.

- Extreme precipitation

Due to the oceanic cliamte, Bergen features plentiful rainfall. Recently, it becoms wetter but has less snowfall. The number of days with heavy rainfall will increase around 100%. Further more, the increase of short-term precipitation is also obviouse which often cause problems. Under the high emission scenario, two-year value will increase by 20%, five-year value around 28%.

- Sea level rise

It is estimated that Bergen will have to face to approximately 1 meter sea level rise in the next 100 years.

- Coastal storms

Wind is a quite uncertain variable, but it is sure that the wind will be wilder.



- Melting snow

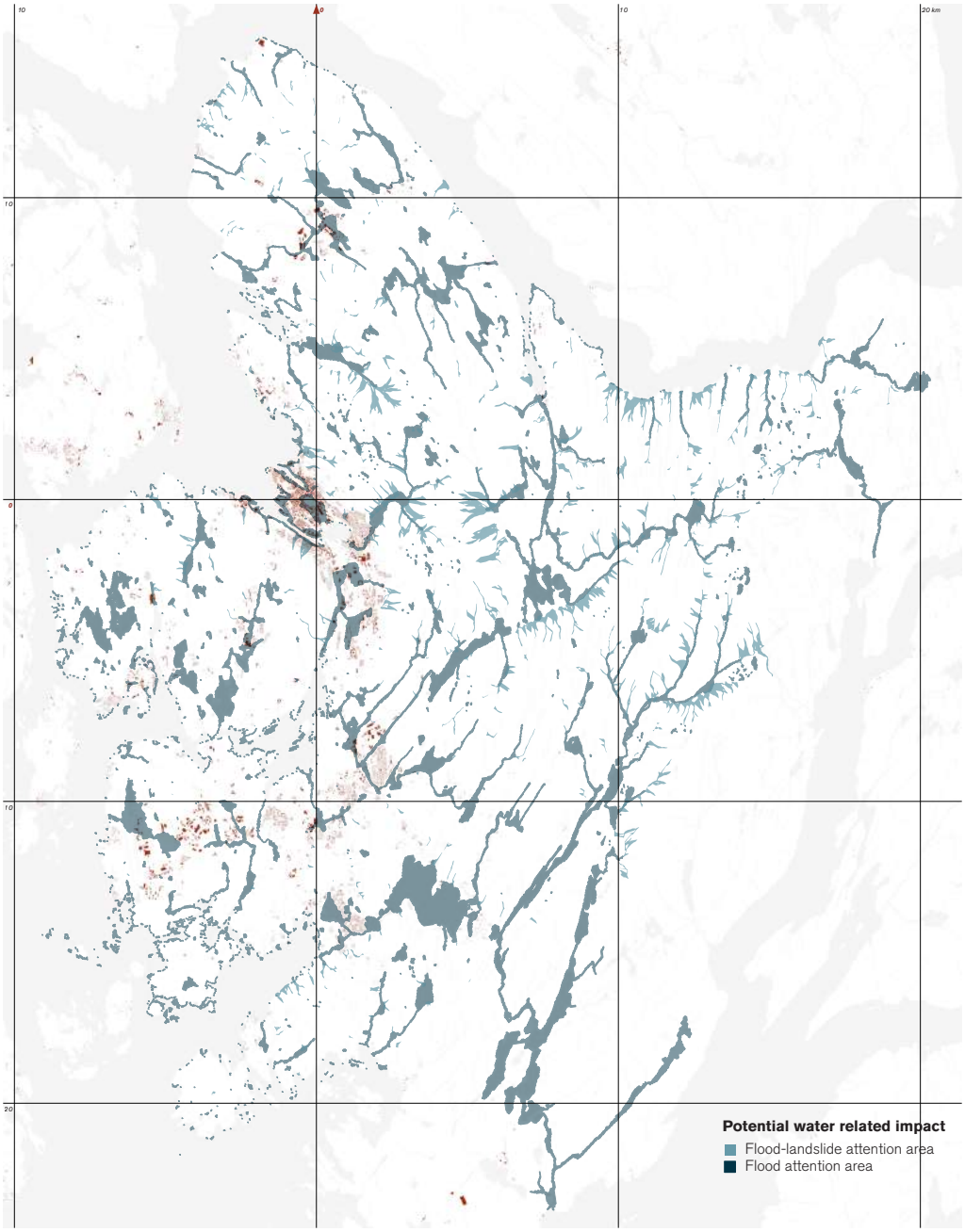
Although the snow season is getting shorter in Bergen, the risk of snow-slide will not decrease if there is a large precipitation on the terrain or flood event.

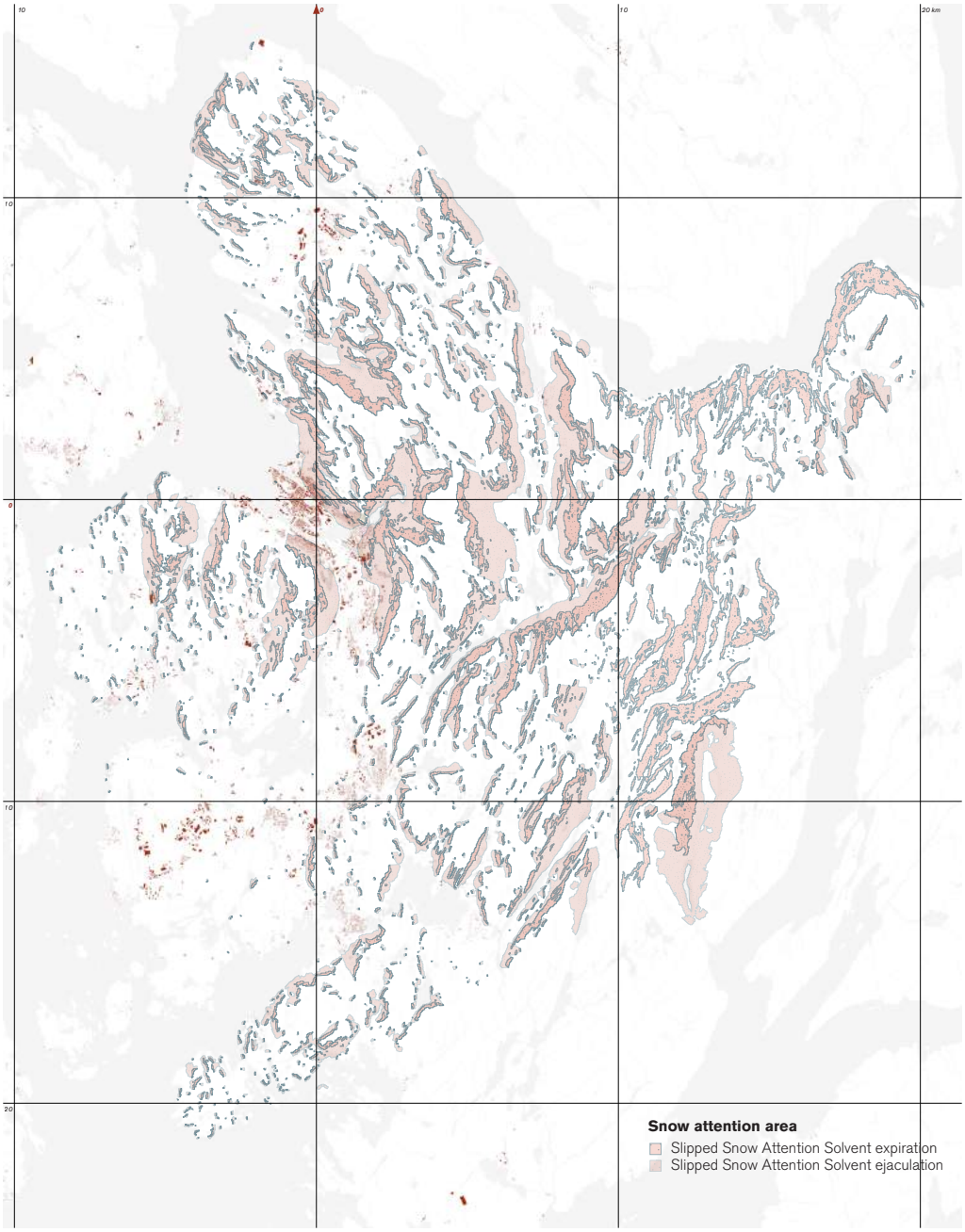
- Stormwater flooding

Because the rainflows are getting bigger and more often, the potential for flooding is likely to increase.

- Landslide

Considering the bump, the landslide is more likely to happen in the populated areas. Meanwhile, land-slide is closly relating with sea level rise and land rising.


10
0
10
20 km
10
0
10
20
Potential water related impact
Flood-landslide attention area
Flood attention area


10
0
10
20 km
10
0
10
20
Snow attention area
Slipped Snow Attention Solvent expiration
Slipped Snow Attention Solvent ejaculation

12

Conclusion of climate change impact:

Bergen has a quite exposed location which results in the frequent and continuous precipitation throughout the year. With climate change, the intensity and frequency of heavy downpours, storms, floods will be increased, along with the floods, landslides and snowslides.

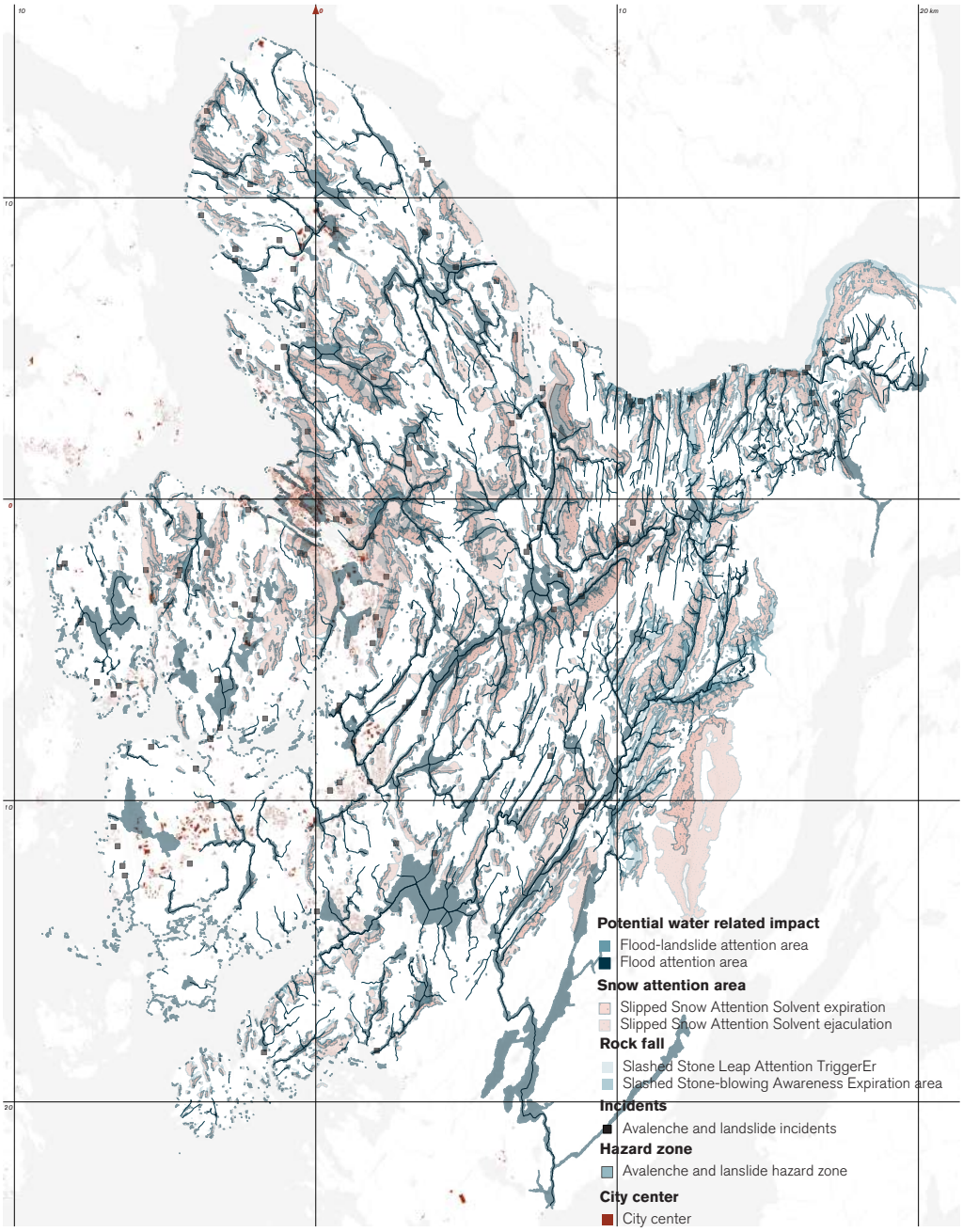
The most significant influence of climate change impact is the water problem. Since 1900, the rainfall has increased by 19% and if the trends continue, it is estimated to increase 40%-50% more. The average annual rainfall is 2500ml and the number of rainday is 242 per year, which means 25%-35% increase of precipitation in the past 100 years. The change in the precipitation pattern is obvious, especially in the western part of Bergen.

Considering the sea level rise and bigger rain flows, the potential flood will happen almost everywhere, especially at the coastland, inter mountain and lowland areas. Compared with the main river, the creek has a higher probability of flood, of which the trend can be verified by the damage of the creek in the recent years. The frequency of storm and flood brings a new challenge to the stormwater management.

Extreme weather is mainly contributed by rain and wind. There has been about 60 incidents reported during the last 20 years. Most of them happen in December and January. It can be concluded through the reported incidents that the west and north are the most vulnerable area. Due to the rise of temperature, the physical environment becomes more uncertain and the possibility of extreme weather will increase.

The possibility of snowslide and landslide will also be increased. The change of future climate change will influence the precipitation pattern. Larger rainfall capacity is likely to increase the pressure of water in the mountain, which will lead to the snowslide and landslide.

Fig. 13. Conclustion map of climate change impact
By author based on NVE


10
0
10
20 km
10
0
10
20
Potential water related impact
Flood-landslide attention area
Flood attention area
Snow attention area
Slipped Snow Attention Solvent expiration
Slipped Snow Attention Solvent ejaculation
Rock fall
Slashed Stone Leap Attention TriggerEr
Slashed Stone-blowing Awareness Expiration area
Incidents
Avalenche and landslide incidents
Hazard zone
Avalenche and lanslide hazard zone
City center
City center

1.2
ASSESSING TRANSITIONAL ENERGY SYSTEM FROM CARBON BASE TO GREEN BASE

The whole energy system can be classified into three processes, energy production which is composed of a diverse natural resource, access to energy and end use.

Existing energy composition:

In the world, Norway is considered as the leader in terms of the renewable energy, because most of electricity comes from hydropower. In addition, among all the energy consumption, 75% (2042TWh) are exported to the surrounding countries like the UK, Germany, the Netherlands and France.

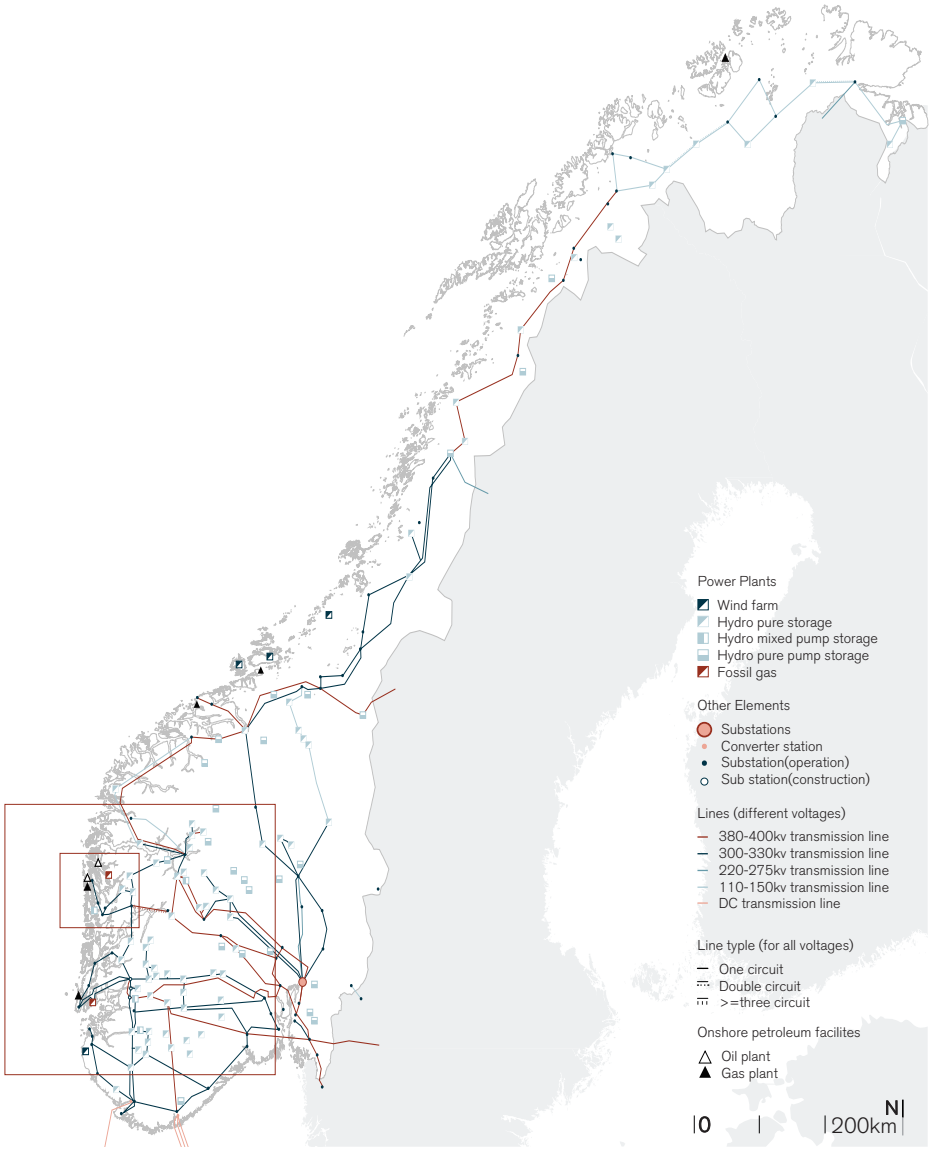
But actually, the situation of Norway is quite special. Because every year, Norway sells renewable energy and meanwhile buy Coal and nuclear power. 76TWh is imported to Norway, the share of fossil fuel is 45% and the proportion of nuclear energy is over 30%.

There are seven onshore petroleum facilities in Norway, two of them are oil plant and the rest are the gas plant. In terms of the power plant, there are only two fossil gas power plant exist. Most of them are hydropower plants and a wind farm. Due to the special topography, energy are transmitted by high transmission line from the mountains to urbanised area. Through converter station, high voltage is converted as low voltage and distributed to households, industry and buildings.

The power system in Bergen is the result of development. In 1900, the first power plant supplied Bergeners with electricity from a steam power plant. 9 years later, Bergen Lysverker started construction of its first hydroelectric power plant. Later, in connection with municipal merger, several power stations merged with Bergen Elektrisitetsverk. In 1996, Bergen Lysverker acquired by BKK, which in retrospect also bought several of the power companies in the Bergen region municipalities.

Today, as the second largest city in Norway, Bergen requires a huge amount of energy. Electricity is the dominant energy carrier, even comparing with a large proportion of heavy industry who uses gas as an energy carrier.

Fig. 14. Power networks in Norway
By author based on NVE


Power Plants
Wind farm
Hydro pure storage
Hydro mixed pump storage
Hydro pure pump storage
Fossil gas
Other Elements
Substations
Converter station
Substation(operation)
Sub station(construction)
Lines (different voltages)
380-400kv transmission line
300-330kv transmission line
220-275kv transmission line
110-150kv transmission line
DC transmission line
Line typle (for all voltages)
One circuit
Double circuit
>=three circuit
Onshore petroleum facilites
Oil plant
Gas plant
N
0
200km

- Primary energy production

Primary energy products are extracted or retrieved directly from nature and have not been through a conversion proposity from other energy, mainly consisting of nature gas, crude oil, water and wind energy, others include NGL, condensate, biofuel and waste, coal.

- Power distribution

The power supply to the City of Bergen is supplied through 25 substations. Transmission line to the transformer stations are mostly operated at 132kV voltage, but part of the network operated with 45kV voltage. Cable networks is preferred in the central areas.

- End use

Net domestic energy consumption mainly includes consumption of secondary energy products, as well as biofuels, natural gas, coal and NGL / ethane, which also means final consumption.
It can be classified into three consumer group, industry and mining , transport and other activities.

- Oil

Oil is mostly distributed by local dealers who are doing delivery by truck to customers on demand.

- Natural gas

In Bergen, there are no distribution systems where gas distributed by pipeline to the consumer. The gas distributed to consumers via tanks and tanker truck.

- Water

- Sun

- Wind

NVE prepared a complete wind map which shows that there is potential for wind power in Bergen.

- Bio fuel

The combustion of wood is the most common form of bioenergy in Bergen.

- Geo-thermal

- Waste

Waste provides heat to the district heating network and electric power in the distribution of electricity. In 2012 delivered system 63 GWh electricity

- Backup & storage

- Energy consumption

Energy transition ambition:

--> 2020

Norway has set the goal to increase the share of renewable energy in the EU from 8.5% in 2005 to 20%, and 67.5% national renewable energy production. The new market mechanism is expected to generate 26.4 TWh electricity every year by 2020. And Bergen aims to reduce 30% emission of greenhouse gas compared with 1991.

-->2030

Norway will be a climate neutral country and Bergen will become a fossil-free city, which means there will be no more oil, coal and natural gas used as fuel.

-->2050

Norway aims to reach 80% shares of renewables in the consumption and drive the export of green energy and high-tech products from the world's most eco-friendly industry.

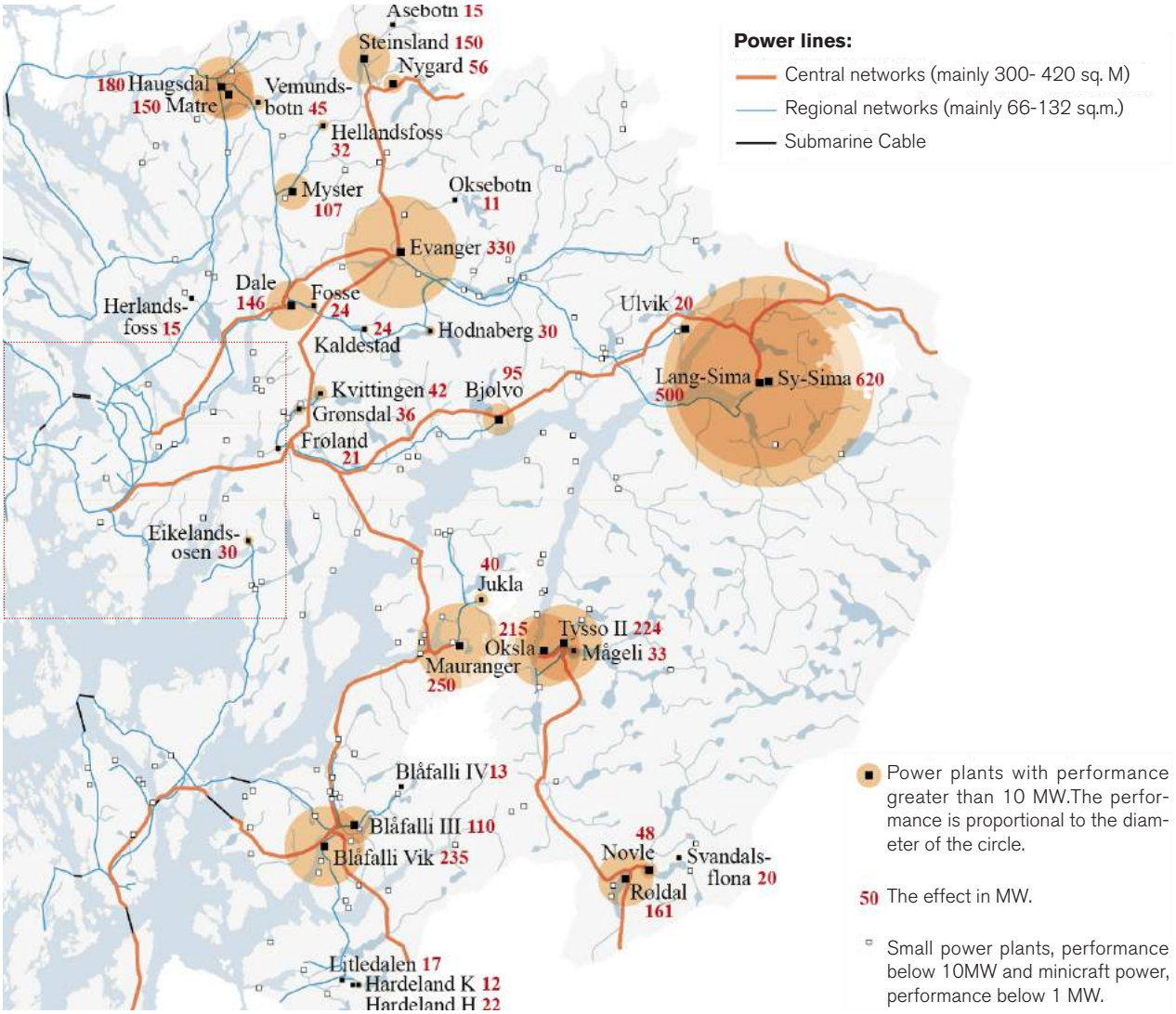
The goal is to keep the increased temperature under 1.5 degrees and limit greenhouse gas in line with the UN agreement.

Transitional energy system:

In Bergen, oil suppliers have had a significant decline in recent years, which is in line with the national guidelines of phasing out oil for heating. And meanwhile, the district heating is growing and will continue in the years ahead. This will also require expansion of the district heating network. But some of the growth will also come through densification as in the center. The distribution of the volume growth is expected to be accretive by new construction and reconstruction of 47% and 53% on existing buildings.

- Statistics Norway, (2014), http://www.ssb.no/energibalanse

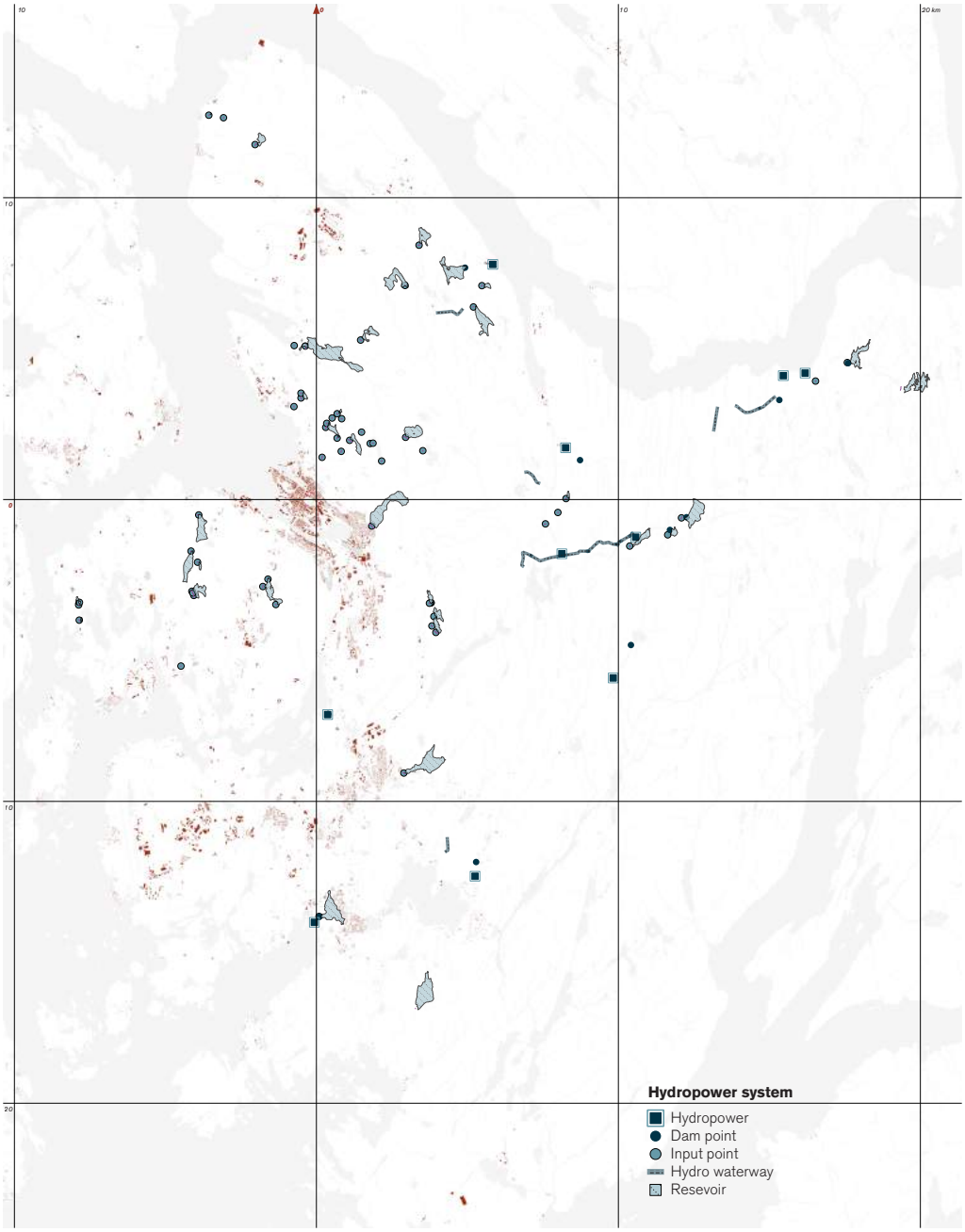
- Ministry of Petroleum and Energy, (2013), National Renewable Energy Action Plan under Directive 2009/28/EC Norway, Inofficial translation of September 2012, based on NRAP in Norwegian of June 2012



15

Fig. 15. Hydropower system in Hordaland
Source: GRIND, https://grind.no/industri-energi-naturressursar/vannkraft-i-hordaland

Fig. 16. Hydropower system in Bergen
By author based on NVE


10
0
10
20 km
10
0
10
20
Hydropower system
Hydropower
Dam point
Input point
Hydro waterway
Resevoir

16

Conclusion of transitional energy system

In Norway, 96.3% of eletricity is generated by hydropower. 13% of Norway's total hydropower production comes from Hordaland.

As the most developed county in Norway, Hordaland owns 189 power plants, 15 of which are the largest power station, generating 80% of the total power. 80% of power plants are micro and small power plants accounting for 7% of total power generation, and most of them belong to private individual owner.

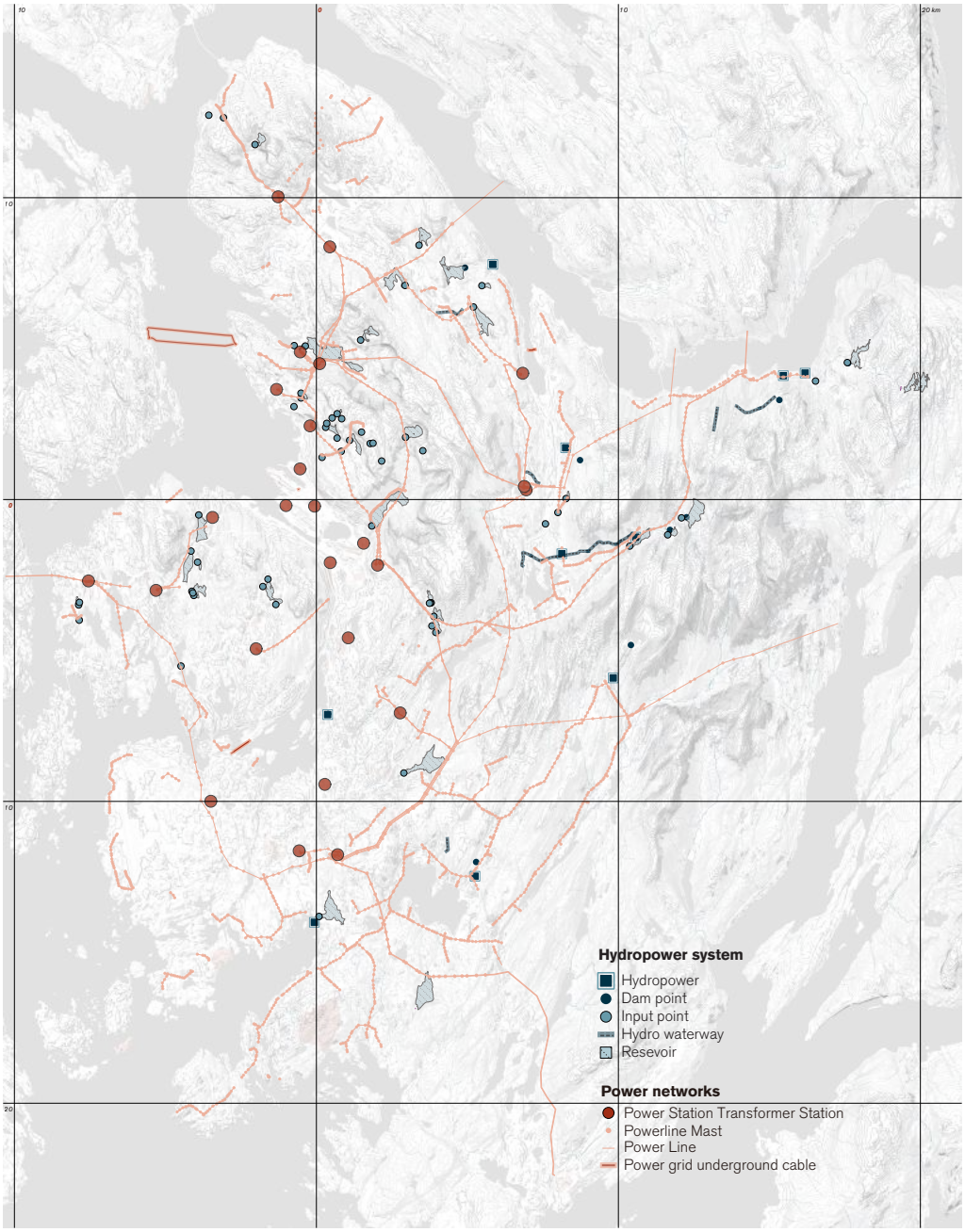
There are no big hydropower stations in Bergen. All of them are small power plants performing below 10MW and micro plants below 1MW. Most of them are run of the river, pumped-storage and mixed hydroelectricity. This is the result of history since the conflict between protecting watercourses and developing hydropower since 1950s. Decisions are made based on the principle of minimizing the influence of ecosystem and environment when rivers and lakes are built for hydropower purposes.

Most of the rivers and lakes are either protected or developed. Recently, only small and micro power plants are built and these will still be encouraged in the future.

In addition, according to NVE, other renewable energy like water, sun, bio-fuel, geo-thermal and waste are positive. In terms of electricity production, hydro, wind and biomass will contribute together, but the proportion will be 137:15:1 by 2020. And biomass, geothermal and hydro thermal will supporting the heating and cooling system with the proportion of 14:4:1.

In Bergen, the transition from a carbon-based environment to renewable energy is easier than other areas. Because there are no distribution systems where gas distributed by pipeline to the consumer. The gas is distributed to consumers via tanks and tanker truck. Similarly, oil is distributed by local dealers who are doing delivery by truck to customers on demand. And the new buildings are designed without oil and gas facility.

Fig. 17. Energy system in Bergen
By author based on NVE


Hydropower system
Hydropower
Dam point
Input point
Hydro waterway
Resevoir
Power networks
Power Station Transformer Station
Powerline Mast
Power Line
Power grid underground cable

17

1.3
ASSESSING THE CHANGE AND OPPORTUNITY ON URBAN STRUCTURE & URBAN SYSTEM

Location of Bergen:

Bergen is situated in the western coastal area of Norway, historically named as Bjørgvin, which indicates the geographic feature of the city, surrounding by seven mountains.

Area and Population:

The total area of Bergen is 465.3 sq.km. of which 445.1 sq.km consist of land.

According to SSB, the population in the municipality was 278,121, and about 420,000 inhabitants living in the Bergen metropolitan region in 2017.

Governance:

Bergen was its own county between 1831-1972. After that, the municipality absorbed four surrounding municipalities and merged into Hordaland county. Bergen is still the administrative centre among other eight boroughs, Arna, Bergenhus, Fana, Fyllingsdalen, Laksevåg, Ytrebygda, Årstad, and Åsane.

Economy sector:

Settling in the western coastal region of Norway provides a unique opportunity for Bergen, which facilitates Bergen to be an international centre for shipping, offshore petroleum industry and aquaculture. Bergen Port is the busiest in Norway, which is crucial for both freight and passengers, with over 300 cruise ship calls a year bringing nearly a half a million passengers to Bergen.

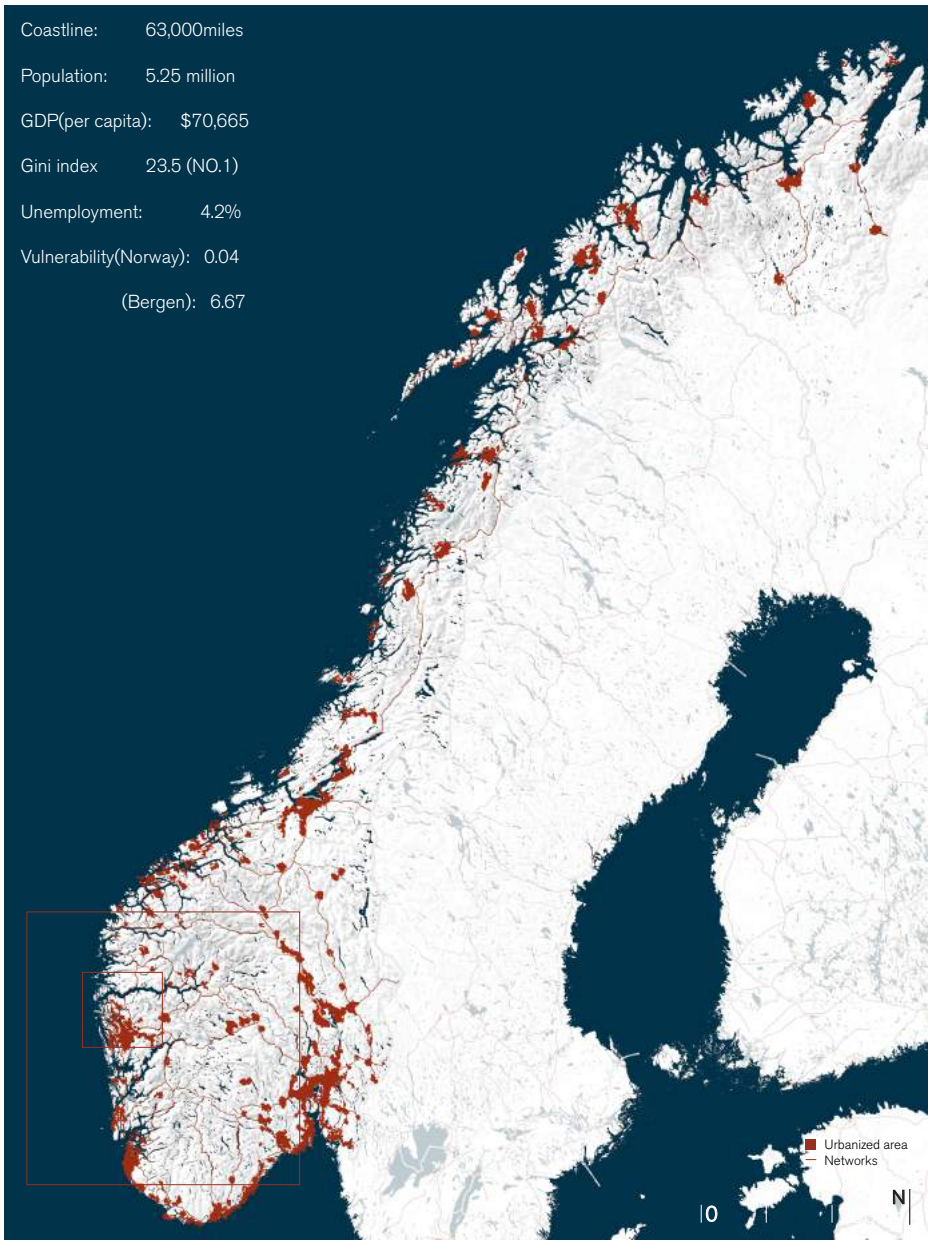
As the second largest city in Norway, the advanced condition attracts many qualified scientists and technicians to come and become a national centre for finance, culture and higher education.

Climate:

Bergen has a relatively high average temperature of 6.7 degrees in Norway, with heavy rainfall in the typical western climate.

- SSB, (2017), https://www.ssb.no/kommunefakta/bergen

Fig. 18. Urban system in Norway
By author based on NVE


Coastline: 63,000miles
Population: 5.25 million
GDP(per capita): $70,665
Gini index 23.5 (NO.1)
Unemployment: 4.2%
Vulnerability(Norway): 0.04
(Bergen): 6.67
Urbanized area
Networks
0
N

- Center structure

The living and working center of Bergen is still the historic center, which is settling in the middle of several mountains.

- Population

Bergen has a high population density with 597.7 inhabitants per km2, By comparison, the average for the county is 22.8.

- Residential

97% of residents live in urban areas. In comparison, 79% of the population of Hordaland living in densely populated areas.

- Industry

81.4% of the employers are working in the tertiary industry, while 18% working in the secondary sector.

- Business

Bergen has over 900 year old history to be known as Norway's most important trade connection with Europe. Through changing times, Bergen has evolved from traditional-industry-based city such as shipping and fisheries into an international center of trade, crafts, industry and finance.

- Road traffic

The traffic pattern is quite similar to the urban structure that the biggest traffic flows are radial, towards the center of Bergen. This reflects both the transport services and travel pattern. But now, there are missing lines and little traffic between west and north, which is only accessible through urban areas. Also, there is potential for more traffic between the west and Bergensdalen when Mindemyren is developed as one of the major business areas of the city with a large number of jobs.

- Water system

Bergen has a good management plan for watercourses and more affinity with water than most other cities. Water is regarded both as an attraction and as an essential component in improving the lives of citizens and visitors alike.

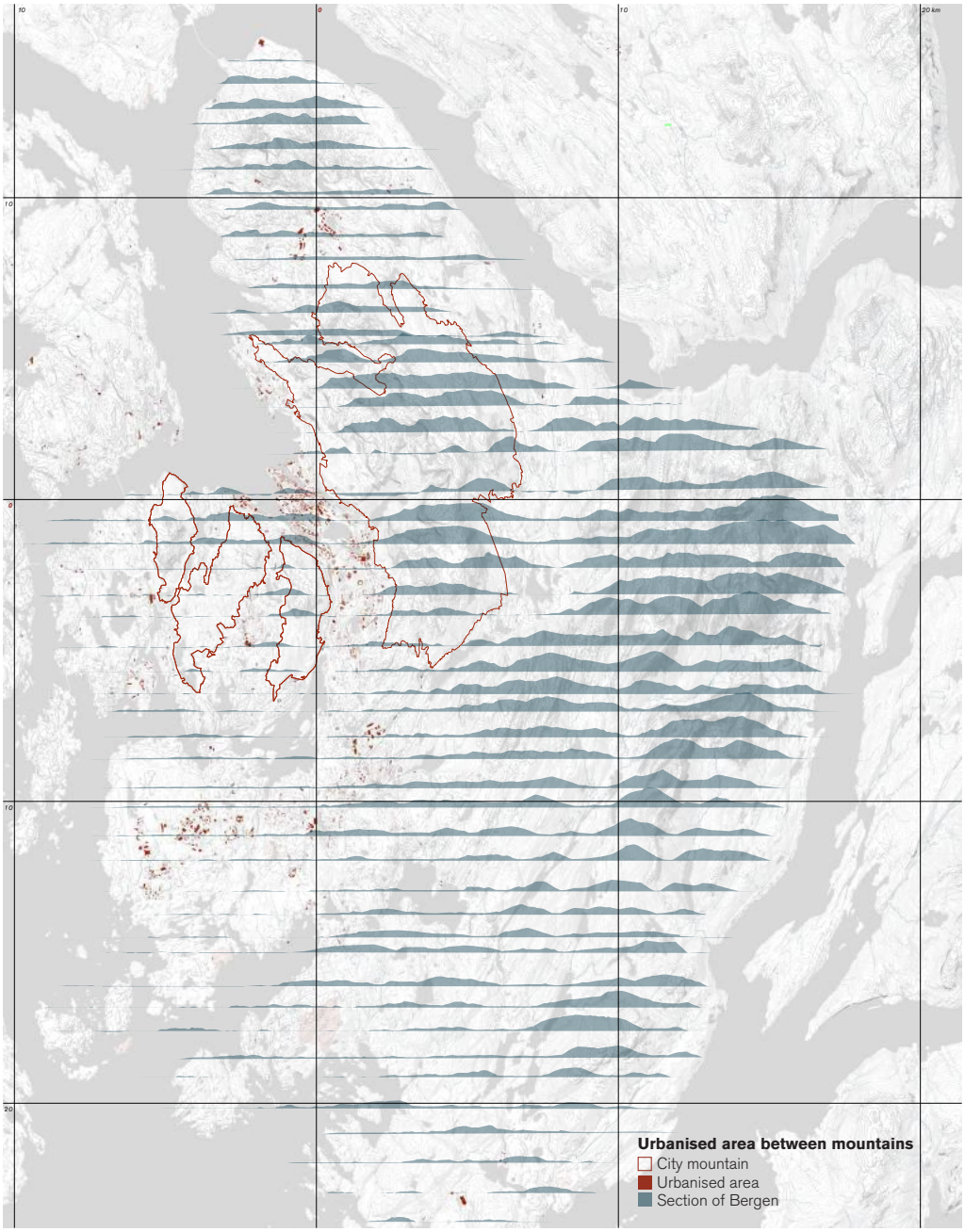
- Green structure

Bergen keeps a large amount of forests and consequtive agriculture areas. The urban regulation promises the green corriders and free outdoor areas. This meanwhile contributes to the capacity of water infiltration and carbon catchment.

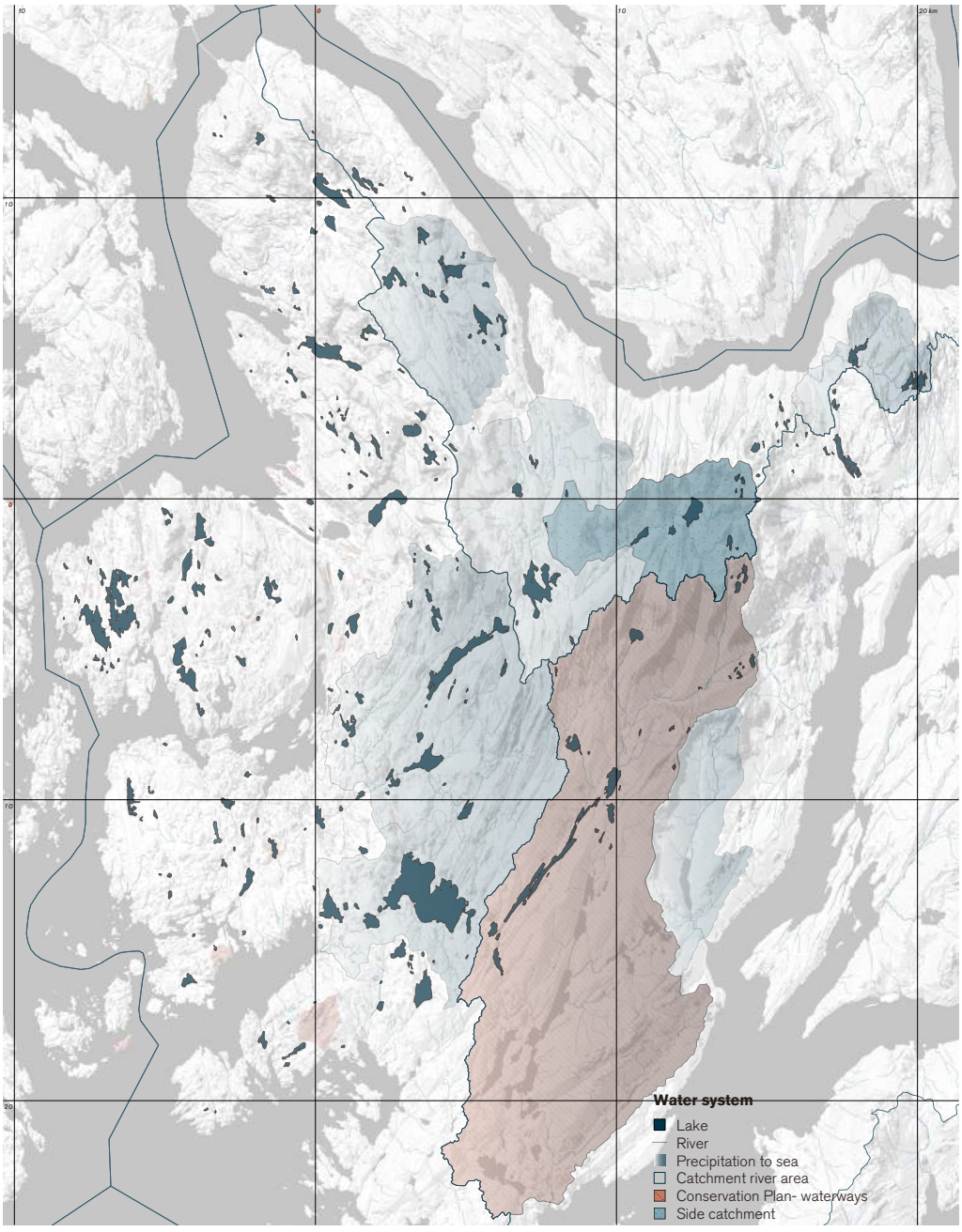
Fig. 19. City and mountains
By author based on NVE

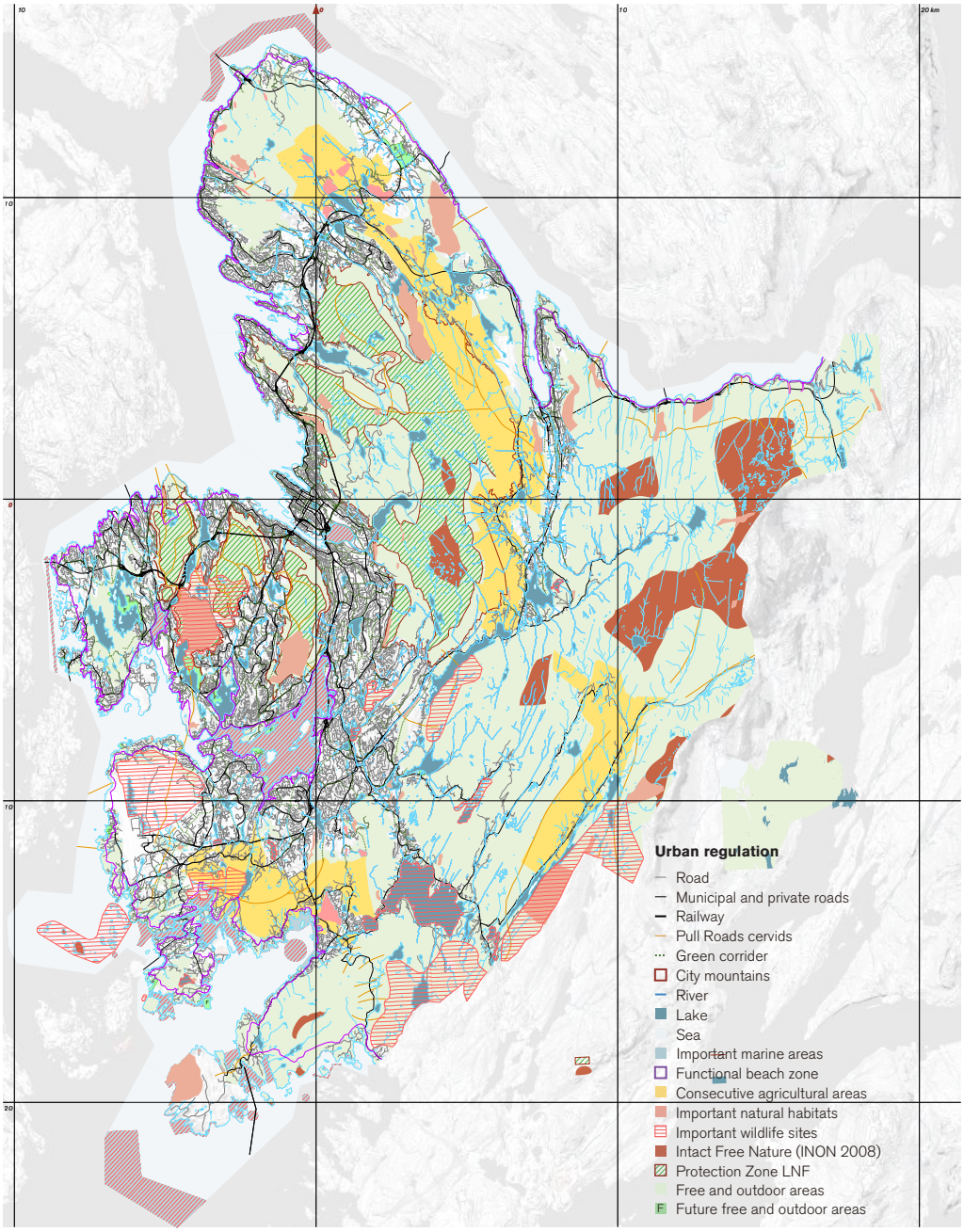
Fig. 20. Water system
By author based on NVE

Fig. 21. Urban regulation
By author based on NVE


10
0
10
20 km
10
0
10
20
Urbanised area between mountains
City mountain
Urbanised area
Section of Bergen

19


Water system
Lake
River
Precipitation to sea
Catchment river area
Conservation Plan- waterways
Side catchment


Urban regulation
Road
Municipal and private roads
Railway
Pull Roads cervids
Green corrider
City mountains
River
Lake
Sea
Important marine areas
Functional beach zone
Consecutive agricultural areas
Important natural habitats
Important wildlife sites
Intact Free Nature (INON 2008)
Protection Zone LNF
Free and outdoor areas
Future free and outdoor areas

Conclusion of urban structure:

Bergen's urban structure is rather centralized with regard to housing and jobs, also includes the services. Therefore, it is obvious to see that Bergen have a dominant center in the city region. To relieve the pressure of the city center, several town centers are distributed and classified into six regions.

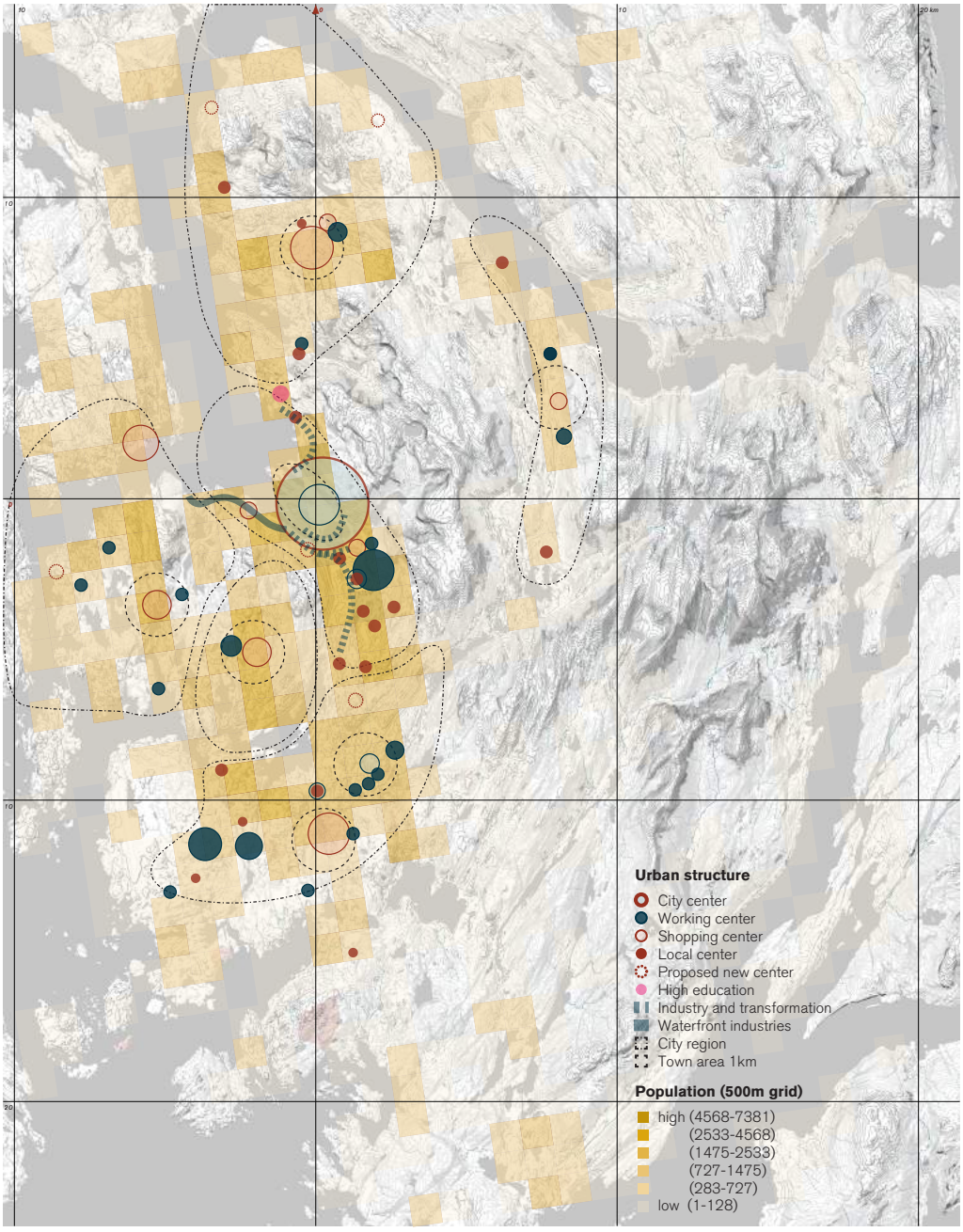
The population is concentrated in the center and decreases progressively when expanding to north, south and west. This is the result of densification of the center of Bergen and the connection with the surrounding towns like Knarvik (in Lindås), Kleppestø (in Askøy) and Straume still needs to be improved.

Although the link between the outer areas to the west and south is satisfied, it is a poor connection between the inner parts of the west and south. Meanwhile, there is also a missing link between west and north, which must go through urban areas when people transfer from north to west. To ensure accessibility not only for residents but also for workers, tourists and the intelligentsia, the development of the transport network in the urban area needs to take the connection of important destinations like ports, district centers, local centers and important tourist destinations together into consideration. Therefore, the existing urban structure of Bergen can be seen as the basic delimitation of the different corridors.

Bergen is growing rapidly which is expected to have 45,000 new homes and more than 17,000 in the surrounding communities by 2040. The number of jobs will accordingly embrace a huge growth. The structure of urban development will face challenges when putting constraints on the location and develop new residential areas, commercial areas and centers.

In addition, the transport network will have implications for the development of the future urban structure. The urgent problem is how to serve 150,000 more people effectively and efficiently in 2040.

Fig. 22. Urban structure
By author based on NVE


Urban structure
City center
Working center
Shopping center
Local center
Proposed new center
High education
Industry and transformation
Waterfront industries
City region
Town area 1km
Population (500m grid)
high (4568-7381)
(2533-4568)
(1475-2533)
(727-1475)
(283-727)
low (1-128)

1.4 EXPLORING PROBLEMS
RELATING SYNERGIES WITH CLIMATE CHANGE RISK AND ENERGY TRANSITION ON URBAN FORM

Climate change is happening and will become more severe in the future. To mitigate this situation, energy system is in the great transition towards renewable energy to reduce the huge amount of greenhouse gas emission. Meanwhile, other urban systems cooperate together to reach the goal of carbon neutral.

But meanwhile, climate change will not stop immediately. The frequent storm, flood, extreme weather will lead to the damage of energy infrastructure and energy disruption, especially the renewable energy infrastructure which is highly rely on climate and environment. In addition, it will cause the loss of life and assets, and even beyond the physical aspects.

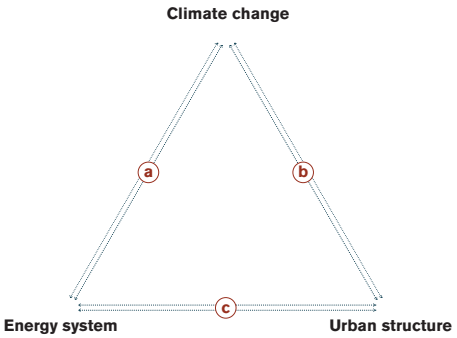
In this relationship, climate change impact, energy transition policy and existing urban structure are three main elements which interact with each other and any two elements can constitute a causal relationship. But, all the impacts will eventually be reflected on the change in the urban structure and urban system, influencing the people living in the city.

When complex systems face hazards or cannot cope with changes, they are in a critical transition(Scheffer 2009). To regain the equilibrium or find a new one, the subsystems 'not only have to redefine themselves but also have to create new relations with each other' (Meyer and Nijhuis, 2014).

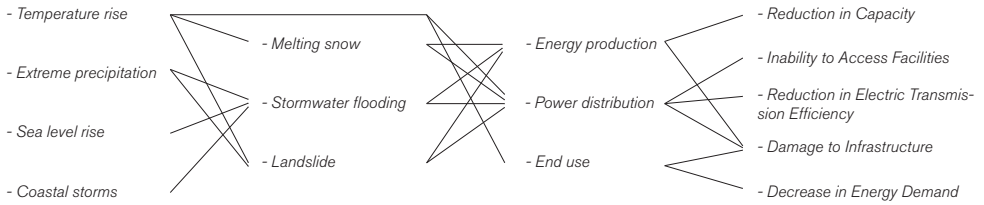
Here, we can regard the climate change impact as the external driven factor and energy transition opportunity as the internal factor because of the subordination of the urban system. Anyone will result in the transformation of urban system, moreover, the joint effort will make this transformation even more complicated and unpredictable.

Thus, to better recognize the problems, analysis of the relation between each two elements are generated. For each relationship, proposal approach will be proposed. After that, synergies with climate change risk and energy transition on urban form can be concluded.

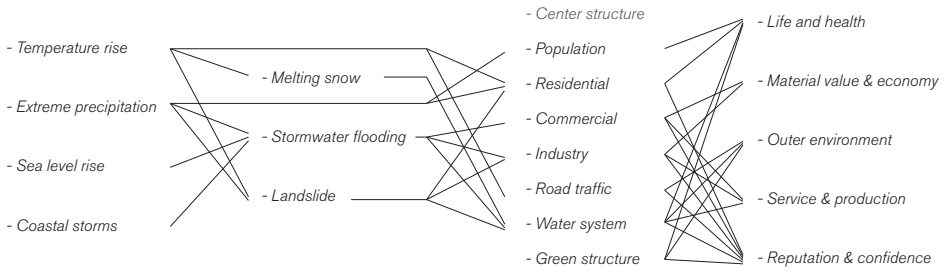
Fig. 23. Relationship between climate change, energy system and urban form
By author based on NVE



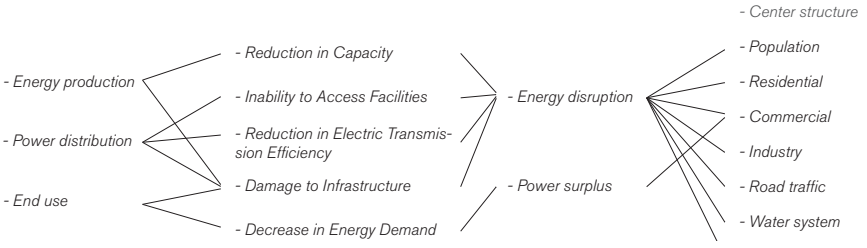
a Climate change ⟺ Energy system



b Climate change ⟺ Urban structure



c Energy system ⟺ Urban structure



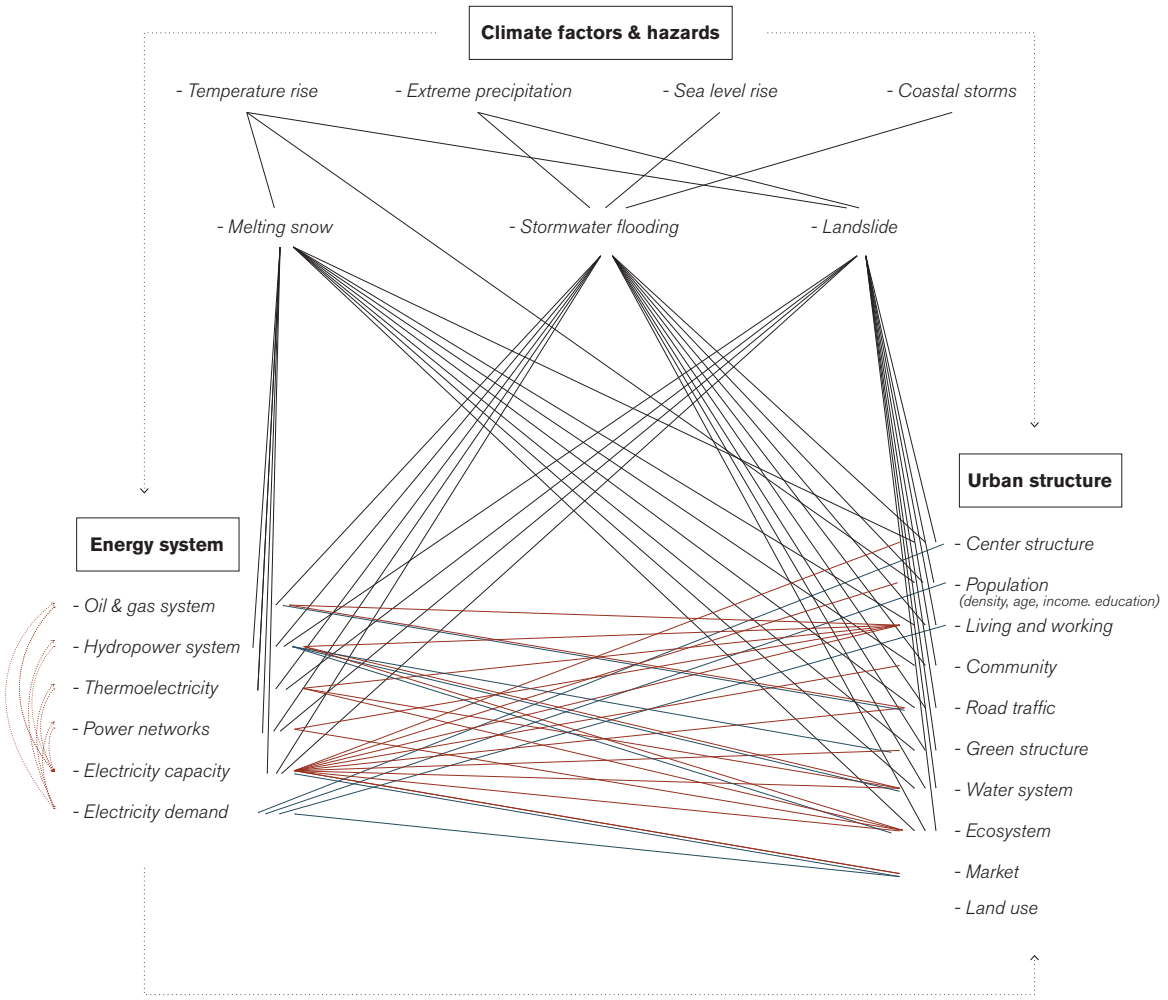
The challenge of climate change and energy transition on urban systems

Rising temptation as the fundamental consequence of climate change, accompanied by other changes in the climate system, leading to the impacts on the ecosystem, social-economy and health of humans. The climate factors change dramatically through temperature, precipitation and sea level. Though someone might benefit from this, for example the boost of agriculture and fishery in the cold area under the condition of global warming, most of the impacts are irreversible and undesirable. The possibility of extreme weather, floods, droughts are increased, which will threaten the nature, infrastructure, buildings, industries and people.

In addition, the proposed energy transition policy challenges the urban systems as well. Although Norway generates a huge amount of green energy and even export to the EU, the country still needs to import fossil fuel like coal, oil and gas to meet the demand. Another problem is that the electricity consumption per capita is extremely high, almost 3 times than the other EU country. To realise the goal of reducing 30% direct greenhouse gas emission in 2012 compared with in 1991, become fossil-free by 2030 and keep the temperature increase below 1.5 degrees till 2050 will lead to the transformation on the energy system and other urban systems as well.

Thus, the combination of climate change impact and transitional energy system threats the whole urban system on its operation and function. The economy depends on the energy system will collapse and the energy structure and urban structure need reconstructing. The people in the changing urban system also suffered from this impact. Especially, the vulnerable groups are harder to adapt to the environment. Considering the trend in the increase of population and the ageing effect, more people will be the victims under the climate change impact.

Fig. 24. Synergies relating climate change, energy system and urban form
By author based on NVE


Climate factors & hazards
- Temperature rise
- Extreme precipitation
- Sea level rise
- Coastal storms
- Melting snow
- Stormwater flooding
- Landslide
Energy system
- Oil & gas system
- Hydropower system
- Thermoelectricity
- Power networks
- Electricity capacity
- Electricity demand
Urban structure
- Center structure
- Population
(density, age, income. education)
- Living and working
- Community
- Road traffic
- Green structure
- Water system
- Ecosystem
- Market
- Land use

1.Climate change and energy system

Due to the sea level rise and more rainfall, almost all of the rivers and lakes will gain more water. On one side, the increased water might cause the surface flood and damage of vulnerable creek which will increase the possibility of the break down of surrounding energy facilities.

The blue outline circle represents the area that might be harmful by potential water-related problems in terms of damage of energy facility. The center area is a typical example. Three power transformer stations are located at the potential flood area. Although these stations almost are the tail of the energy system, the disruption will still happen and influence the end user.

On the other side, considering the large amount of hydropower stations, dams, reservoir and advanced knowledge, it is possible to utilise the increased water and turn it into energy.

The black outline circle stands for the area might benefit from potential flood. Here, it is obvious to see that almost all the hydropower system have the opportunity to utilise the increased water. Most of them are located between the mountains at the lowland.

Besides, snowslide and landslide accompaied. The red outline circle means the area might be harmful by snowslide and landslide. Due to the large age of many energy infrastructure, the system is quite vulnerable.

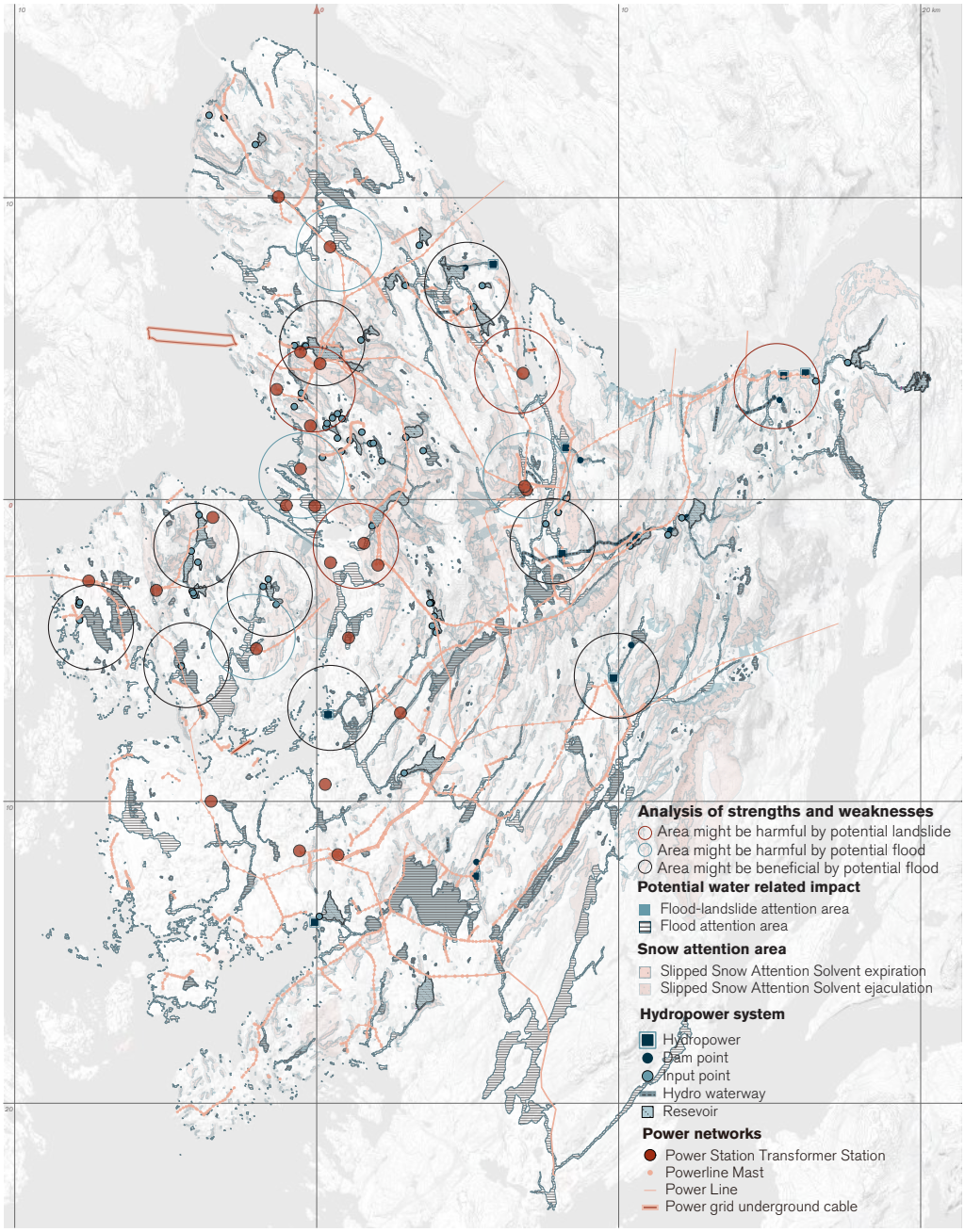
Defining the proposal approach

- update energy infrastructure and regular checking

- prevent the infrastructure from flood and landslide or remove to other places

- improve the robustness of hydropower system and the capacity of reserviors as the primary condition to increase hydro production

Fig. 25. Climate change and energy system
By author based on NVE


Analysis of strengths and weaknesses
Area might be harmful by potential landslide
Area might be harmful by potential flood
Area might be beneficial by potential flood
Potential water related impact
Flood-landslide attention area
Flood attention area
Snow attention area
Slipped Snow Attention Solvent expiration
Slipped Snow Attention Solvent ejaculation
Hydropower system
Hydropower
Dam point
Input point
Hydro waterway
Resevoir
Power networks
Power Station Transformer Station
Powerline Mast
Power Line
Power grid underground cable

2.Climate change and urban structure

From ‘Shipping city of Bergen’ to the ‘Rain City’ , Bergen is facing the challenge of dealing with even more water, – both from the sea and from the sky.

As the urban areas are concentrated in the west, south and north, more attention needs to be paid on these areas. The blue outline triangle indicates the urbanised area might be harmful by the probable flood. Due to the limited land in Bergen, the areas are relatively centralized, which might lead to great losses once floods happen. Center of Bergen might suffer the most. Both coastal area and inland area will be flooded, which has plentiful industries, residential and office.

One of the reasons to focus on the urbanised area is the low ground level and high-valued property. Another reason is that the densification of urbanised area and largely construction of paved roads and infrastructure decrease the capacity of water infiltration, if stormwater management cannot drain away water in time, the possibility of surface flood will be increased.

With the temperature increasing and the precipitation change, snowslide and landslide is more likely to threaten the city.

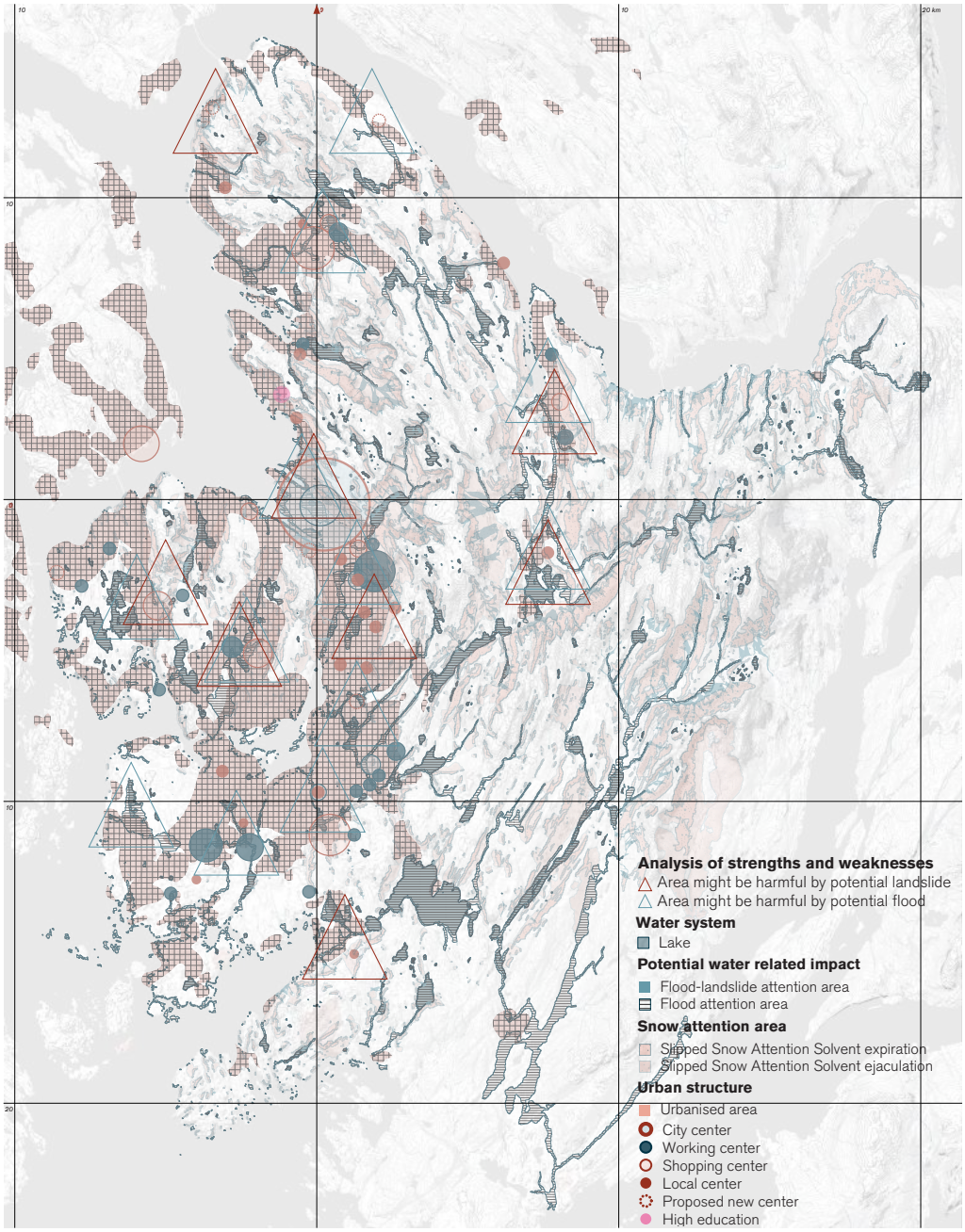
Here used red outline triangle to show the urbanised area might suffer from snowslide and landslide. Since the city is surrounded by seven mountains, many areas are at stake. Considering the factor of landslide and snowslide, it usually happens near the water system.

Defining the proposal approach

- It is quite important to reduce the societal risks associated with climate changes and enhanced precipitation and flood water exposure within the built environment.

- Prevention measures are needed for the urbanised area which has high possibility to suffer from landslide and snowslide.

Fig. 26. Climate change and urban system
By author based on NVE


Analysis of strengths and weaknesses
Area might be harmful by potential landslide
Area might be harmful by potential flood
Water system
Lake
Potential water related impact
Flood-landslide attention area
Flood attention area
Snow attention area
Slipped Snow Attention Solvent expiration
Slipped Snow Attention Solvent ejaculation
Urban structure
Urbanised area
City center
Working center
Shopping center
Local center
Proposed new center
High education

3.The energy system and urban structure

With time, the energy system has become the most important one among the urban systems, which support the life and work of people and promise the development of society. Power generation is value creation, which generates revenues for the state and municipalities.

But on the other side, the more dependent on the energy system, the more damage will be once risk happens. A power failure can influence health, and even cause the loss of life and assets. Furthermore, the existing and future business development reply on robust power supply, whose break off will lead to the huge loss of society beyond the physical aspect.

The red square shows the areas have a relatively high dependence on energy system, according to the population, residential, office, industry and center system. While the blue one represents the area have less energy demand and have the potential to be self-sufficient through hydropower.

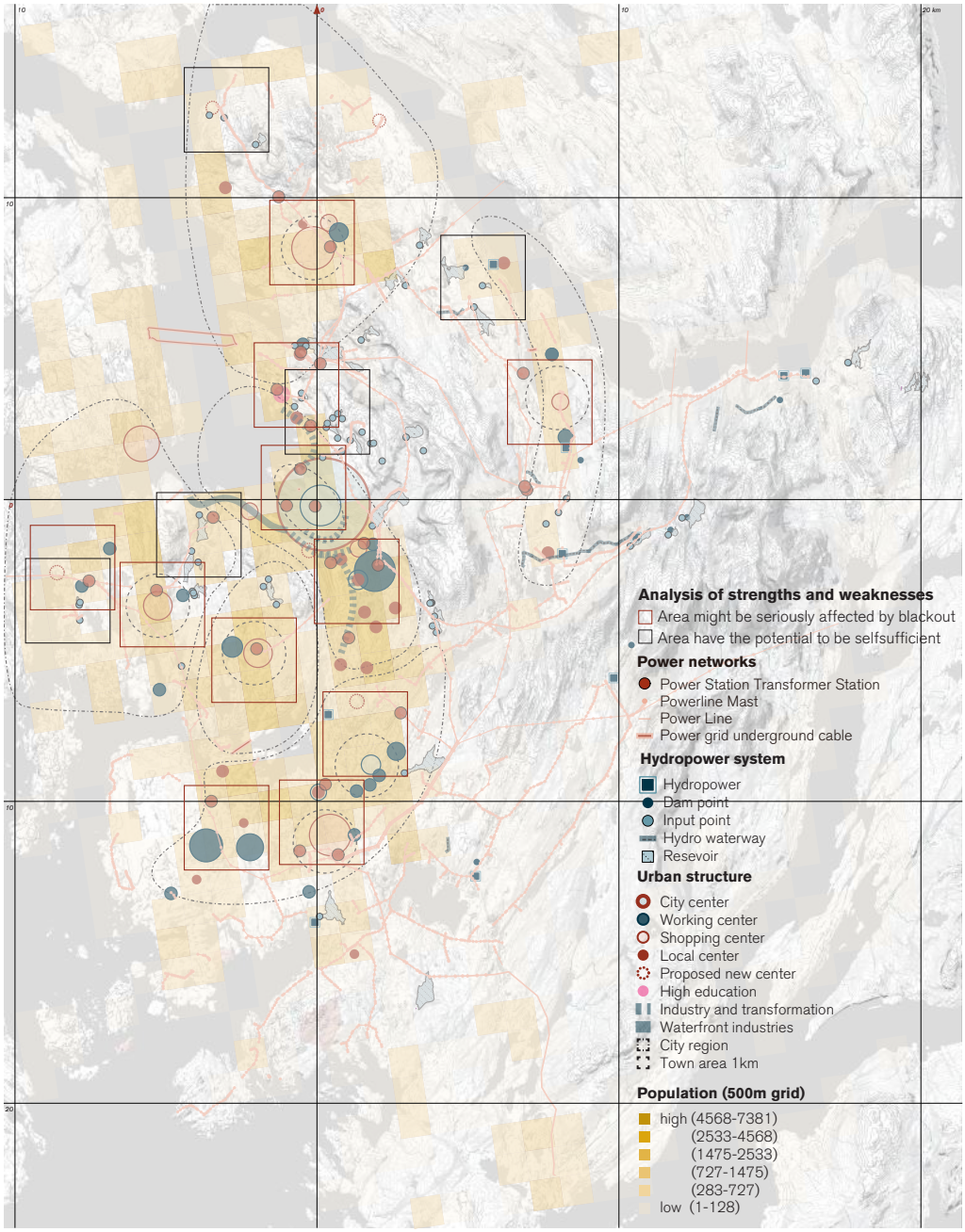
In the west of Norway, especially Bergen, has a great potential for renewable power generation. But the lack of capacity prevents utilisation of this potential. In the Hordaland, the total annual power deficit is 2 TWh. In addition, the limitation of grid capacity will also confine the growth of activity and value creation. In addition, lack of capacity between regions will limit the range of the price both for business and private.

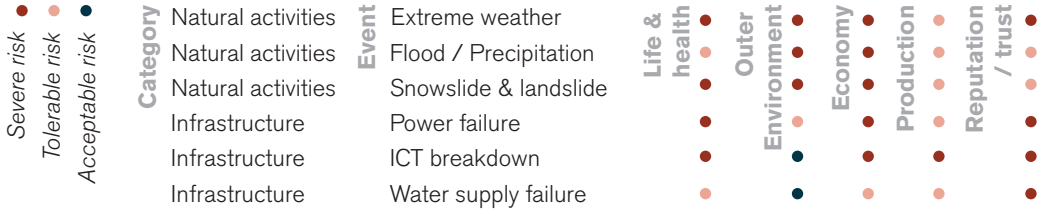
Considering the high rainfall and many mountains in Bergen, it is estimated that there is a great potential for hydropower, around 30% growth over the next ten years. The goal of increasing the share of renewable energy production can be realised through establishing new small scale hydroelectric power, which is a cost-effective and practical way. It is also important to improve the capacity of power transportation when oversupply.

Defining the proposal approach

- strengthen the high share energy system area especially the centers and develop the potential of self sufficiency

Fig. 27. Energy system and urban structure
By author based on NVE


Analysis of strengths and weaknesses
Area might be seriously affected by blackout
Area have the potential to be selfsufficient
Power networks
Power Station Transformer Station
Powerline Mast
Power Line
Power grid underground cable
Hydropower system
Hydropower
Dam point
Input point
Hydro waterway
Resevoir
Urban structure
City center
Working center
Shopping center
Local center
Proposed new center
High education
Industry and transformation
Waterfront industries
City region
Town area 1km
Population (500m grid)
high (4568-7381)
(2533-4568)
(1475-2533)
(727-1475)
(283-727)
low (1-128)



Conclusion

Through superimposing the former analysis layers together, it can be concluded that the risks are concentrated mainly on three regions, one is the west wing of Bergen, one is the north-south axis from Åsane across Bergen center to Flesland which has an airport, the other is in Arna between mountains.

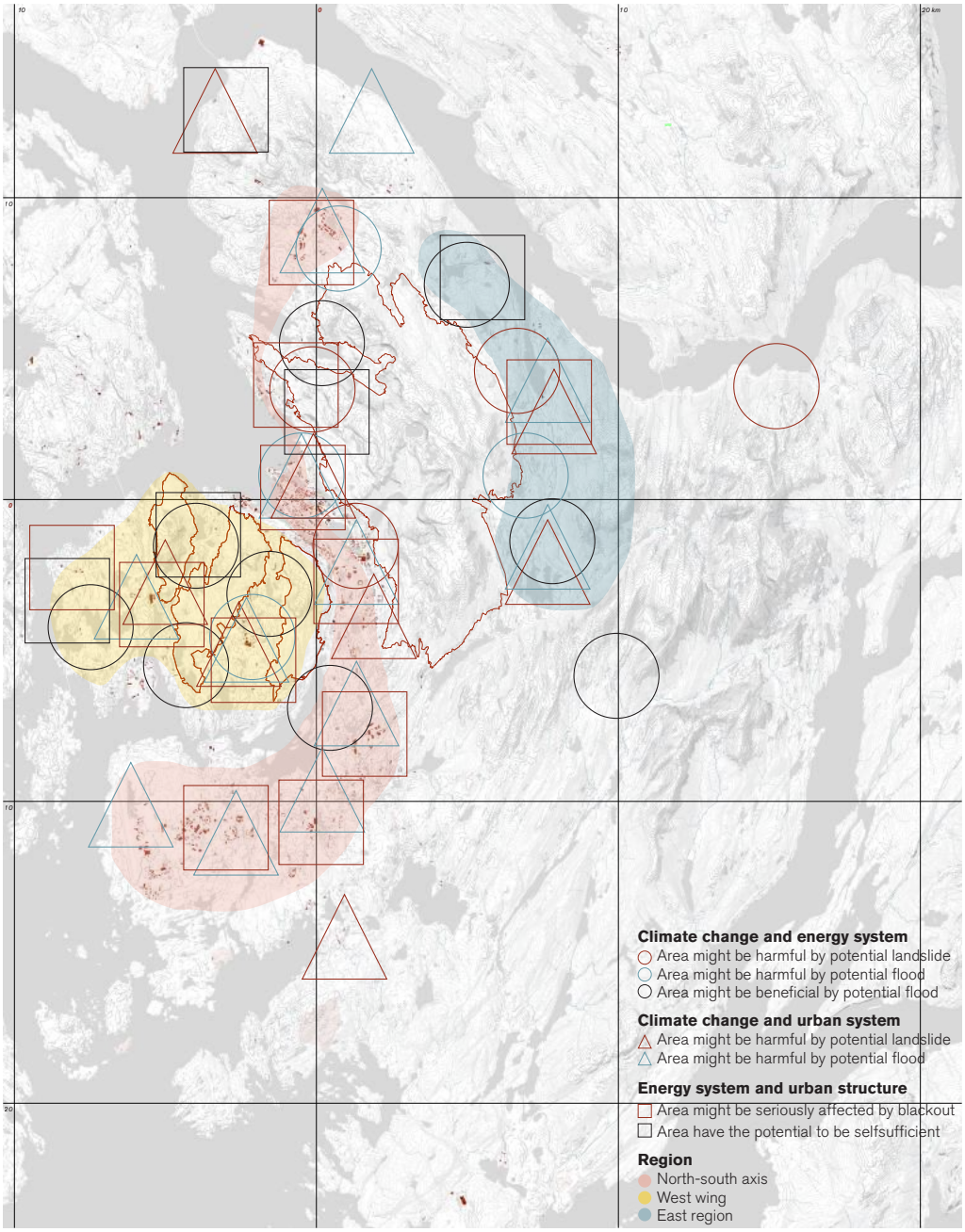
The western part is planned to have more future centers and extend to further west connecting with Straume and outer north with Strusshamn. Due to the complicated topography, this region is less developed than the center area, which meanwhile enables the future planning to take more precautionary measures towards climate change and energy transform policy into consideration.

The north-south axis is quite densified and has the trend to spread more to further north and south. New development can hardly place on this highly developed area, thus more work of updating and regeneration will be done on this axis, especially along the road from the center to the airport.

In the east region, there is less town center and housing is located more dispersedly. More attention needs to be paid on the relationship between climate change and energy system.

- Bergen Kommune, (2014), Bergen ROS (overordnet risiko- og sårbarhetsanalyse for Bergen) 2014

Fig. 28. Conclustion map of risk and potential in Bergen
By author based on NVE


10
0
10
20 km
10
0
10
20
Climate change and energy system
Area might be harmful by potential landslide
Area might be harmful by potential flood
Area might be beneficial by potential flood
Climate change and urban system
Area might be harmful by potential landslide
Area might be harmful by potential flood
Energy system and urban structure
Area might be seriously affected by blackout
Area have the potential to be selfsufficient
Region
North-south axis
West wing
East region

1.5
FROM RISK TO OPPORTUNITIES

Considering the associated impact of climate change and energy transition, the energy system and other urban systems have a high potential to be at stake. The aim is to convert the potential risks of disruption in energy supply deriving from the climate change impact and other threats into opportunities which mean having spare and continuous energy and even promote the development of the whole society.

1. Risk = Hazard x Vulnerability

To reverse the risks, the first step is to understand what are the risks. Here, risk is the possibility of incurring loss or misfortune in terms of urban system related to climate change impact and energy transition. Hazards is conceptualised as potential threats triggered by climate change or transitional energy system. Vulnerability is the attribute of a system, which results in expected losses.

2. Reducing vulnerability

In the relationship, "Risk=Hazard x Vulnerability", it is supposed that as long as improving one of the variables, either reducing the possibility of hazard or enhance the vulnerability to have less expected losses can reduce risks. Considering that the hazards are quite unsure and minimising the possibility of hazard is closely related with the technology of forecast, thus only vulnerability enhancement will be discussed.

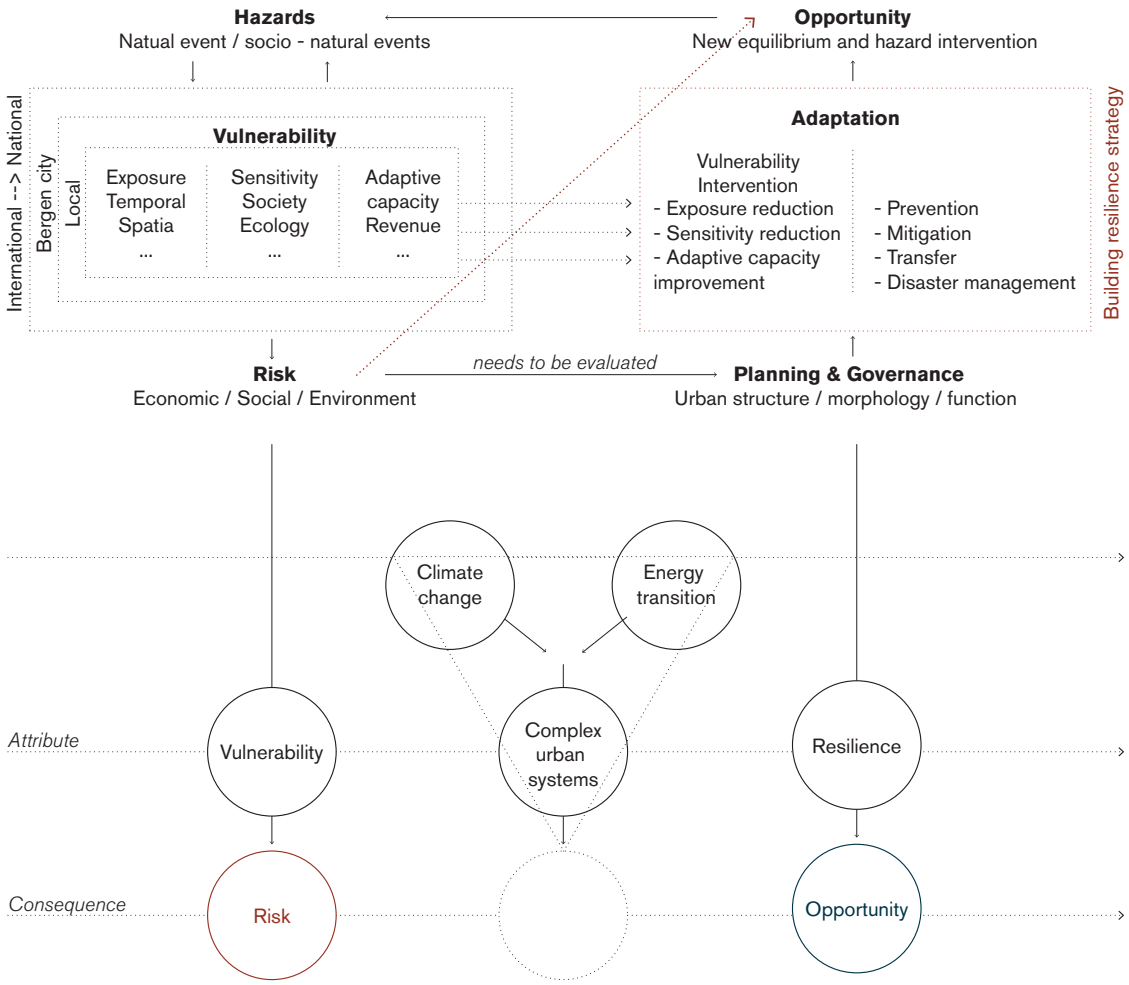
Vulnerability is defined as "susceptibility to harm" (IPCC, 2014), which is made up of three dimensions, including exposure, sensitivity and adaptive capacity (Downing et al., 2001; Polsky et al., 2007). These three dimension have come together to determine the vulnerability.

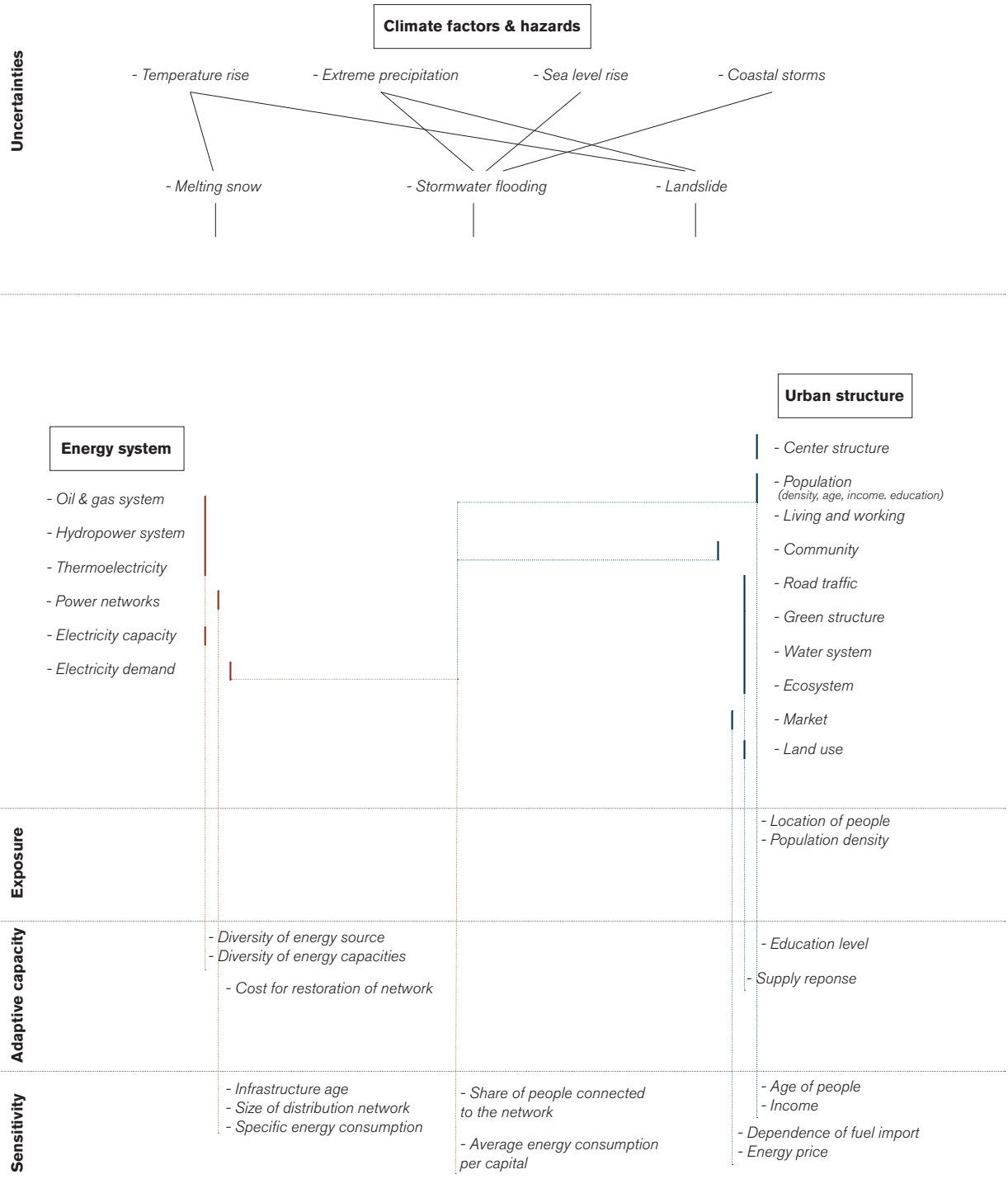
According to the literature review, some important vulnerability indicators are selected according to exposure, sensitivity and adaptive capacity of the energy system and other urban systems, which will also be used as the evaluation later.

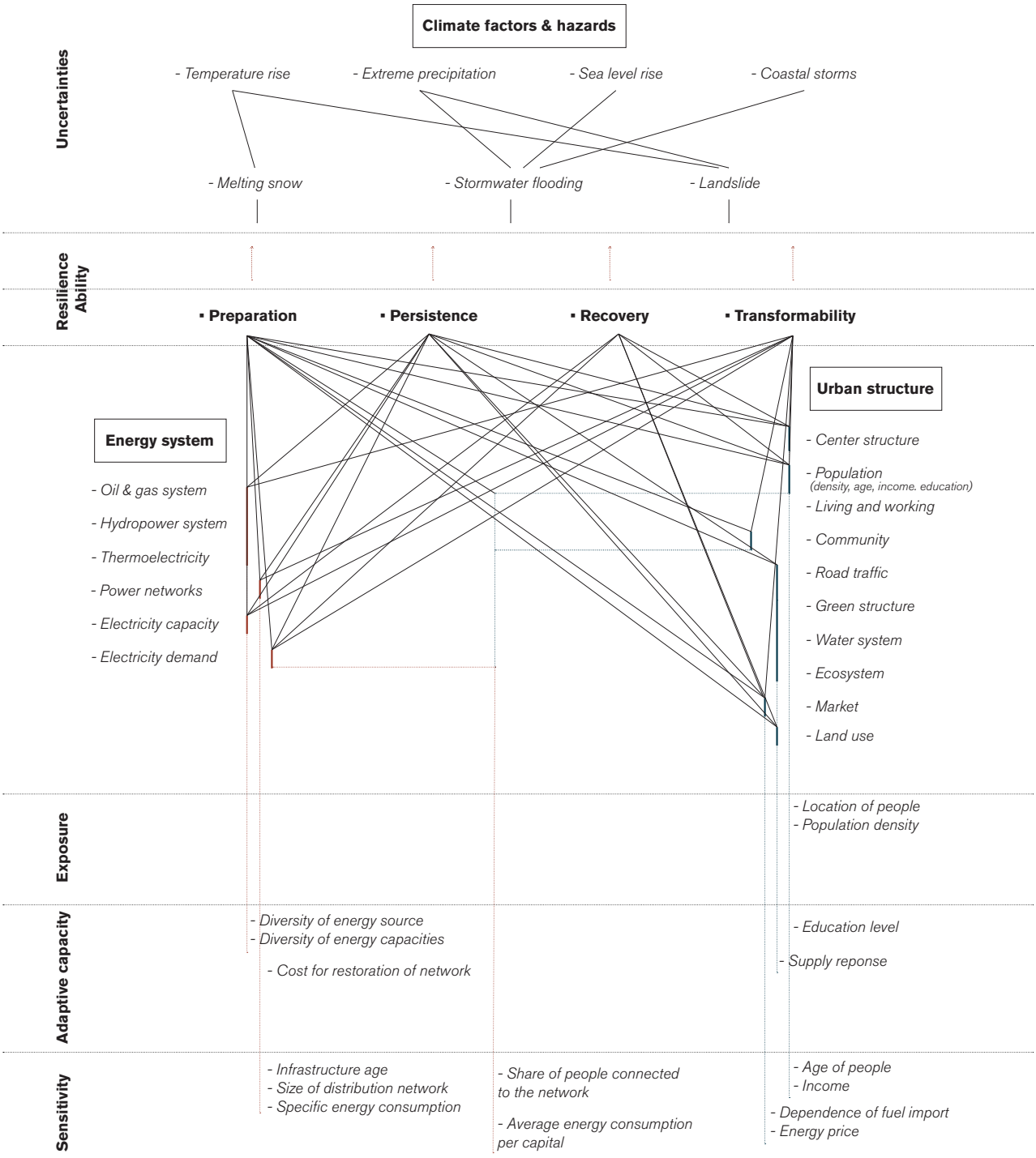
Fig. 29. Analitical framework
By author

Fig. 30. Vulnerability analysis
By author

Fig. 31. Improving resilience ability through vulnerability
By author


Hazards
Natual event / socio - natural events
Opportunity
New equilibrium and hazard intervention
International --> National
Bergen city
Local
Vulnerability
Exposure
Temporal
Spatia
...
Sensitivity
Society
Ecology
...
Adaptive
capacity
Revenue
...
Adaptation
Vulnerability
Intervention
- Exposure reduction
- Sensitivity reduction
- Adaptive capacity
improvement
- Prevention
- Mitigation
- Transfer
- Disaster management
Building resilience strategy
Risk
Economic / Social / Environment
needs to be evaluated
Planning & Governance
Urban structure / morphology / function
Climate
change
Energy
transition
Attribute
Vulnerability
Complex
urban
systems
Resilience
Consequence
Risk
Opportunity


Climate factors & hazards
Uncertainties
- Temperature rise
- Extreme precipitation
- Sea level rise
- Coastal storms
- Melting snow
- Stormwater flooding
- Landslide
Energy system
- Oil & gas system
- Hydropower system
- Thermoelectricity
- Power networks
- Electricity capacity
- Electricity demand
Urban structure
- Center structure
- Population
(density, age, income. education)
- Living and working
- Community
- Road traffic
- Green structure
- Water system
- Ecosystem
- Market
- Land use
Exposure
- Location of people
- Population density
Adaptive capacity
- Diversity of energy source
- Diversity of energy capacities
- Cost for restoration of network
- Education level
- Supply reponse
Sensitivity
- Infrastructure age
- Size of distribution network
- Specific energy consumption
- Share of people connected to the network
- Average energy consumption per capital
- Age of people
- Income
- Dependence of fuel import
- Energy price


Climate factors & hazards
Uncertainties
- Temperature rise
- Extreme precipitation
- Sea level rise
- Coastal storms
- Melting snow
- Stormwater flooding
- Landslide
Resilience Ability
▪ Preparation
▪ Persistence
▪ Recovery
▪ Transformability
Energy system
- Oil & gas system
- Hydropower system
- Thermoelectricity
- Power networks
- Electricity capacity
- Electricity demand
Urban structure
- Center structure
- Population (density, age, income. education)
- Living and working
- Community
- Road traffic
- Green structure
- Water system
- Ecosystem
- Market
- Land use
Exposure
- Location of people
- Population density
Adaptive capacity
- Diversity of energy source
- Diversity of energy capacities
- Cost for restoration of network
- Education level
- Supply reponse
Sensitivity
- Infrastructure age
- Size of distribution network
- Specific energy consumption
- Share of people connected to the network
- Average energy consumption per capital
- Age of people
- Income
- Dependence of fuel import
- Energy price

3. Enhancing resilience

The initial definition of resilience insists the definition that system has a better durability and adaptively which enables the system comes back to the balance situation after a shock or a disaster.

But here the definition of evolutionary resilience is adopted which cannot be only 'recover from shocks' but also have the ability to prepare and seize 'transformability opportunities that emerge from changing' (Davoudi et al., 2016). It puts the emphasis on the better equilibrium point after the hazards, achieving the development of the social-economic system, ecosystem and environment.

Thus, not only vulnerability reduction intervention like exposure reduction, sensitivity reduction and adaptive capacity improvement will be considered, but also other adaptation measures like prevention, mitigation, transfer and disaster management will be included.

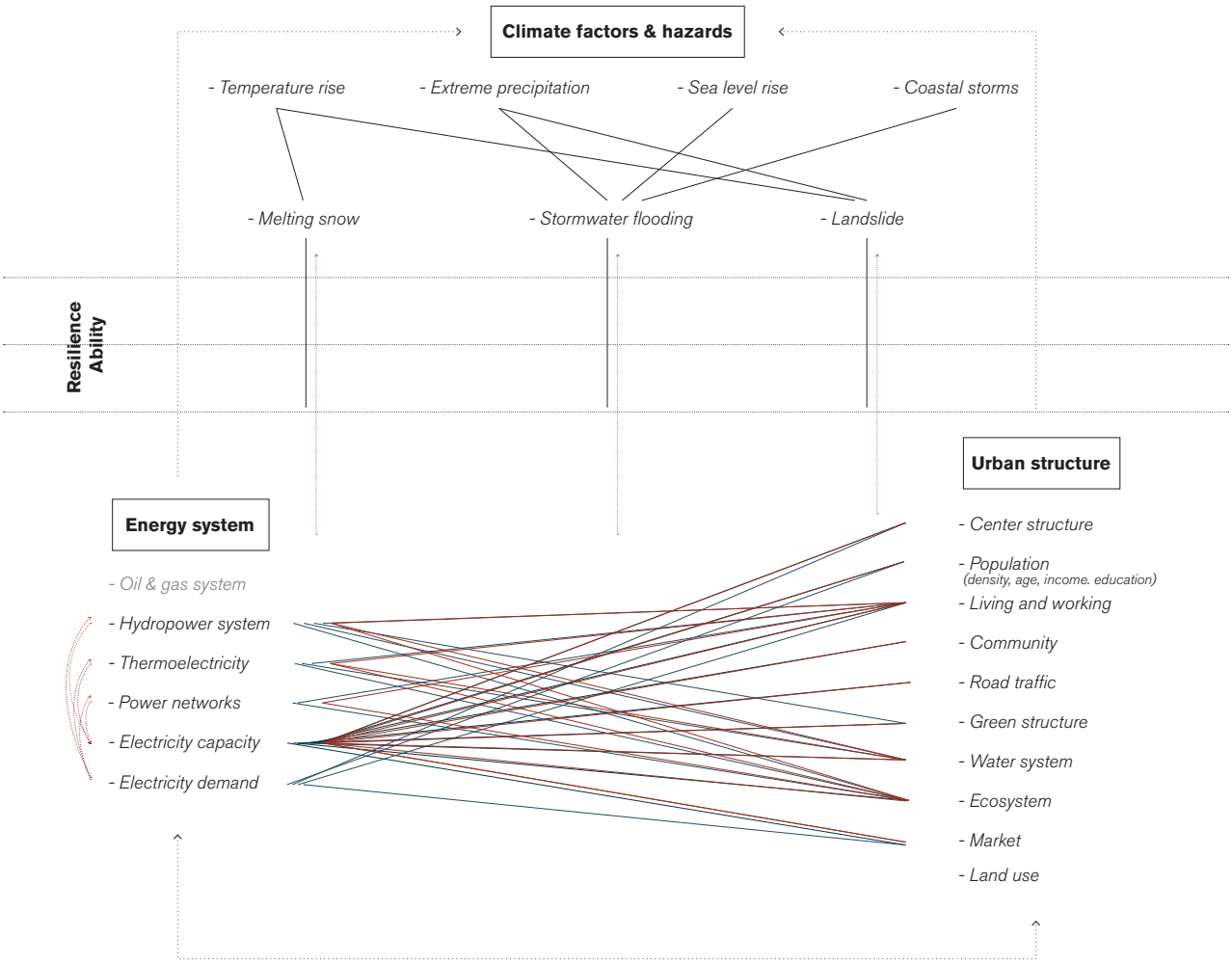
There are four dimensions constitute the framework of evolutionary resilience, including preparation, persistence, recovery and transformability (Holling, 1973; Barata-Salgueiro and Erkip, 2013; Sharifi et al, 2016; Davoudi et al., 2016). The resilience criteria is also built on the basis of these four dimensions.

4.Opportunities = Transform x resilience

Not only the vulnerability attributors but also the resilience ability of the energy system and the urban structure will be improved according to the evolutionary resilience principle. The extent of either reducing or increasing the capacity of the system depends on the resilience principle, according to the criteria based on literature review and its dynamic environment on the basis of analysis and field trip.

Thereby the potential risks of climate change impact might be mitigated and even utilise this change as the opportunity to achieve a better socio-economic status.

Fig. 32. Improving resilience ability and mitigation of climate change
By author


Climate factors & hazards
- Temperature rise
- Extreme precipitation
- Sea level rise
- Coastal storms
- Melting snow
- Stormwater flooding
- Landslide
Resilience
Ability
Energy system
- Oil & gas system
- Hydropower system
- Thermoelectricity
- Power networks
- Electricity capacity
- Electricity demand
Urban structure
- Center structure
- Population
(density, age, income. education)
- Living and working
- Community
- Road traffic
- Green structure
- Water system
- Ecosystem
- Market
- Land use

2 SCENARIO

2.1
DEFINING TRENDS

Driving forces:

Climate change can be seen as the external factor and energy transition is the internal factor. Transitions will finally take place on urban systems.

Urban systems are quite complex, which can be summarised into three layers: the layer of natural system, the layer of occupation including urban form and agriculture and the layer of infrastructure networks. Each layer has its own speed but meanwhile these three layers interact each other and achieve a balance.

Climate change takes place on the natural layer and the consequent climate change affects other layers. Similarly, energy transition is implemented on the infrastructure, which will then influence the urban structure and the natural system. Also, population growth is another factor that cannot be ignored. The development of population and economy will definitely change the urban system and influence the natural environment.

Thus, driving forces can be concluded as the impact of climate change, political agenda of energy transition and social-economic development.

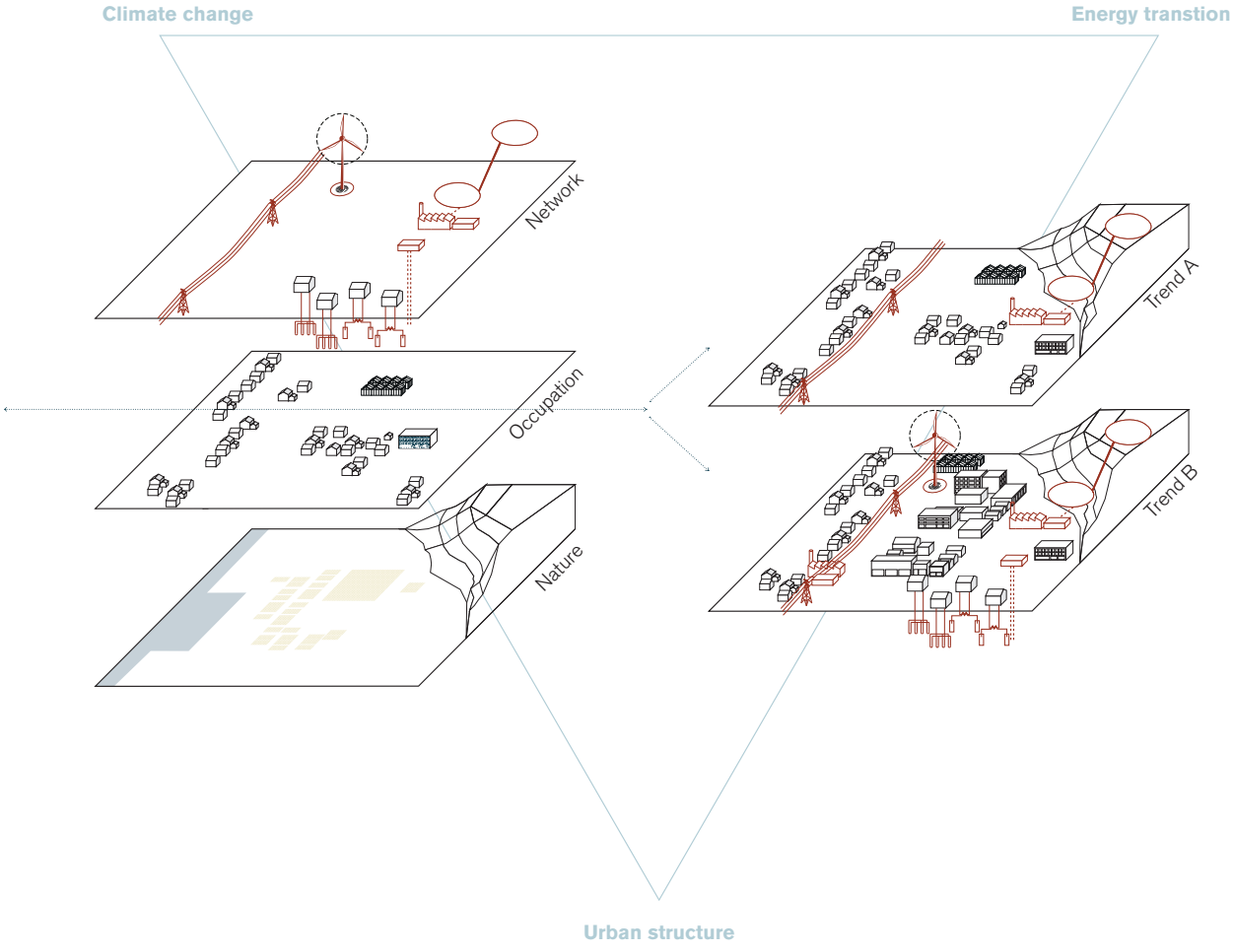
1. Defining trends

- The trend of climate change:

According to the fifth Assessment Report of IPCC (AR5), four Representative Concentration Pathways (RCPs) are adopted as the projection towards 2100, which are RCP2.6, RCP4.5, RCP6, and RCP8.5.

On the basis of RCPs, Klima rapport 2100 proposed climatic prediction based on the most expected future scenario RCP4.5 and the least intervened scenario RCP8.5. In view of RCP4.5, the range of temperature increase in 2050 is between 1.3 degrees and 2.3 degrees. In the scenario RCP8.5, the rise of temperature is between 2 degrees and 3.3 degree.s

Fig. 33. 3 Layers of urban system and 2 integrating trends of climate change, energy transition and population growth
By author


Climate change
Energy transtion
Network
Occupation
Nature
Trend A
Trend B
Urban structure

- The trend of energy transition:

Norway has the ambition to achieve 80% shares of renewable energy production in 2050. Although the share in 2017 is already 67.5%, the country still needs a lot of efforts.

Due to the lack of documents, conservative projection is proposed, suggesting a 5% fluctuation based on the goal.

- The trend of urban development (social-economic trend)

According to the population projection of Statistics Norway (SSB), the national population will pass 6000 000 just after 2030, which means the population increased1000 000 in less than 20 years. The upper limit is 7900 000 and lower limit is 6000 000.

The estimated population of Bergen in 2050 is 348 000, which is close to the lower limit projection 310 000. The upper limit is 420 000.

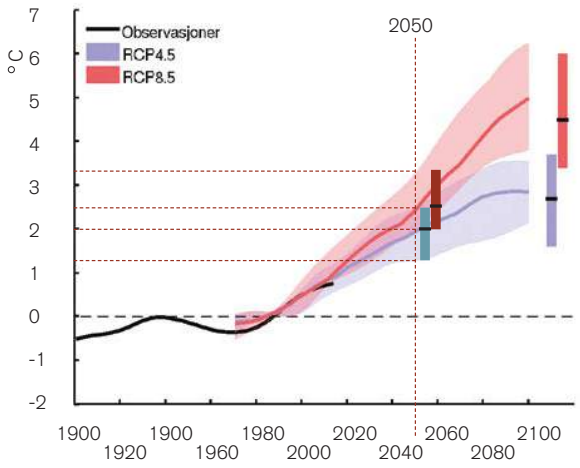
2. Integrating trends

Due to the dynamics of city, it is important to integrate all these trends and consider the synergy impact.

In one word, the city Bergen will continue to grow at a rapid speed. Temperature is estimated to increase between 1.3 degrees to 3.3 degree. Energy transition is in the great transition to realise the goal of 80% shares of renewable energy production.

Fig. 34. Temperature increase projection towards 2100
Source: Klimaraport2100 of Norway

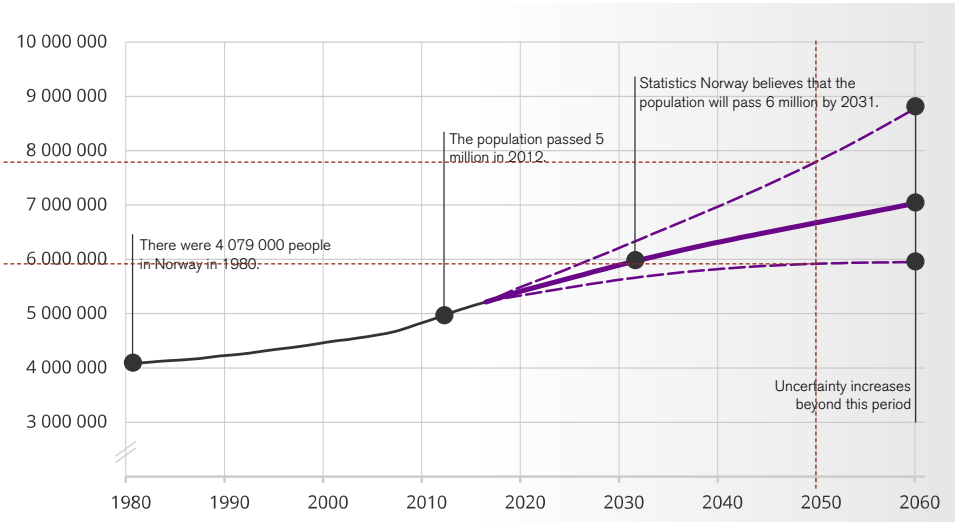
Fig. 35. National population projection towards 2100
Source: SSB



Larger temperature increase under scenario of comparatively high green-house gas emissions

Smaller temperature increase under scenario of most probable greenhouse gas emissions

34



High national growth
High fertility
High life expectancy
High net immigration

Main option

Low national growth
Low fertility
Low life expectancy
Low net immigration

35

2.2
BUILDING EXPLORATORY SCENARIOS

Why we need scenarios:

Because of the synergies of dynamic natural environment, dynamic social-economic development and uncertain climate change, the future of Bergen becomes a mystery. This will bring difficulties and challenges to the urban development planning.

But, it is pointless to try to predict the future. Since there are so many factors influencing the future of a city, what we can anticipate is several possible development. Although the scenarios based on the projections still remain abstract and lack specificity from a spatial perspective, they provide guidance for designers and help to identify what adaptation measures will be necessary in the Bergen area.

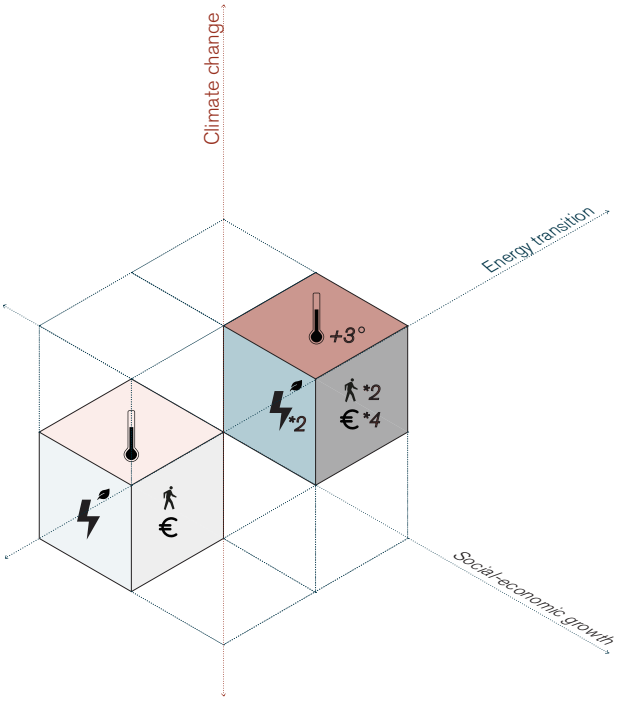
The outcomes of these scenarios need to be tested in the map. By exploring through different scenarios, we try to provide the best answers not only for the short term planning but also for midterm and long-term.

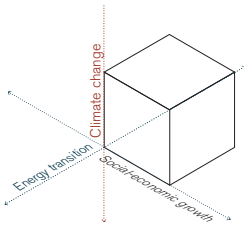
Building two exploratory scenarios

By integrating the trends, two different scenarios are developed. One is Scenario Mild which choose the lower limit of temperature increase(1.3 degrees), less share of renewable energy production according to the national agenda(75%) and 310 000 populations. The other one adopted the projection that might lead to drastic transition, namely Scenario Drastic. It is supposed to be 3.3 degrees of temperature increase, 85% share of renewable energy production and 420 000 residential livings in a city.

If climate change, energy transition and social-economic growth are regarded as three axises composing space coordinates system, these two scenarios will be located at diagonal location, which indicates two opposite possible future of Bergen.

Fig. 36. Exploratory scenarios
By author





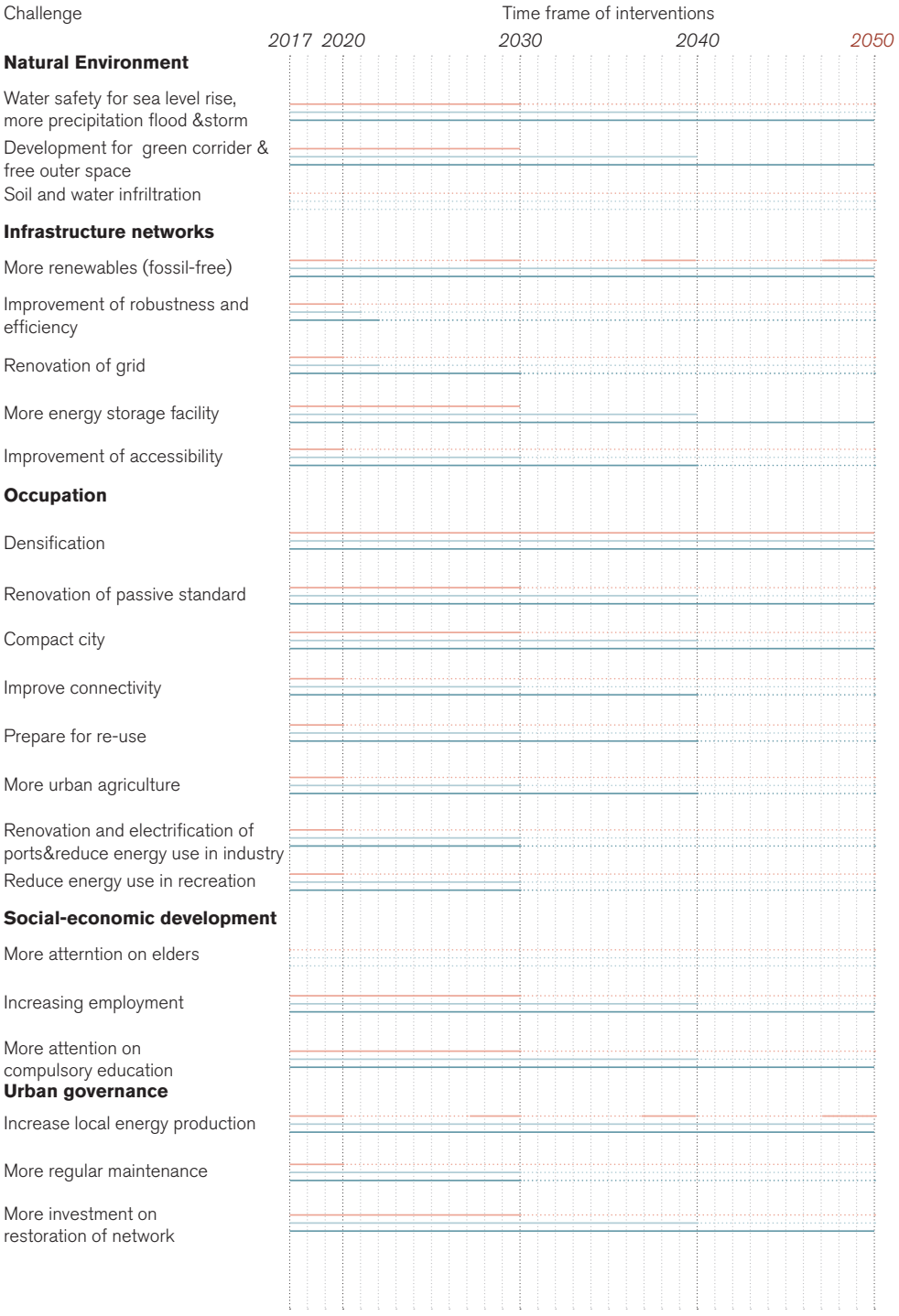
	Scenario Mild	Expected	Scenario Drastic
Climate change	+1.3°	+1.5°	+3.3°
Share of renewals production *(nation)*	75%	80%	85%
Social growth *(nation)*	6000 000		7900 000
(Bergen)	310000	348000	420000

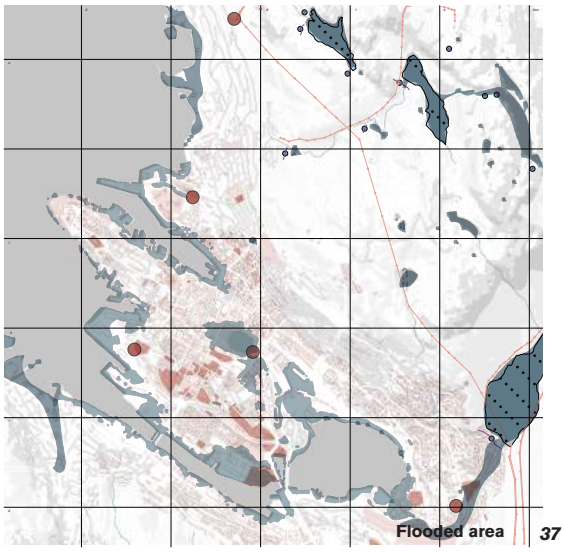
2.3
EVALUATION OF CURRENT SITUATION

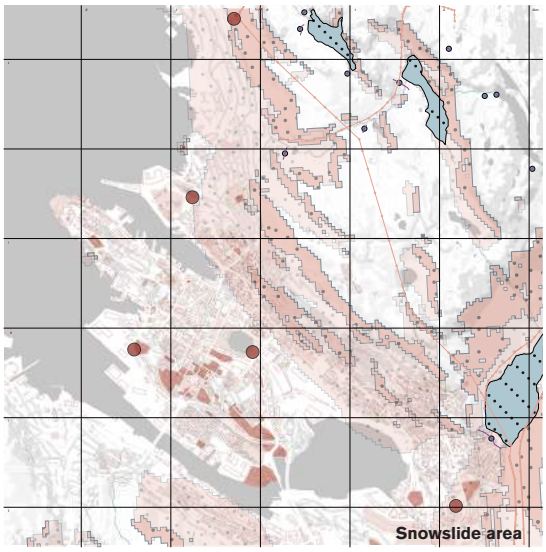
Factor	Ranking criteria	Phenomena rank 1	2	3	4	5	Value for Resilience P1	P2	R	T
Natural Environment										
Water	type & size more>less	good				poor	x	x		x
Green space	quality & size high>low	good				poor	x	x		x
Infrastructure networks										
Energy resource	type more>less	diverse				simplex	x	x		x
Energy generation & distribution infrastructure	age small>large	robust				weak	x	x		
Power networks	spatially distribution large>small	efficient				inefficient	x	x	x	
	type separated>cental	selfsufficient				interdependent	x	x	x	x
Energy storage facilities	amount more>less	better respond to emergencies				rely on risk managment	x	x		x
Transport	connectivity more>less	efficient				inefficient	x	x	x	
Occupation										
Housing	density high>low	diverse				simplex	x	x	x	x
	type passive>normal	less energy demand				more energy demand	x	x		x
Street system	connectivity more>less	efficient				inefficient	x	x	x	
Urban space	mixed-functionality more>less	diverse				simplex	x	x	x	
Agriculture	amount more>less	a lot				few	x	x		x
Ports & industry	amount more>less	a lot				few	x	x		x
Recreation	amount lew>more	a lot				few	x	x		x
Social-economic development										
Population	age middle>young&old	less vulnerable				more sensitivity	x	x		x
	income high>low	more adaptivity				less adaptivity	x	x	x	x
	education level high>low	more adaptivity				less adaptivity	x	x		x
Urban governance										
Reliance on imports	dependence low>high	selfsufficient				more uncertainties	x	x		x
Regular maintenance	frequency high>low	safe				dangerous	x			
Investment on restoration of network	amount high>low	better risk management				poor	x	x		x

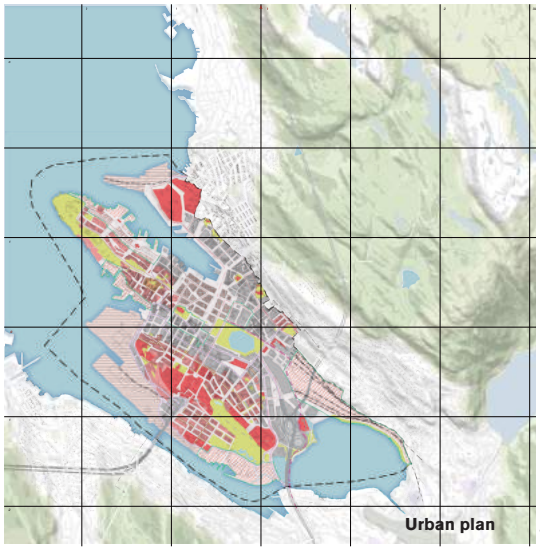
P1=Preparation P2=Persistence R=Recovery T=Transformability


Factor
Norway
Bergen
Bergenhus
1 2 3 4 5
1 2 3 4 5
1 2 3 4 5
Natural Environment
Water (type)
Green space (quality)
Infrastructure networks
Energy resource (type)
Energy generation & distribution infrastructure (type)
Power networks (distribution)
(type)
Energy storage facilities (amount)
Transport (connectivity)
Occupation
Housing (density)
(type)
Street system(connectivity)
Urban space (mixed-functionality)
Agriculture (amount)
Ports & industry (amount)
Recreation (amount)
Social-economic development
Population (age)
(income)
(education)
Urban governance
Reliance on imports (dependence)
Regular maintenance (frequency)
Investment on restoration of network (amount)


Challenge
Time frame of interventions
2017 2020
2030
2040
2050
Natural Environment
Water safety for sea level rise, more precipitation flood &storm
Development for green corrider & free outer space
Soil and water infriltration
Infrastructure networks
More renewables (fossil-free)
Improvement of robustness and efficiency
Renovation of grid
More energy storage facility
Improvement of accessibility
Occupation
Densification
Renovation of passive standard
Compact city
Improve connectivity
Prepare for re-use
More urban agriculture
Renovation and electrification of ports&reduce energy use in industry
Reduce energy use in recreation
Social-economic development
More atterntion on elders
Increasing employment
More attention on compulsory education
Urban governance
Increase local energy production
More regular maintenance
More investment on restoration of network







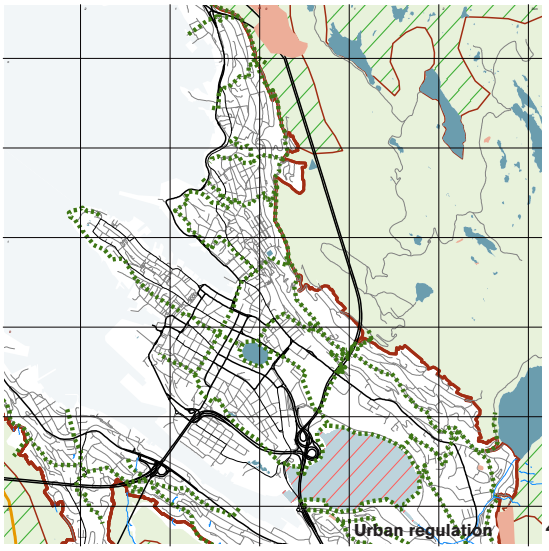


Fig. 37. Flooded area
By author based on NVE

Fig. 38. Snowslides
By author based on NVE

Fig. 39. Urban plan
By author based on NVE

Fig. 40. Urban regulation
By author based on NVE

Power networks
- Power Station Transformer Station
- Powerline Mast
- Power Line
- Dam point
- Input point
- Hydro waterway
- Resevoir

Potential water related impact
- Flood-landslide attention area
- Flood attention area

Snow attention area
- Slipped Snow Attention Solvent expiration
- Slipped Snow Attention Solvent ejaculation

Urban plan
- Sea
- City center
- Urban development areas
- Residential
- Public building
- Free areas and gardens
- Mixed-use (including office)
- Road
- Tunnel
- Main street
- Collect street
- Important bus routes
- Light rail
- Light rail stop
- Railway
- Harbour area
- License limit for district heating
- plan Limits

Urban regulation
- Road
- Municipal and private roads
- Railway
- Pull Roads cervids
- Green corrider
- City mountains
- River
- Lake
- Sea
- Important marine areas
- Functional beach zone
- Consecutive agricultural areas
- Important natural habitats
- Important wildlife sites
- Intact Free Nature (INON 2008)
- Protection Zone LNF
- Free and outdoor areas
- Future free and outdoor areas

2.4
DESIGN & PLANNING CHALLENGE

According to the evaluation table based on Bergen Center- Bergenhus, Bergen municipality and Norway, the factors with lower value can be seen as a design and planning challenge in the future.

Nature:

Due to the climate change, more water will be brought to Bergen by precipitation, sea level rise and storm, which will directly lead to surface flooding and flooding with landslide, especially in Bergenhus. Thus more interventions regard to water safety need to be taken, including the development of small and micro hydropower to turn the situation of more water into an opportunity to generate more energy. Meanwhile, green space like open outdoor space and green corridor should be improved.

Occupation:

The compact city can help to improve energy efficiency and decrease the energy use when densifying. The renovation of buildings for passive design, reuse of waste heat, reduce energy demand in housing, electrification of ports can help to relieve pressure on the energy system.

Infrastructure network:

The robustness and efficiency and energy infrastructure become more important when facing increased risk of extreme weather. The diversity of resource and electricity storage will be the trend.

Social-economic development and government:

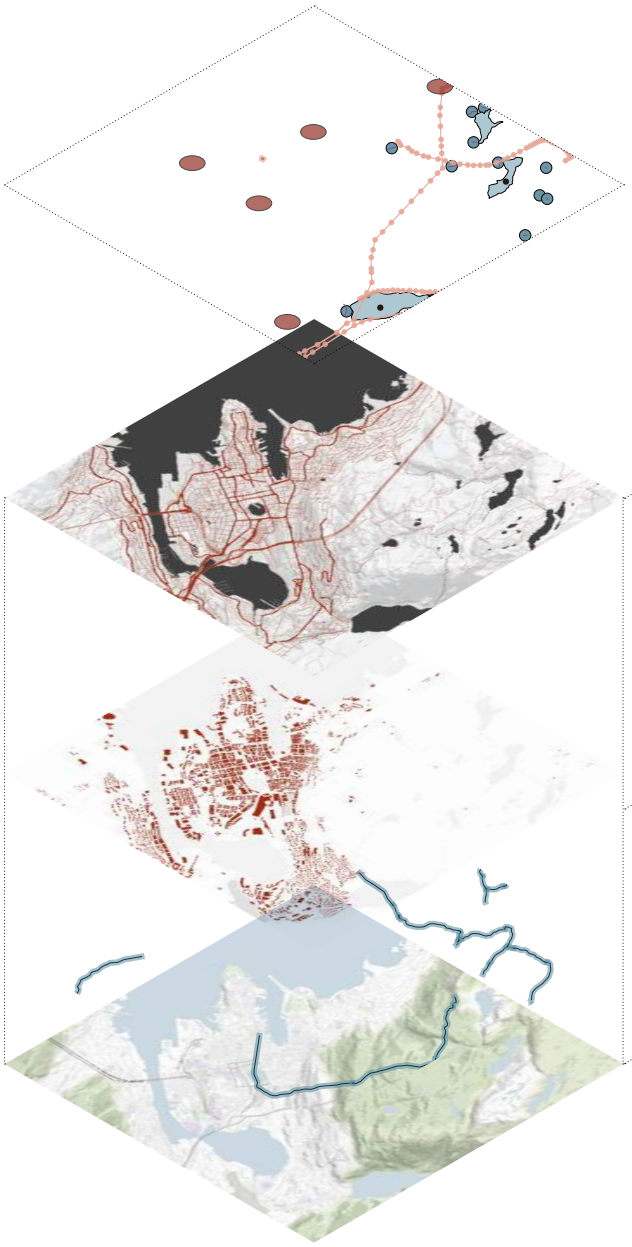
Bergen has over 25% elders older than 65, high percentage of low income family with children and a high rate (25%) of people between 21-29 without a degree in the study or professional education. This means higher sensitivity compared with other cities under climate change.

The improvement of urban governance thus is quite important to prevent the hazards and quickly respond to the sudden events, for example increasing the regular routine maintenance and investment on restoration.

Fig. 41. Subsystems
By author based on NVE

Fig. 42. Section of Bergen center
Source: by author based on google earth

Fig. 43. Key points along coastal line
Source: by author based on Google map



Social-economic development

More attention on elders
Increasing employment
More attention on compulsory education

Urban governance

Increase local energy production
More regular maintenance
More investment on restoration of network

Infrastructure networks

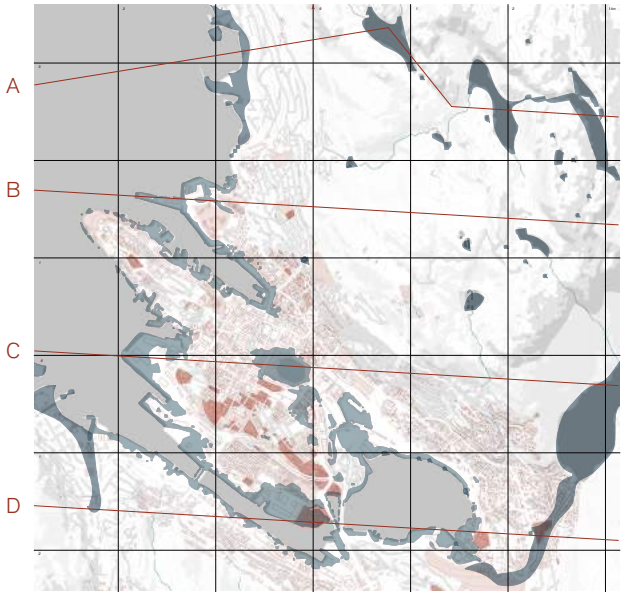
More renewables (fossil-free)
Improvement of robustness and efficiency
More energy storage facility
Renovation of grid
Improvement of accessibility
Improve connectivity

Occupation

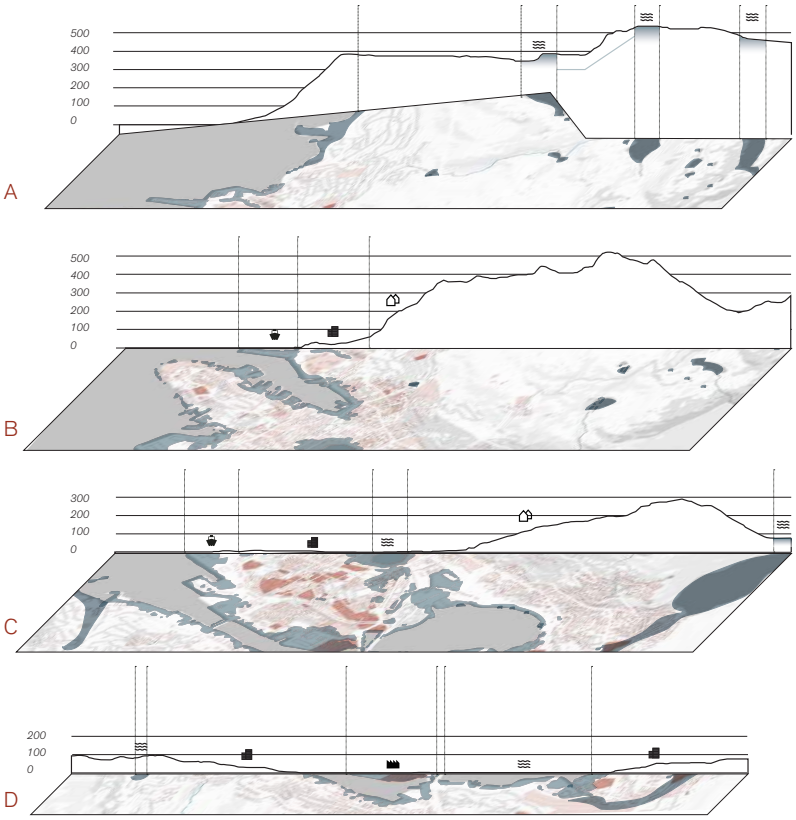
Compact city
Densification
Renovation of passive standard
Renovation and electrification of ports&reduce energy use in industry
Reduce energy use in recreation
More urban agriculture
Prepare for re-use

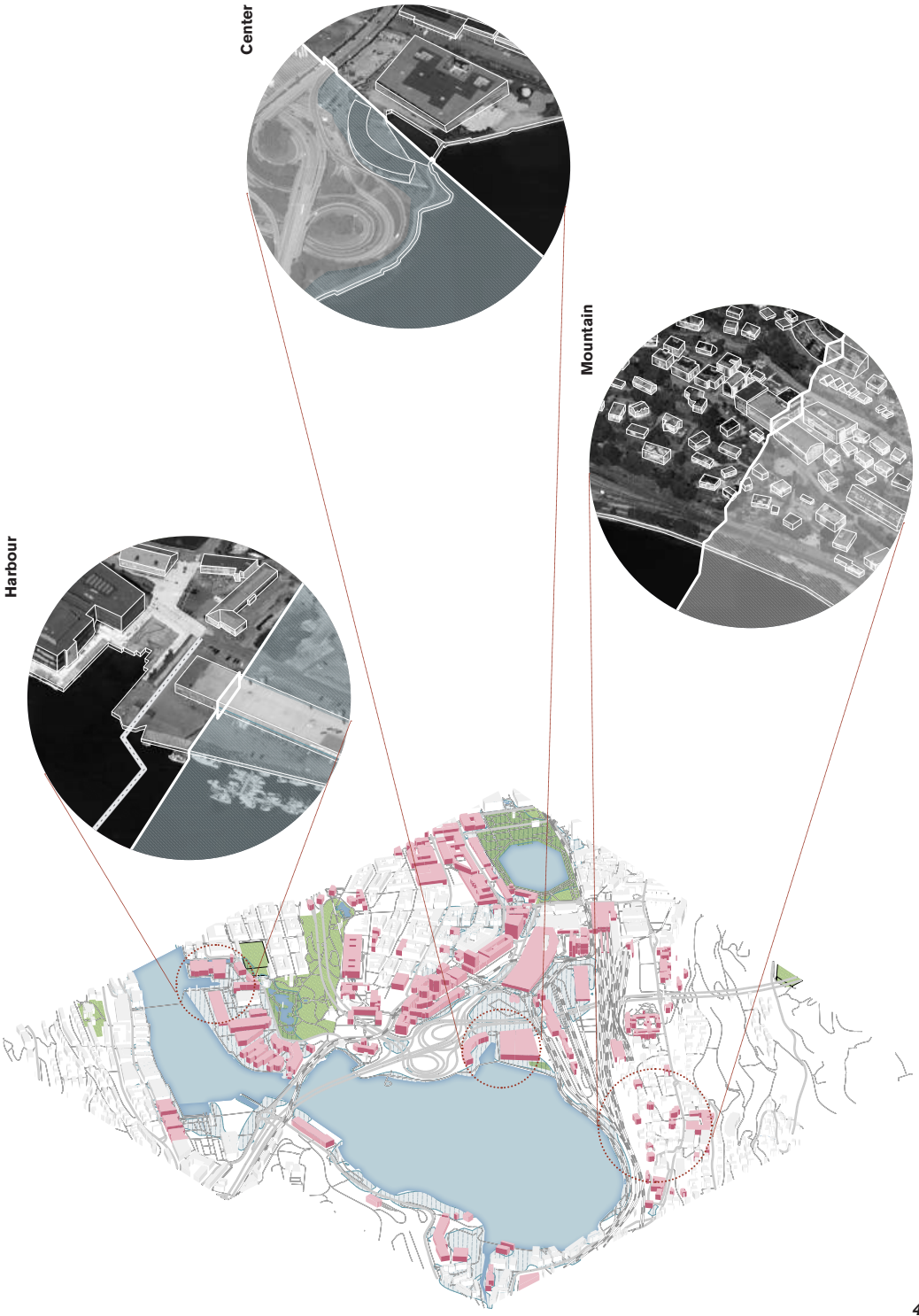
Natural Environment

Water safety for sea level rise, more precipitation flood &storm
Development for green corrider & free outer space
Soil and water infiltration


A
B
C
D

102


500
400
300
200
100
0
A
500
400
300
200
100
0
B
300
200
100
0
C
200
100
0
D


Center
Mountain
Harbour

2.4.1
CHALLENGE OF CLIMATIC CHANGES IN MONTHS AND YEARS

According to the Kartverket Institution of Norway, till 2050, the range of sea level change under low emission scenarios is 16cm (5-27) and high emission scenarios' is 20cm (7-33). And, the height of tide will change during the days and seasons. Meanwhile, other climatic factors have obvious difference during different seasons, for example precipitation value per day, wind intensity, high and low temperature and daytime.

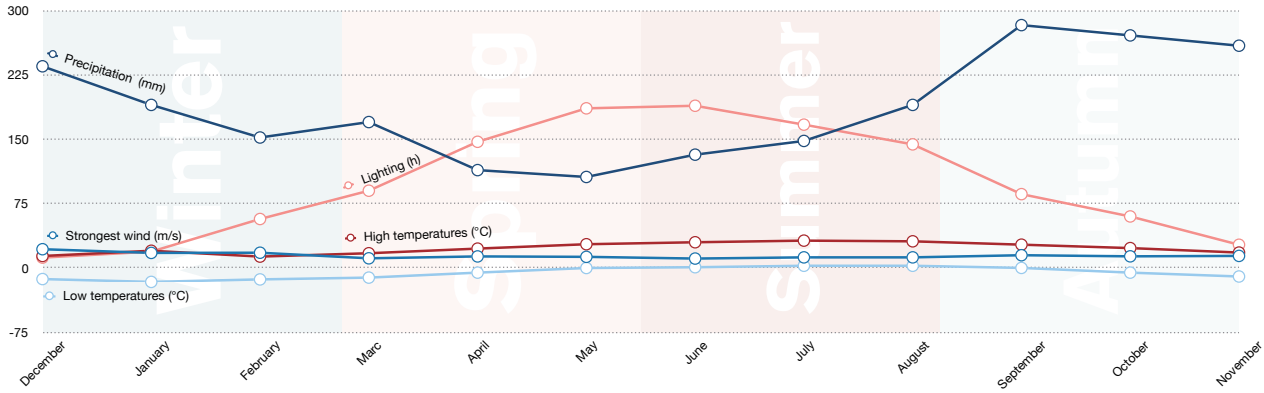
Winter has a lot of precipitation (70mm maximum/day) and very strong wind intensity(21.8m/s). This means more defensive measure needs to be taken. But meanwhile, it might provides more energy if more rain water storage and wind turbines are built in the in proper position. In addition, the cold weather and few daytime call for more indoor activities and more energy use on gas and lightning.

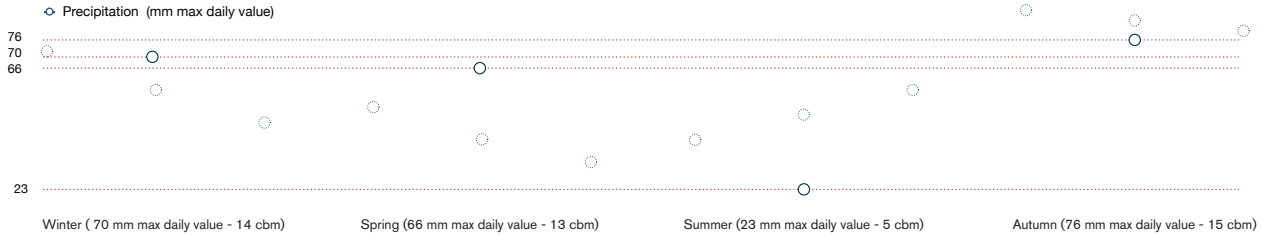
Spring has less precipitation than winter, but still high (66mm maximum/day), relatively high wind intensity(17m/s), which means more rainwater collection and wind turbines are needed. The temperature and daylight are quite suitable for people to go outside, so more outdoor activities can be organised. Meanwhile, the solar panels are useful to generate more energy.

Summer has the least precipitation in all seasons(23mm maximum/day) and the lightest winds(12m/s), which is the best season for tourists, not only to visit Bergen city but also the fjords. The high temperature will contribute to more evaporation. Thus, measures needs to be taken. The long daytime is suitable for solar energy.

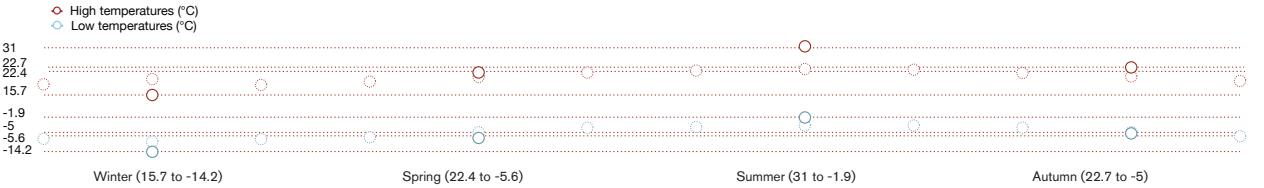
Autumn is a rainy season. But light wind, comfortable temperature and long sunshine duration make the weather in Bergen pleasant if rain shelter is provided.

Fig. 44. Seasonal variation
By author based on data on SSB

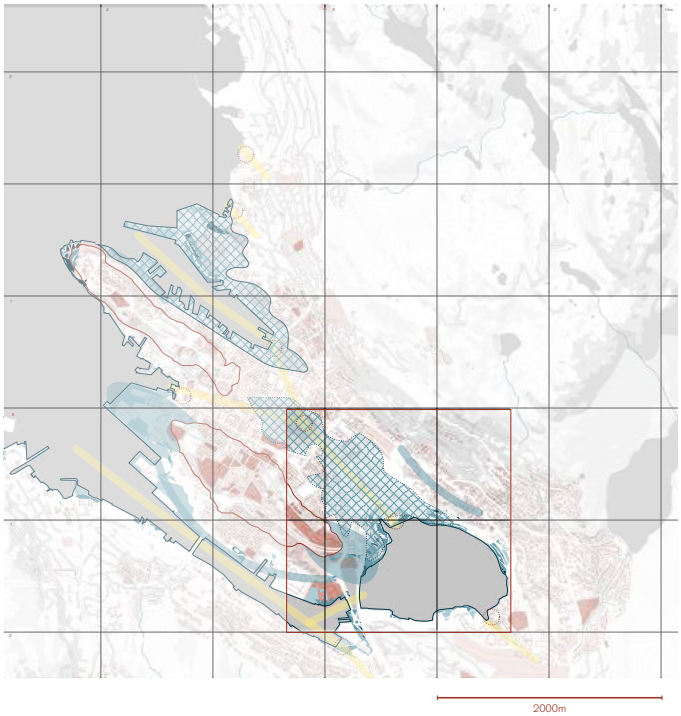

300
225
150
75
0
-75
Precipitation (mm)
Lighting (h)
Strongest wind (m/s)
High temperatures (°C)
Low temperatures (°C)
December
January
February
Marc
April
May
June
July
August
September
October
November


Precipitation (mm max daily value)
76
70
66
23
Winter (70 mm max daily value - 14 cbm)
Spring (66 mm max daily value - 13 cbm)
Summer (23 mm max daily value - 5 cbm)
Autumn (76 mm max daily value - 15 cbm)


Wind intensity (m/s)
21.8
17
14.8
12
Winter (maximum 21.8 m/s)
Spring (maximum 17 m/s)
Summer (maximum 12 m/s)
Autumn (maximum 14.8 m/s)


High temperatures (°C)
Low temperatures (°C)
31
22.7
22.4
15.7
-1.9
-5
-5.6
-14.2
Winter (15.7 to -14.2)
Spring (22.4 to -5.6)
Summer (31 to -1.9)
Autumn (22.7 to -5)


Daytime (hours / day)
16
13
11
7
Winter (7 h/daily)
Spring (13 h/daily)
Summer (16 h/daily)
Autumn (11 h/daily)



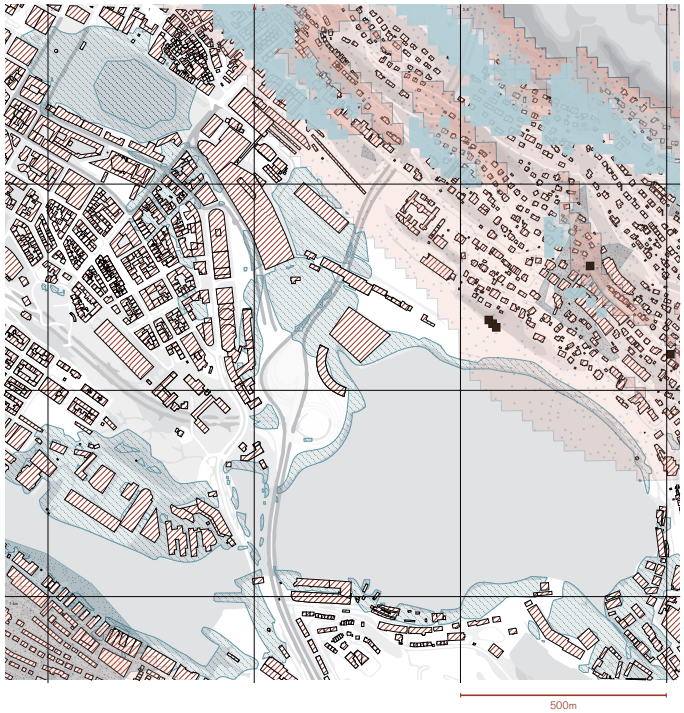


Fig. 45. Landscape shape
By author based on NVE

Fig. 46. Potential coastal flood, snow slide and landslide
By author based on NVE

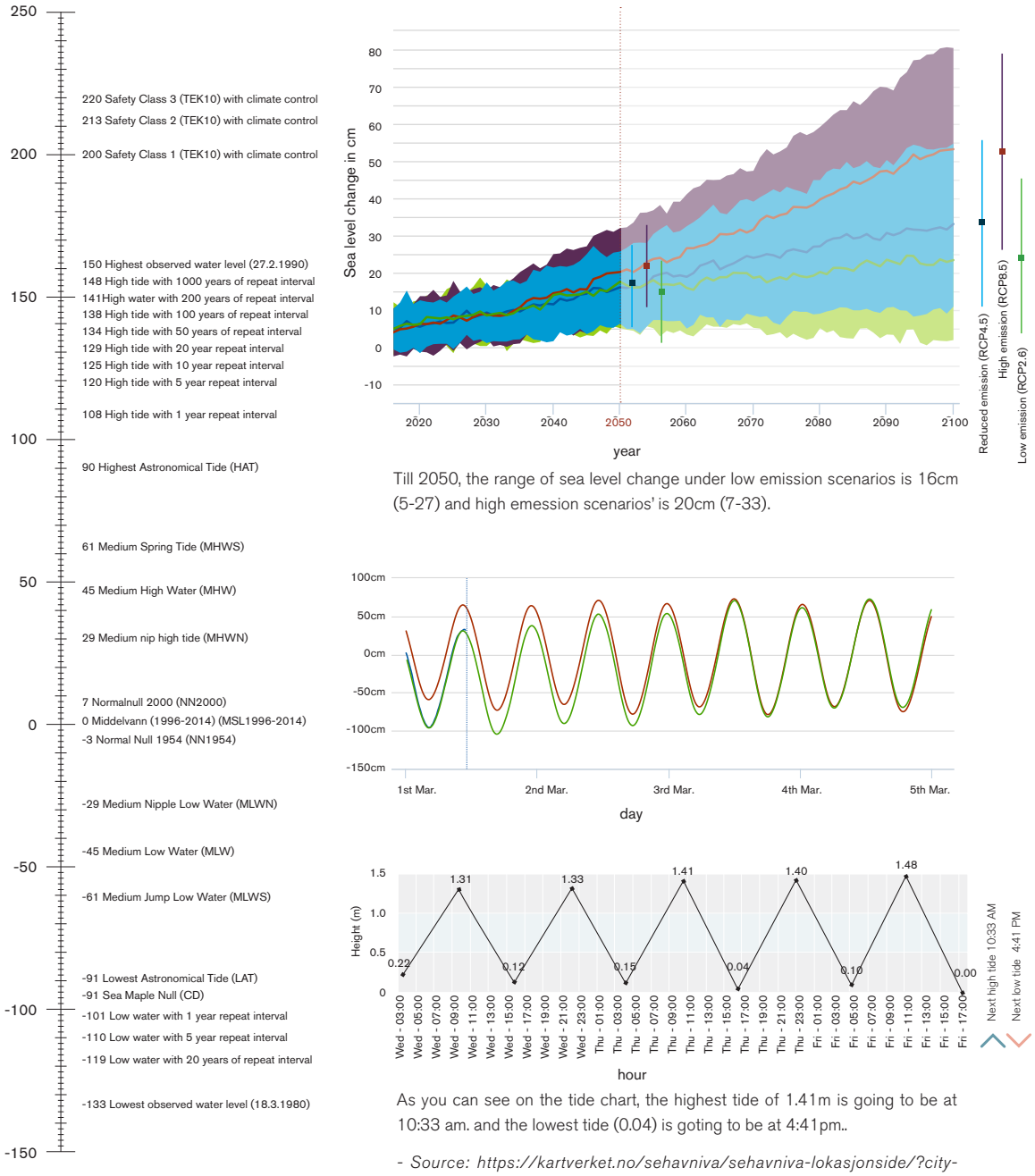


Fig. 47. Tide wave variation
By author based on data on Kartverket

Till 2050, the range of sea level change under low emission scenarios is 16cm (5-27) and high emession scenarios' is 20cm (7-33).

As you can see on the tide chart, the highest tide of 1.41m is going to be at 10:33 am. and the lowest tide (0.04) is goting to be at 4:41pm..

- Source: https://kartverket.no/sehavniva/sehavniva-lokasjonside/?city-id=9000002&city=Bergen#4/4

2.4.2
CHALLENGE OF ENERGY SYSTEM IN ENERGY GENERATION AND CONSUMPTION

Bergen and energy

The total energy consumption within the Bergen municipality's boundaries is approximately 6.7 TWh, which constitutes around three per cent of Norway's total energy consumption. The energy consumption for purposes other than transport, the stationary energy consumption, is 4.6 TWh. Of this, the con- sumption of electricity constitutes 3.7 TWh per year. If the stationary energy use of households in Bergen is divided by the number of inhabitants, the consumption is 8,450 kWh per person (2008), compared to the national average of around 9,200 kWh (2008).

In the selected area, the population is 4968. According to the amount of per capita consumption in Bergen, the consumption of this area is 41.98 GWh.

- Bergen Kommune, Siemens & Bellona(2011), Bergen SmartCity - Energy efficiency.

Bergen Municipality

- Total energy consumption	*6.7 TWh*
- Of which stationary energy use	*4.6 TWh*
- Of which use of electricitys	*3.7 TWh*

Stationary energy use can be broken down as

- Just over 120,000 homes	*2.1 TWh*
- 6,600 commercial properties	*1.7 TWh*
- 500 industrial companies	*0.8 TWh*

Local area of Bergen (selected area)

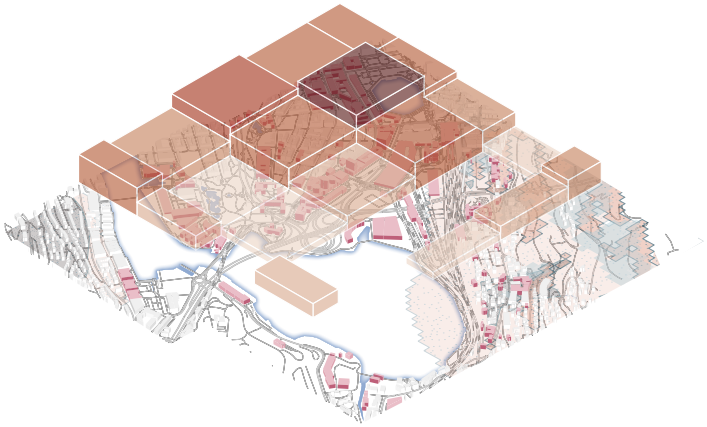
- Estimated electricity consumption	*0.07 TWh*

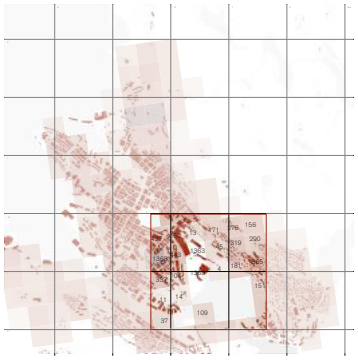
Stationary energy use can be broken down as

- Just over 3,435 homes	*0.041 TWh*
- 1,091commercial properties	*0.8 TWh*

- The calculation is based on the data from Statistics Norway (SSB) and report 'Bergen SmartCity' published by Bergen Kommune.

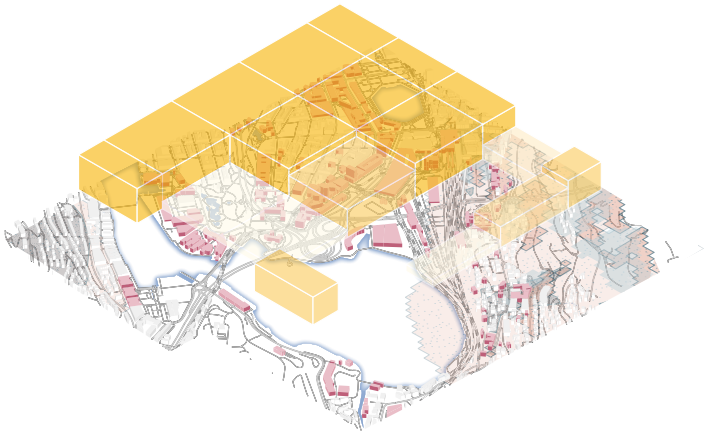
Fig. 48. Density of population, dwelling, business in Bergen centre
By author based on data on SSB

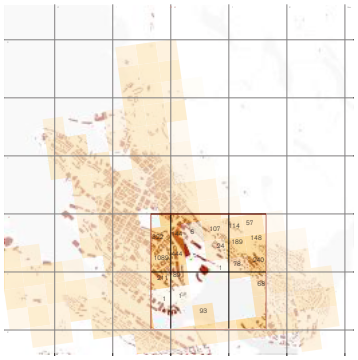




Population (250m grid)

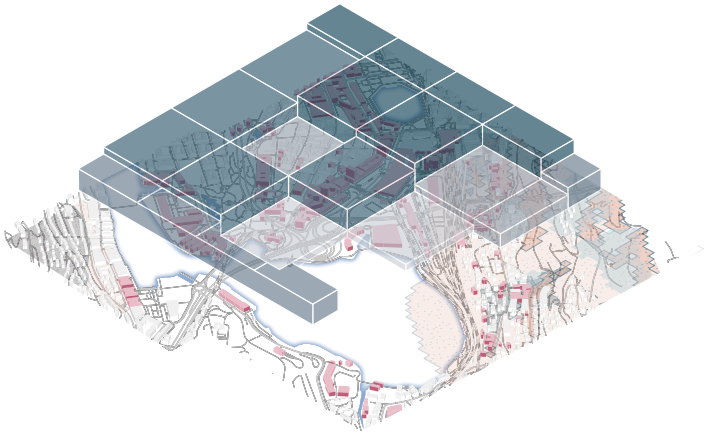
- 1-31inhabitants (<500 per km2)
- 32-124 inhabitants (500-2000 per km2)
- 125-312 inhabitants (2000-5000 per km2)
- 313-624 inhabitants (5000-10000 per km2)
- 625-1249 inhabitants (10000-20000 per km!
- 1250 or more residents (> 20000 per km2)

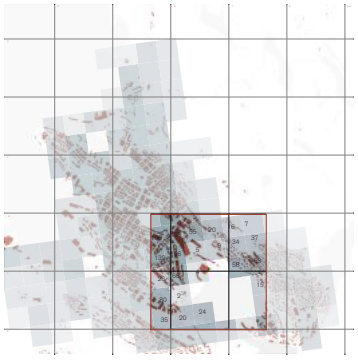




Dwelling (250m grid)

- 1 housing (<20 per km2)
- 2-6 homes (20-100 per km2)
- 7-31 homes (100-500 per km2)
- 32-124 housing (500-2000 per km2)
- 125 or more homes (> 2000 per km2)





Business (250m grid)

- 1-4 businesses
- 5-19 businesses
- 20-49 businesses
- 50-99 businesses
- 100-499 businesses

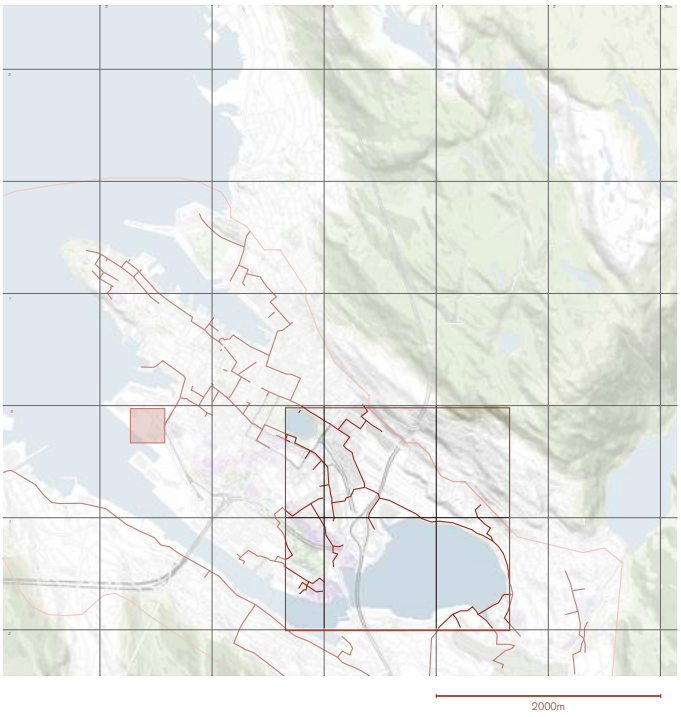
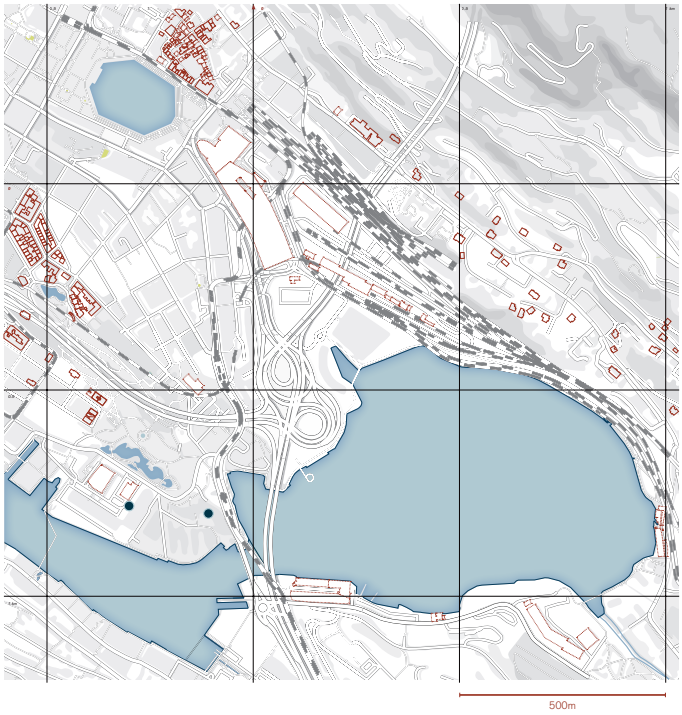




Fig. 49. District heating system
By author based on NVE

Fig. 50. Water management
By author based on NVE



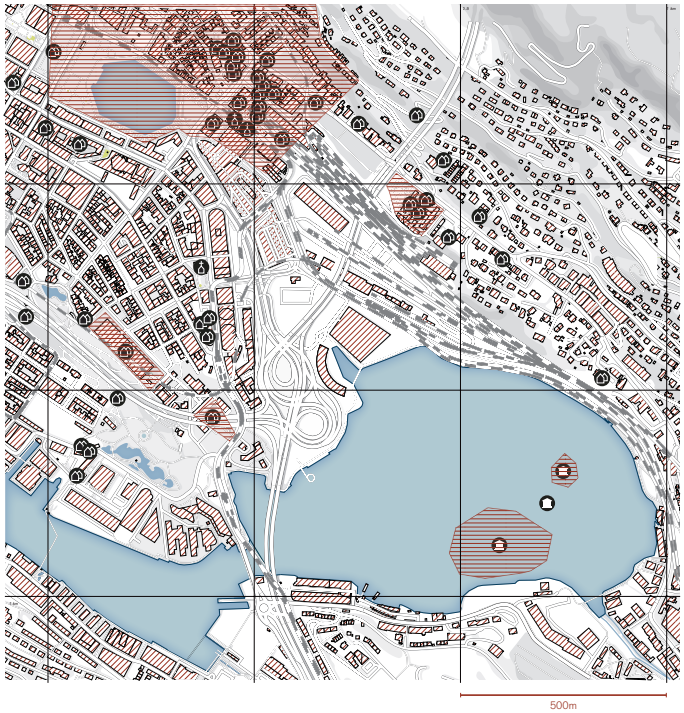


Fig. 51. Maintenance/ demolish programe in local scale (map)
By author based on Bergen kommune

Fig. 52. World heritage sites in local scale (map)
By author based on Bergen kommune

2.4.3
CHALLENGE OF FUTURE DEVELOPMENT IN POPULATION AND INFRASTRUCTURE

As the second largest city in Norway, Bergen has a powerful attraction to residents, immigrants, workers, students and tourists. To this extent, the future development will be huge and rapid.

Housing:

According to the projection of the municipaliy, in 2050 the population will increase at between 1.2 times and 1.65 times. Thus, the local area needs to provide 700 more housing to meet future residents.

Public service:

In Bergen, the public service is distributed and functions well, especially the educational institutions like schools. In the chosen area, there are a lot of schools, kindergartens and retirement and nursing homes, but only one sports space which can never meet the demand of the society.

Commercial and business:

Bergen is an international centre for aquaculture and shipping, and a national center for media, tourism and finance. But there are few large shopping malls, most of the commercial are shops along the street. In the selected area, there is only one shopping mall which is attached with a bus station in a disordered place.

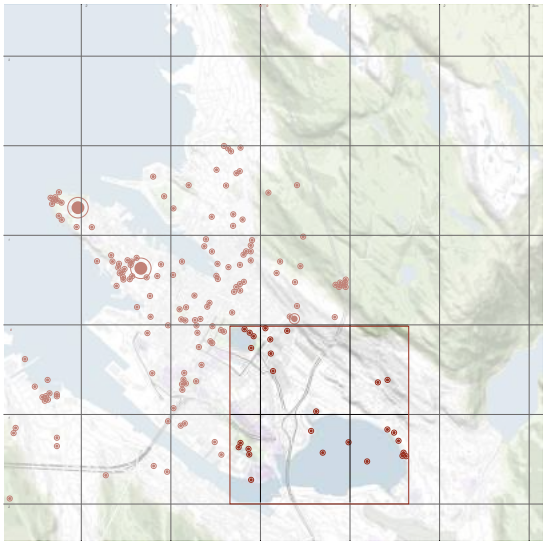
Tourism:

The main income source for the city is tourism. But compared with the city center, the selected area is quite unpopular. Thus, it is important to include the enhance the appeal when increasing the housing and public service for future increased population.

Fig. 53. Popular area (map)
By author based on data on SSB

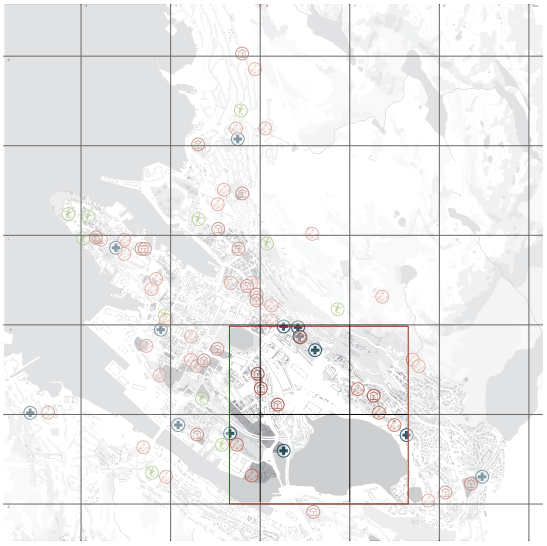
Fig. 54. Public building (map)
By author based on NVE

Fig. 55. Perspective of public buildings in Bergen centre
By Bergen kommune



Popular area ***53***

- More than 15 marked
- Other popular areas



Public building ***54***

- Sports
- Kindergarten
- School
- Retirement and nursing homes



Public buildings in Bergen centre ***55***

114

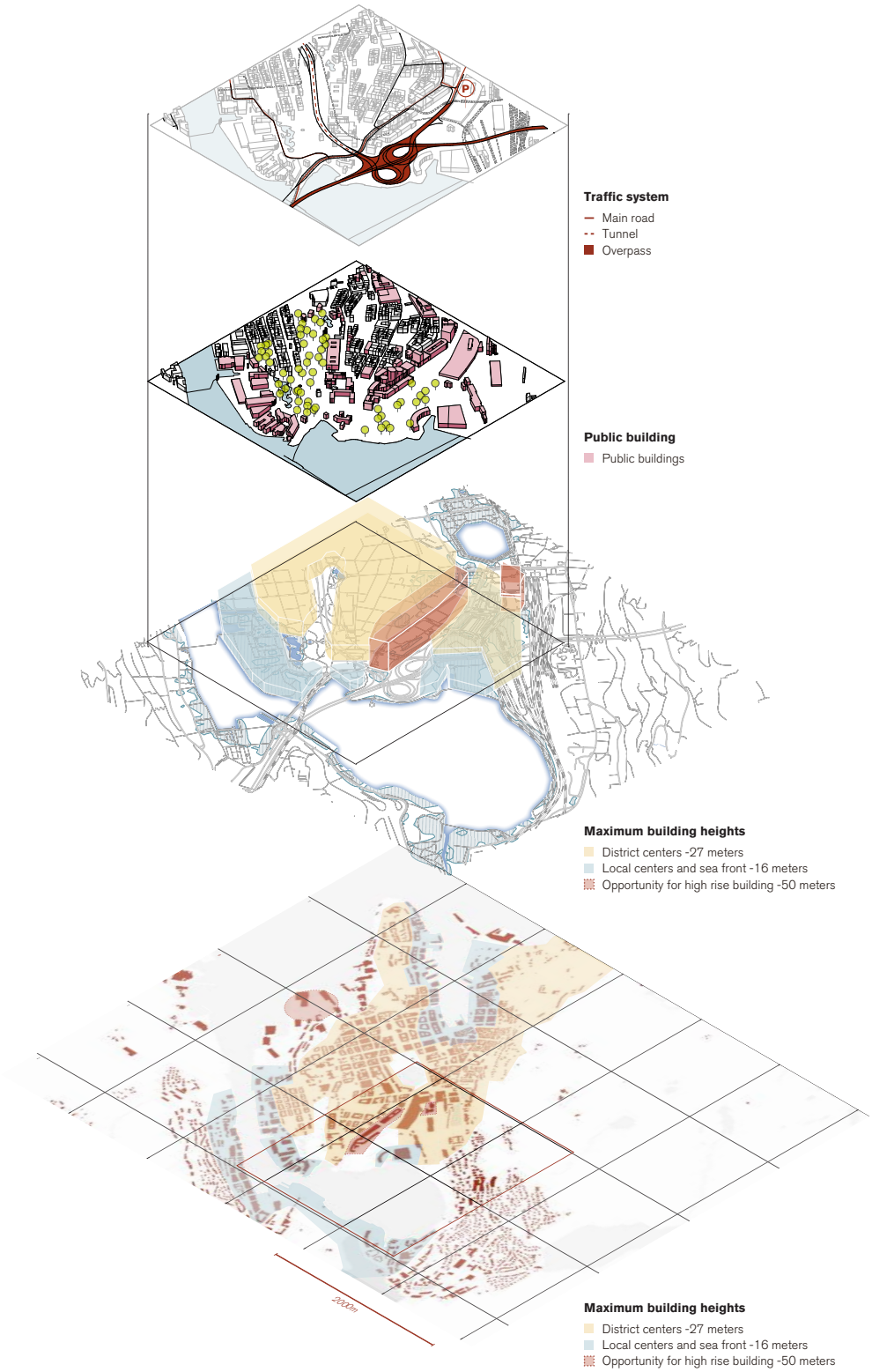
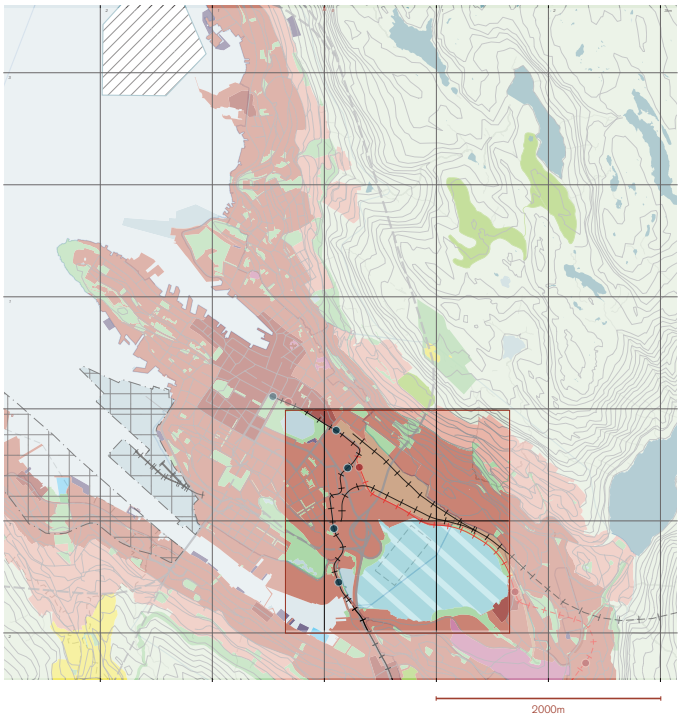


Fig. 56. Exploded view of systems and regulated height in local scale (axonometric)
By author based on Bergen kommune



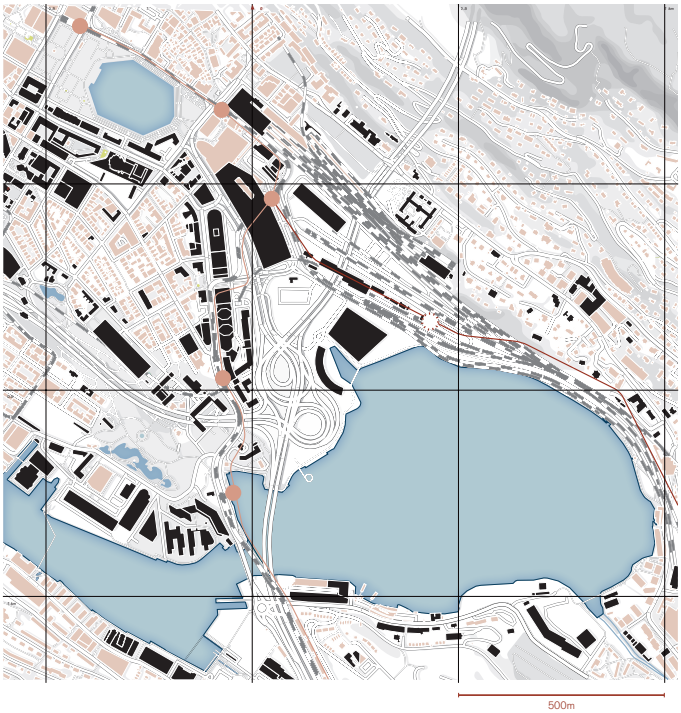
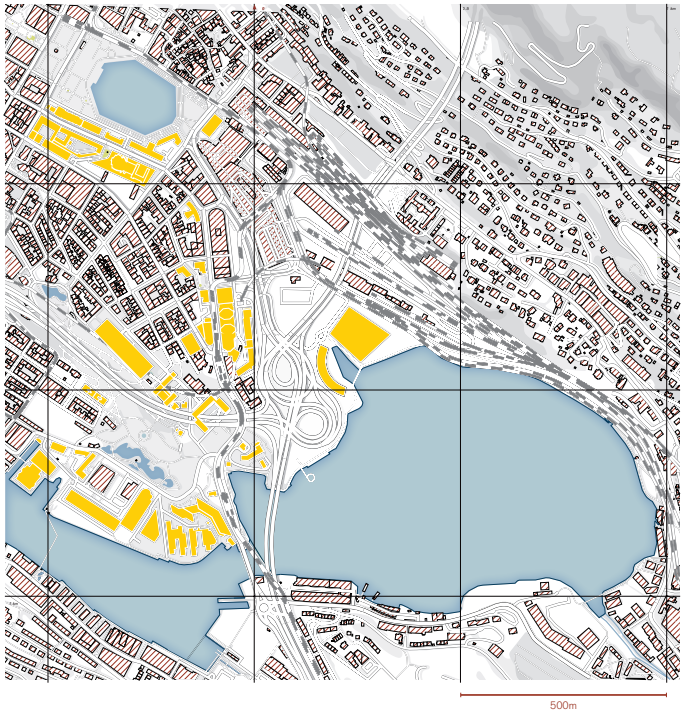


Fig. 57. Area objectives in Bergen centre(map)
By author based on Bergen kommune

Fig. 58. Functions in local scale(map)
By author based on Bergen kommune



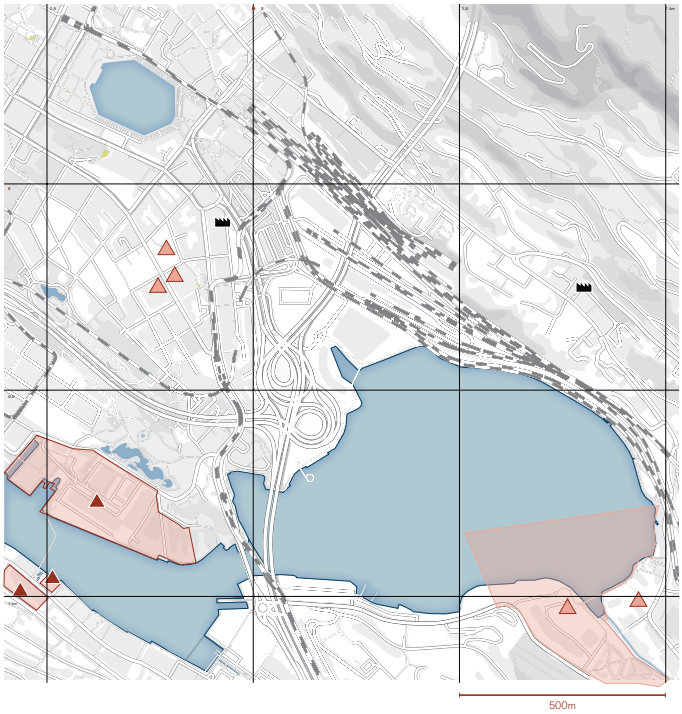
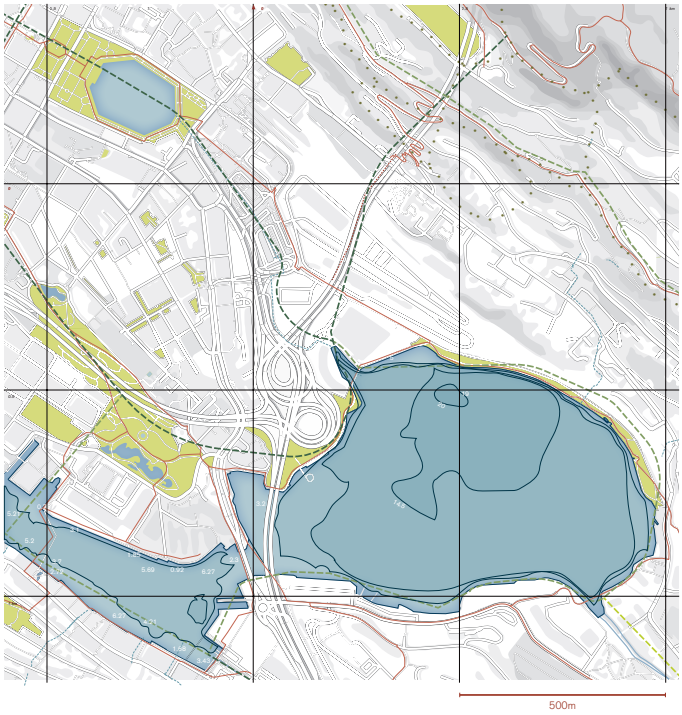
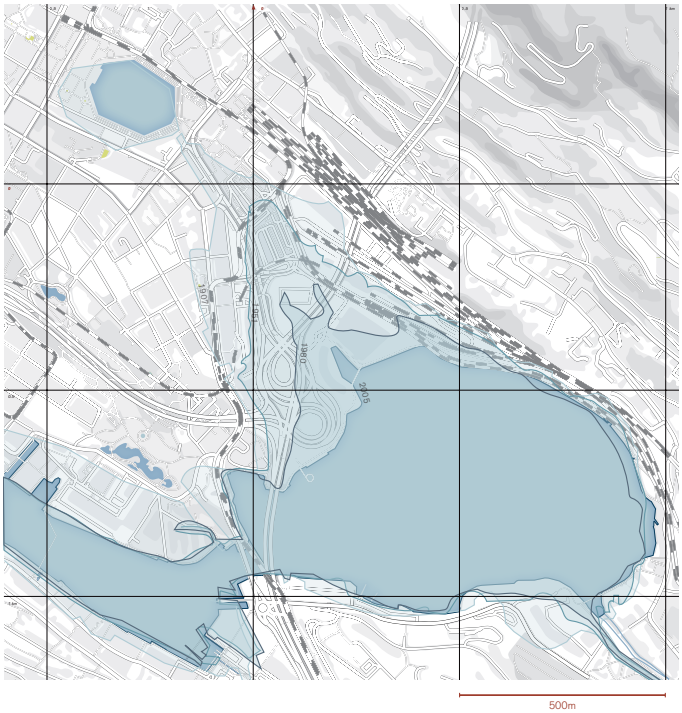


Fig. 59. Social-cultural program in local scale (map)
By author based on Bergen kommune

Fig. 60. Contaminated sites in local scale (map)
By author based on Bergen kommune



61



62

Fig. 61. Blue & green connection in local scale (map)
By author based on Bergen kommune

Fig. 62. Changing shoreline in history in local scale (map)
By author based on Bergen kommune

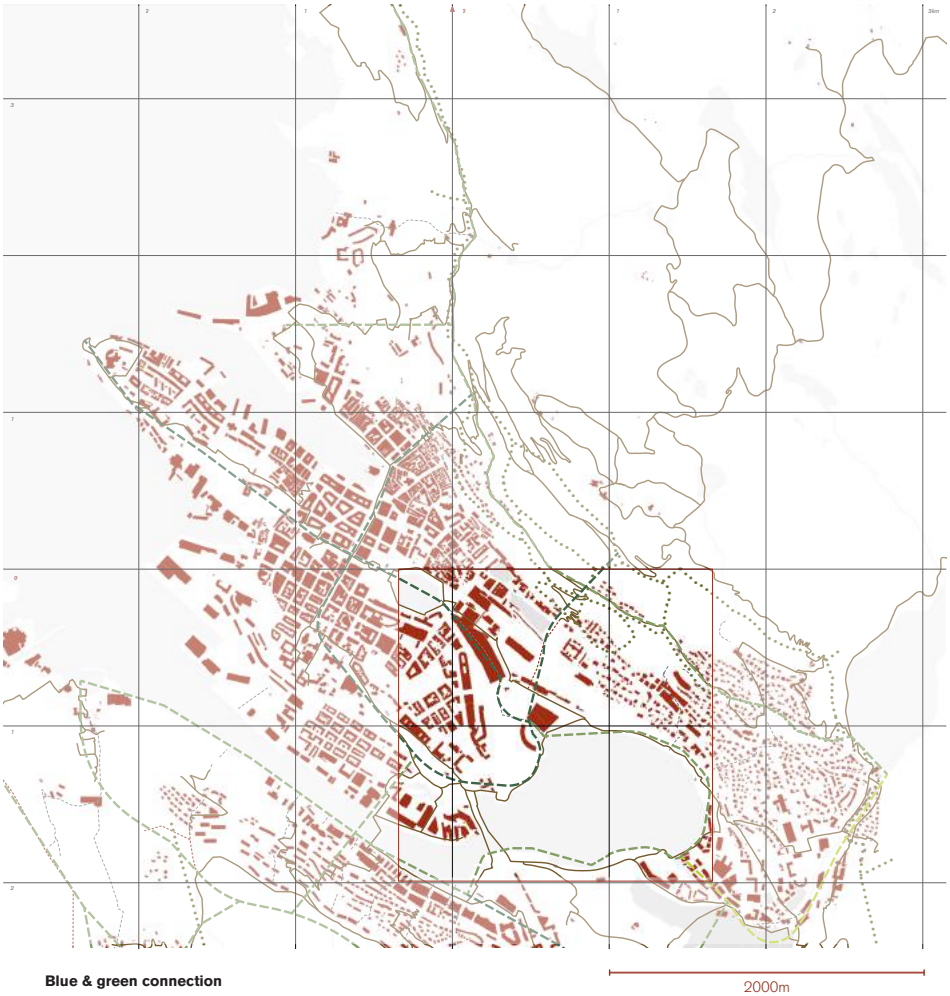


Fig. 63. Blue & green connection in Bergen city (map)
By author based on Bergen kommune

Fig. 64.65.66 Green trace, urban blue-green corridor, open waterways (photo)
By Bergen kommune

Green traces:

The connection aims to strengthen and develop green tracks for walking and other traffic, which provide access to parks and open-air areas and good experience. This not only focus on opportunities of the trip but also ecological corridors with the right width and vegetation. The connection in the chosen area links future hiking areas around Langavatnet with mountain areas. The connections are via existing hiking and green area.Norway will be a climate neutral country and Bergen will become a fossil-free city, which means there will be no more oil, coal and natural gas used as fuel.



64

Urban blue-green corridor:

Development of existing and new urban space will provide opportunities for meeting places of city life. And blue-green corridors can help to resist and divert flooding while establishing new ecological corridors. In the chosen area, the map shows an axis that extends from Lille Lungegårdsvannet to Store Lungegårdsvann, which uses open systems for water management to provide good development of blue-green urban space.



65

Open waterways:

Open waterways provide safe drainage of flood water through built-up areas, which are particularly important in terms of managing future climate change. In this map, the important lakes, streams and rivers and marked, which provides the living environment for aquatic organism and creates new adventure opportunities in city space. The chosen area includes forest and organic corridors.



66

2.5
RECOMMENDATION & PROPOSAL

- What society do we want to have in 2050?

As a low-carbon society, Bergen will have a high roportion of renewables and be free from greenhouse gas emissions. Till 2050, Bergen will be the impetus of Norway to export green energy and high-tech products.

Although climate changes will continue, they will have been mitigated to a great extent. Meanwhile, Bergen will have more tolerance for sea level rise, precipitation, storms, and even be able to utilise the exceeded rainfall and tide-surge as water energy to generate more electricity. The energy system will be more robust and have a better management after a shock.

Based on that, the city shall provide a pleasant and green environment for living and working, with good air equality and great biodiversity. The electrification of transport will be improved as the change of urban structure. Through coordinating networks, Bergen will be more friendly to pedestrians and cyclists, also the travellers.

- What measures will ensure the 2050 vision?

Instruments and adaptive measures are the key that secures the investment realization of goal and ensures predictability and necessary flexibility in climate and energy policy.

Thus the factors used for evaluation are categorized into five themes: resource, infrastructure, resources, land use and urban form, social-economic development and governance.

- Resource

In the natural environment, improving resilience means reducing emission of greenhouse gas and minimizing generation-related impacts on various resources such as water, air, forests and biodiversity.

Measures such as appealing various sectors to cut emission, introducing environmental regulation, shift from coal and oil to electrification, water treatment are helpful.

Fig. 67. Relation of regions
By author

- Infrastructure

Stability, reliability, flexibility, and efficiency of the energy system is the first essential to achieve energy resilience. Here, factors are classified into energy production, transmission, and distribution, including energy storage.

Fortification of the infrastructure can protect them against potential interference and disruption. To ensure the ability of the system, regular maintenance and upgrading are needed. Appropriate increase in the frequency of checks can better promise the security.

- Land use and urban form

The planning of land use and urban morphology is the regarded as the central focus to urban designers.

Functional mix is encouraged due to less energy consumption and better accessibility. Also this will influence the travel pattern and distribution system. Urban morphology is related to the density pattern, housing type and street networks. The minimum density of the city is important to promote transition pattern. Local systems such as district energy systems can enhance efficiency, independence, reliability, and flexibility of urban energy systems. According to Novotny (2013), an average density between 80 and 200 persons per ha is the ideal situation for energy implications.

- Social-economic development

Demographics, health, education and behavioral aspects is important in terms of exposure reducing and adaptive capacity improvement. Thus, socio-economic equality should be paid more attention, as well as the awareness of recycling.

- Governance

Besides technology and design qualifications, urban systems should also feature powerful institutional mechanisms. Urban governance is essential to coordinate various systems, monitoring performance and managing the market.

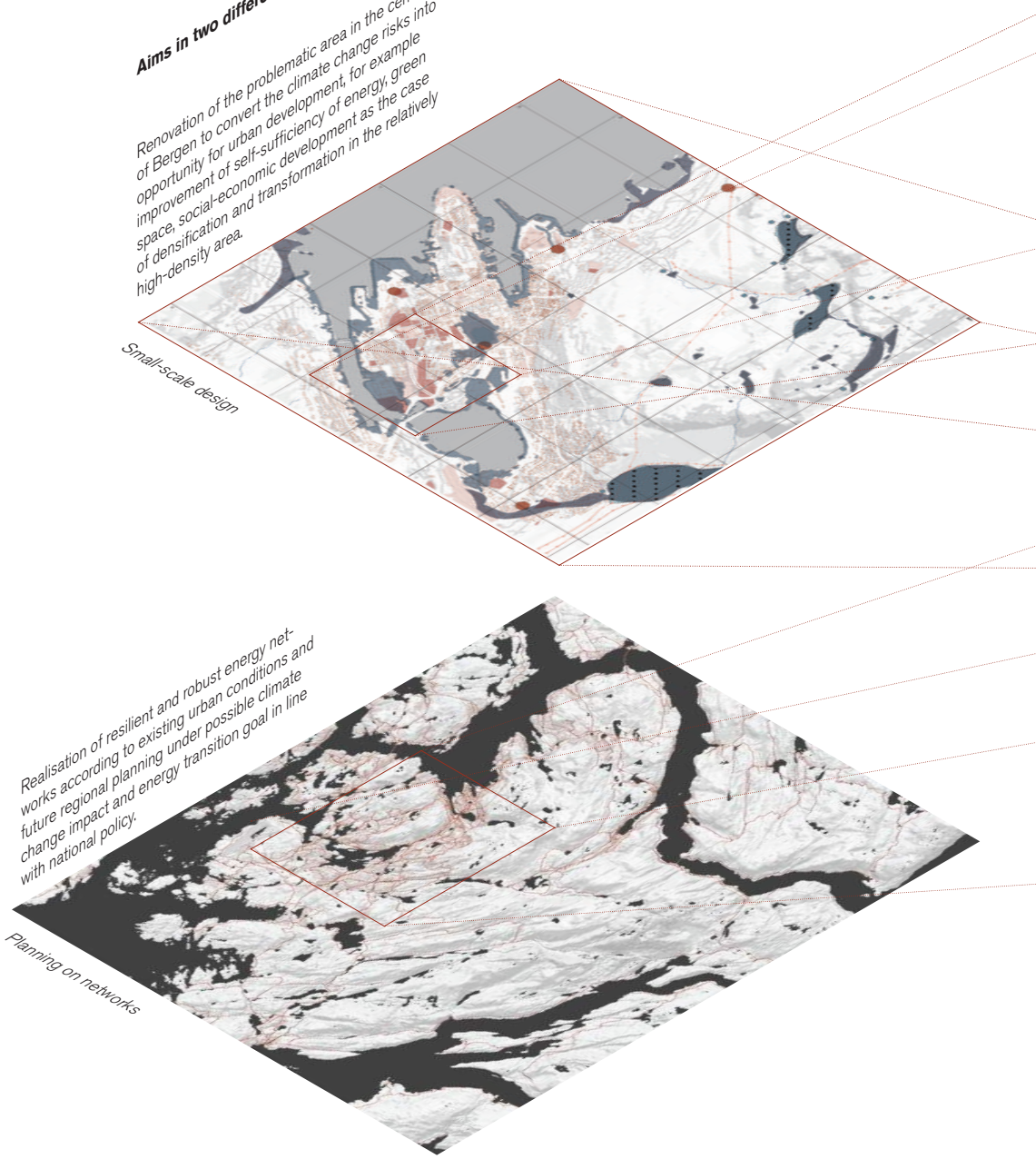
Aims in two different scales

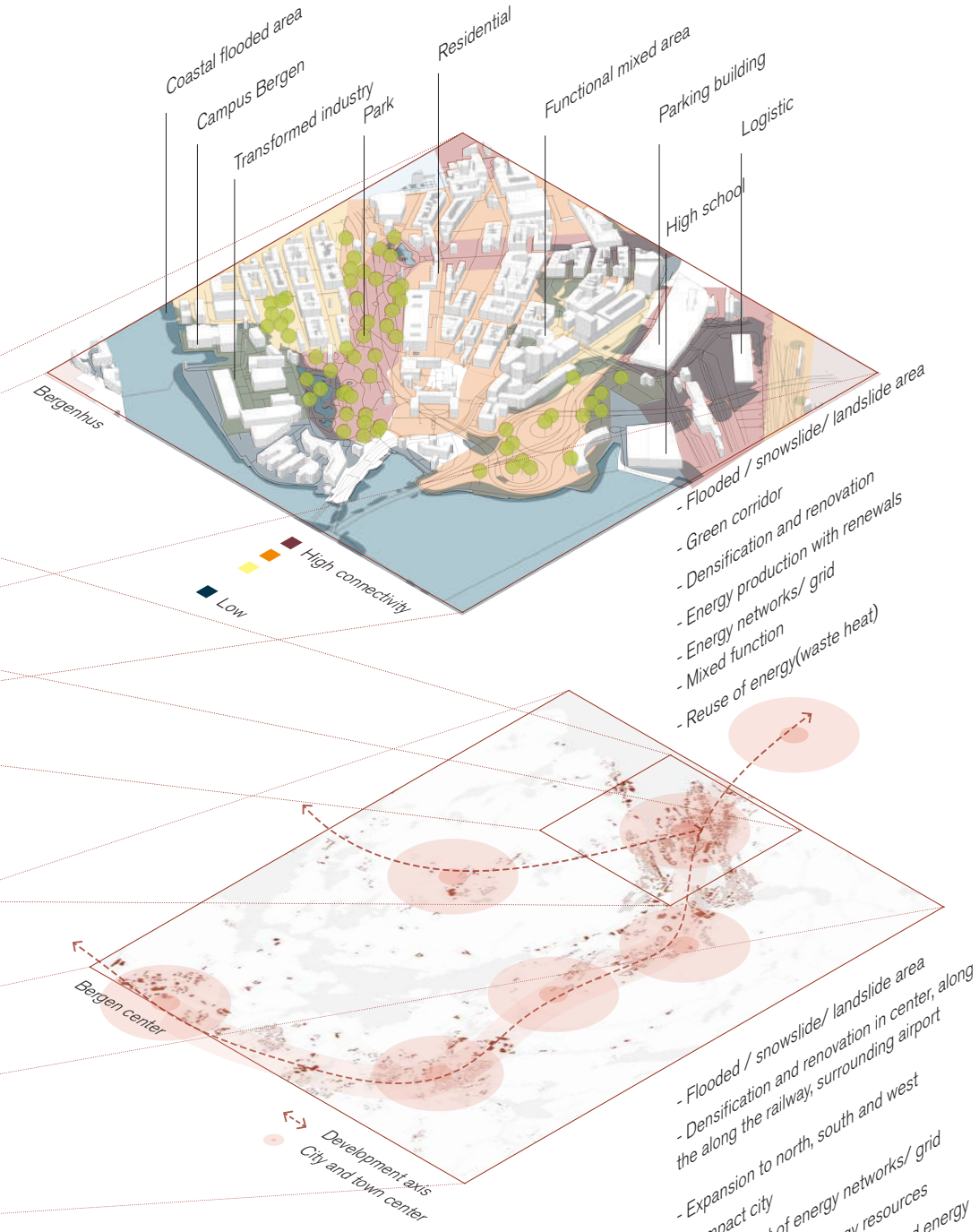
Renovation of the problematic area in the center of Bergen to convert the climate change risks into opportunity for urban development, for example improvement of self-sufficiency of energy, green space, social-economic development as the case of densification and transformation in the relatively high-density area.

Small-scale design

Realisation of resilient and robust energy networks according to existing urban conditions and future regional planning under possible climate change impact and energy transition goal in line with national policy.

Planning on networks





Tasks in specific area

3 DESIGN

3.1
CLIMATE CONSENSUS - SCIENTIFIC VIEWS ON CLIMATE CHANGE

The aim of the design is to convert the potential risks from the climate change impact and other threats into opportunities, which mean the city will not only be safe and liveable, but also be prosperous and sustainable.

So it is important to recognize different kinds of risks in the local scale and the influence on these three layers, infrastructure network, occupation and natural environment.

There are mainly three kinds of risks, pluvial flooding due to the extreme precipitation, coastal and fluvial flooding due to storm surge and high water levels and landslide and snowslide due to wind and precipitation. Flooding is happening on the edge of shoreline and along the road between Lille Lungegårdsvannet and Store Lungegårdsvann, which will mainly influence the public buildings. The possible landslide and snowslide are likely to happen on the foot of mountain and predominantly affects some housing and few public buildings.

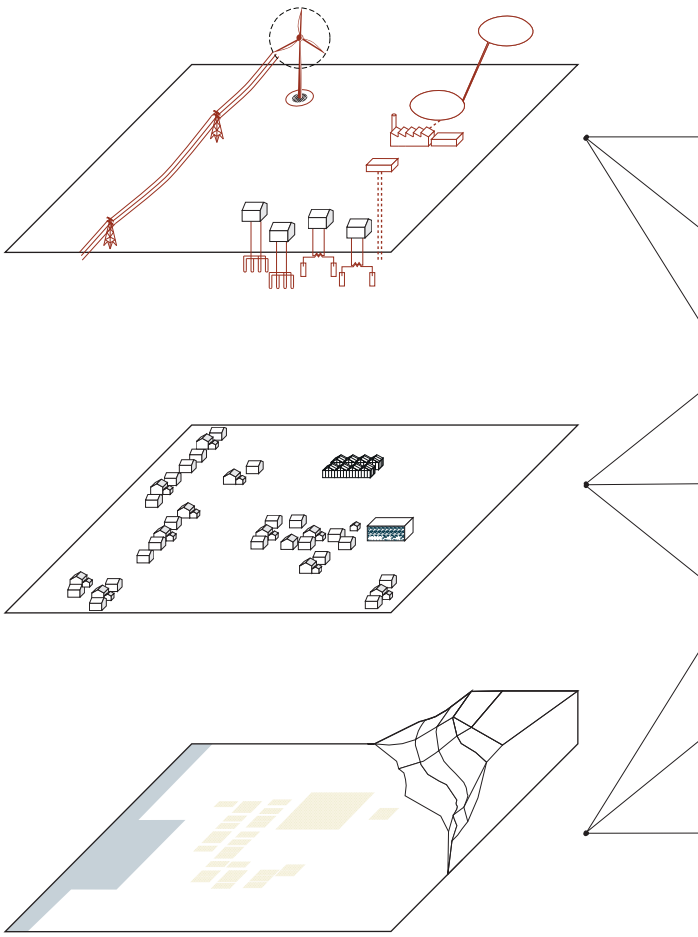
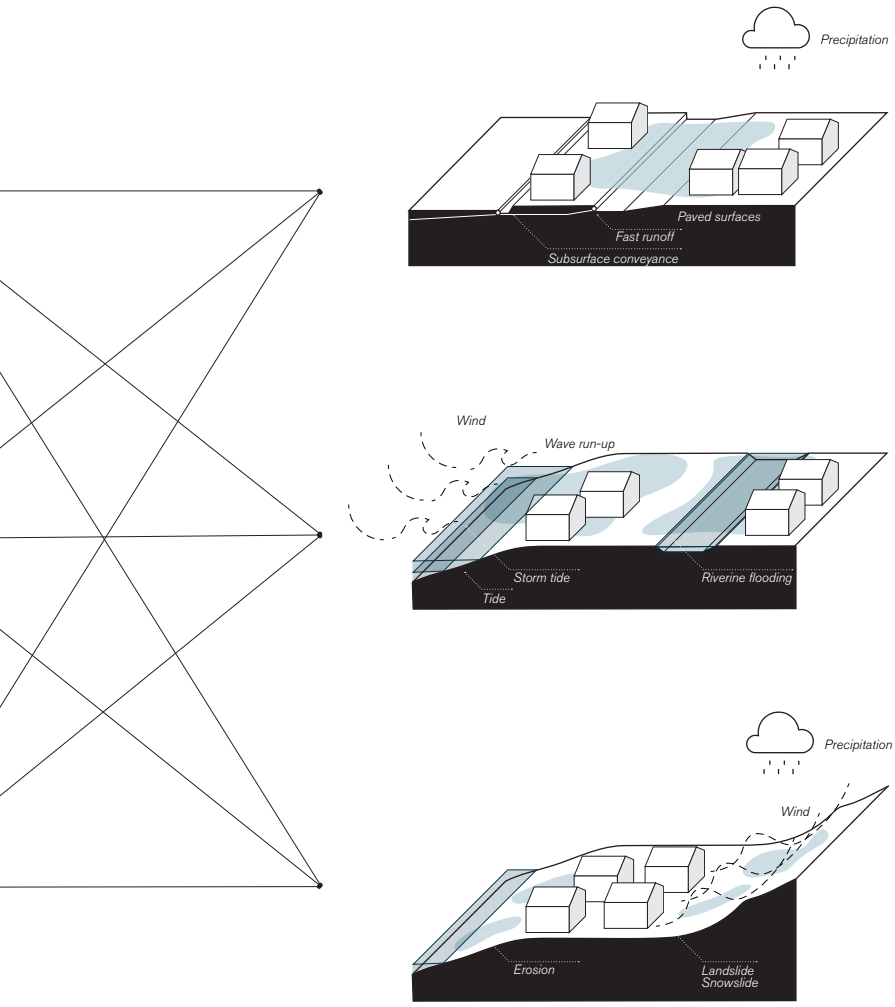


Fig. 68. Different risks and three layers
By author



- Pluvial flooding

Extreme precipitation may cause flash-flooding or in-land flooding. If rain-storms cannot be stored or evacuated in time, the drainage system will be over-loaded, resulting in city water-logging.

- Coastal and fluvial flooding

Storm surge is the largest contributing factor of high water levels. In addition, the storm will increase the wave movement and the tide will affect the water level.

Riverine floods are determined by the high water level which caused by high discharge of upstream and/or the combi-nation of high sea level.

- Landslide and snowslide

Extreme precipitation combine with wind will cause a landslide and snowslide in the mountain region.

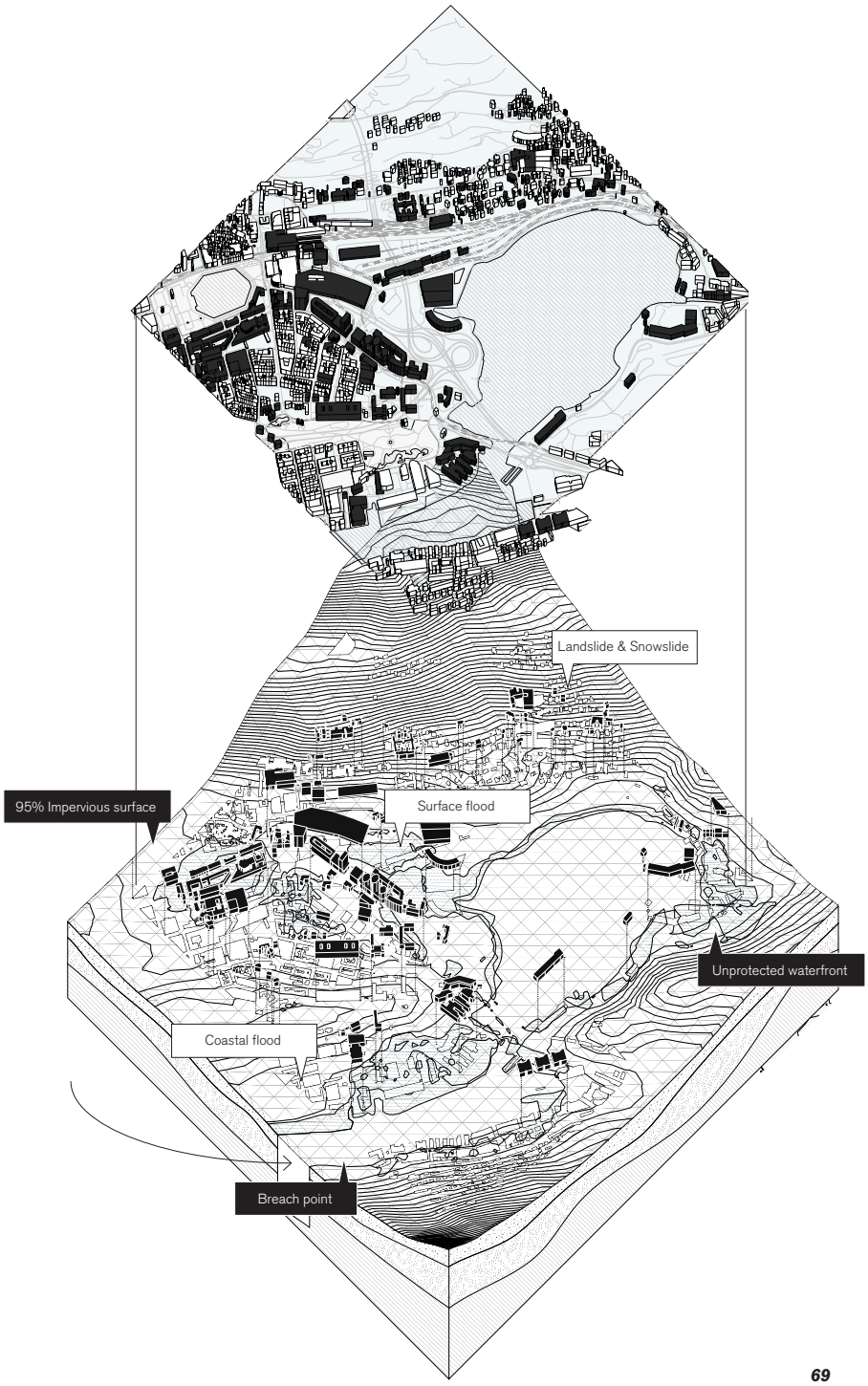
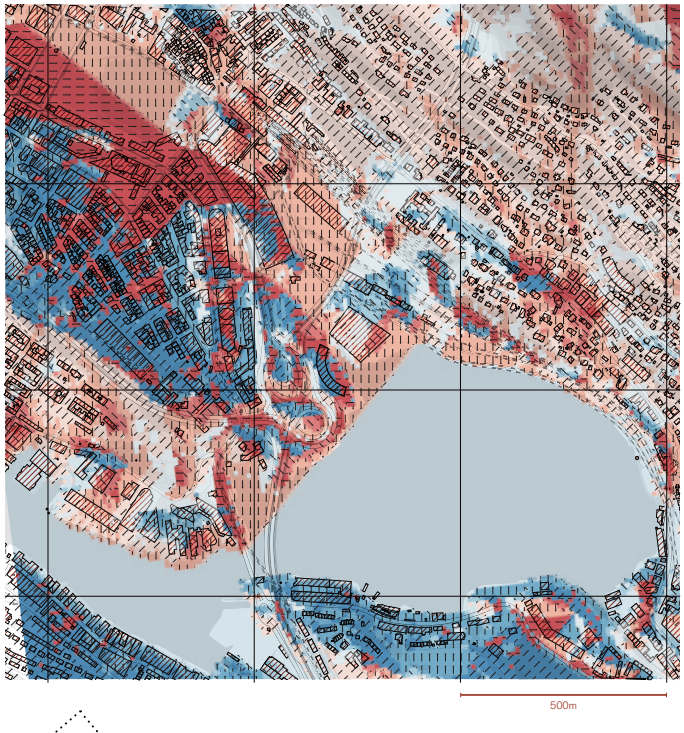
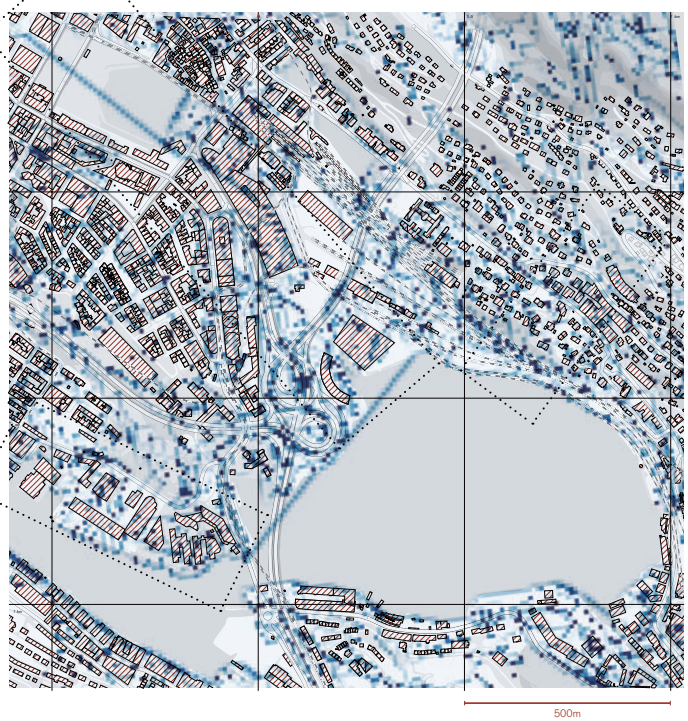


Fig. 69. Potential risks and urban structure combining with terrain(isometric)
By author



70



71

Fig. 70. Flow direction of potential pluvial flood in local scale (map)
By author based on ArcGIS analysis

Fig. 71. Flow accumulation of potential pluvial flood in local scale (map)
By author based on ArcGIS analysis

3.2
VULNERABILITY ASSESSMENT - RECOGNIZATION OF RISKS IN LOCAL SCALE

- Extreme water levels as a result of

▪ Storm surge and/or offshore storm events

▪ High river discharges

▪ (Under) performance of flood defense measures

- Overwhelming of the urban drainage system as a result of

▪ Extreme precipitation

▪ Land use and impermeable surfaces

▪ (Under) performance of drainage system

- Landslide & snowslide as a result of

▪ Earthquake and tsunami

▪ Precipitation and snow melt

▪ Surface water scouring and soaking

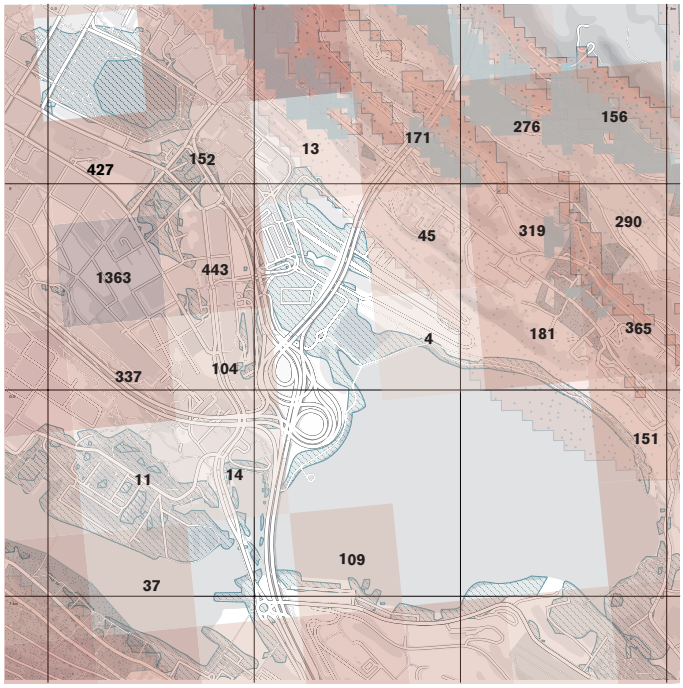
When these impacts happen on the urban structure, different urban systems will be affected to varying degrees, vulnerable houses and people will become victims.

On one side, vulnerability assessment indicates the exposure, sensitivity and adaptive capacity and helps to define the vulnerable population and infrastructure. On the other side, it helps to analyse the potential impacts in the aspects of physical, social, culture, economic, environment, which gives a suggestion about the protection zone and protective measures.

In the local scale of Bergen, not so many people will be influenced by flooding. But most of the important infrastructure like central railway station, harbours, bus stations will be flooded. And housing that located at the foot of mountains might be suffered from the landslides and snowslides. So the emphasis is put on the shoreline, the harbour region, the central area, and the mountain side.

Fig. 72. Potential coastal flood, snow slide and landslide in local scale (map)
By author based on Bergen kommune

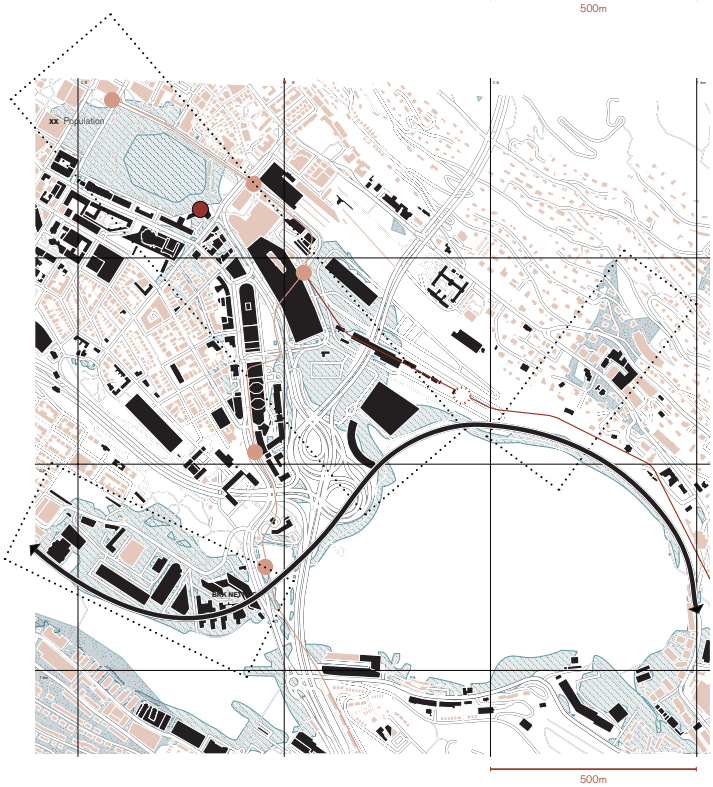
Fig. 73. Potential influence on urban structure in local scale (map)
By author based on Bergen kommune



Potential coastal flood, snow slide and landslide

- Flooded area
- Potential landslide hazzard
- Slipped snow attention solvent expiration area
- Slipped snow attention solvent ejaculation area
- Slashed stone leap attention trigger area
- Slashed stone-blowing awareness expiration area
- Landslide record

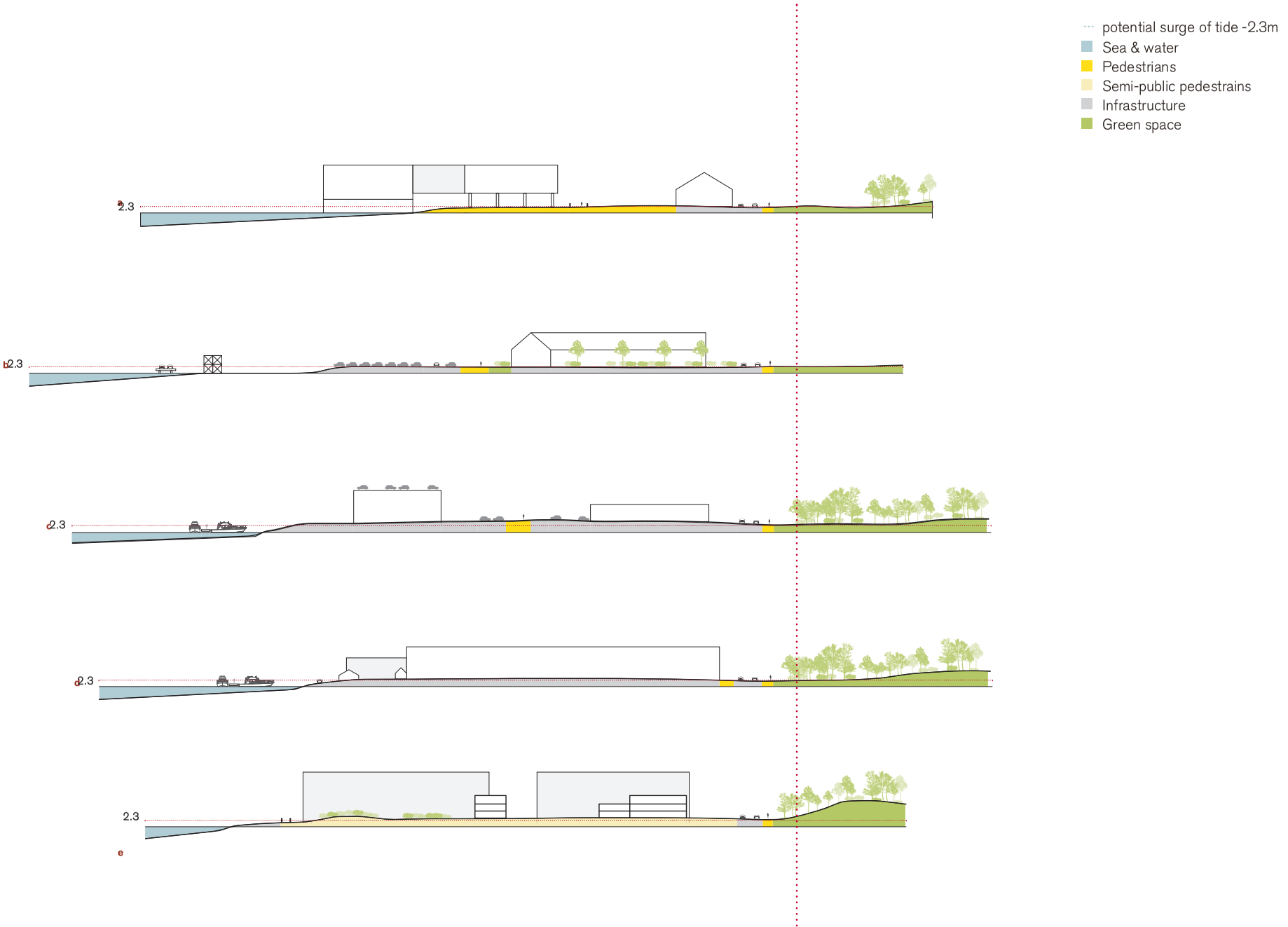
72

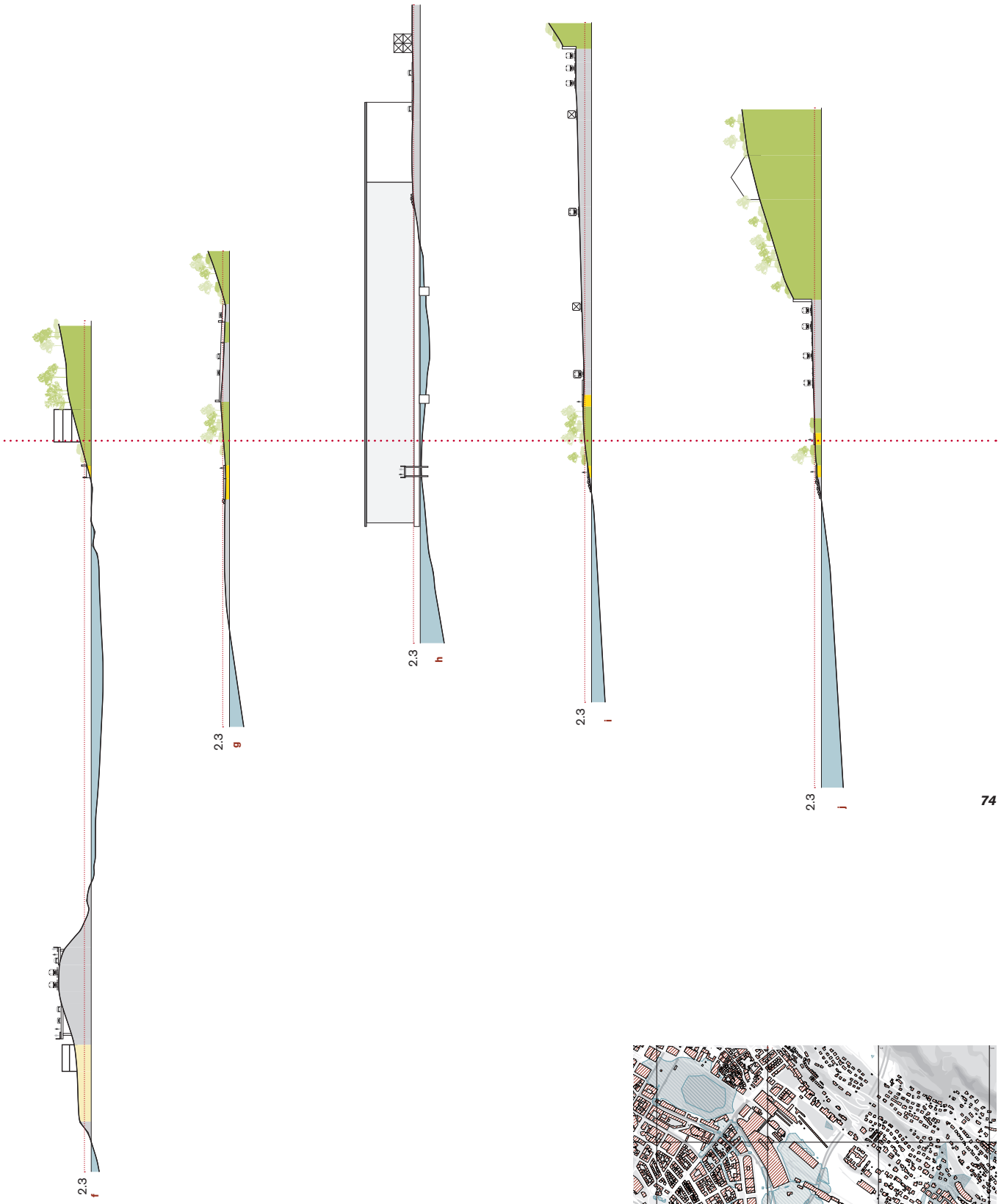


Potential influence on urban structure

- Power transformer station
- Dwellings
- Other funtion buildings
- Existing light rail station
- Existing light railway
- Future light rail station
- Future light railway

73


potential surge of tide -2.3m
Sea & water
Pedestrians
Semi-public pedestrains
Infrastructure
Green space
2.3
2.3
2.3
2.3
2.3
a
b
c
d
e



74

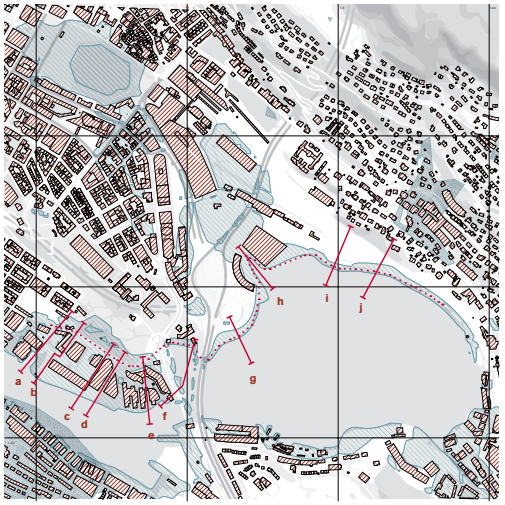


Fig. 74. Existing sections along coastal line
By author

134

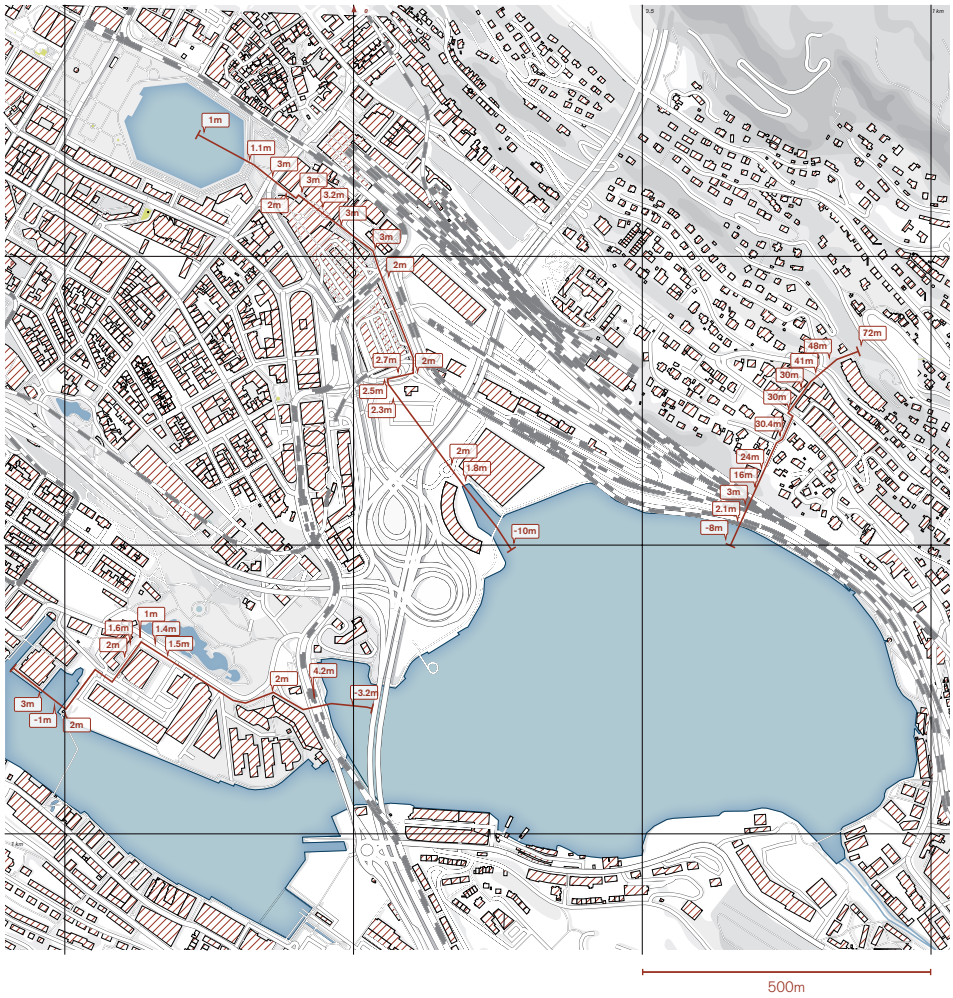


Fig. 75. Three selected sections combining with terrain
By author based on SSB

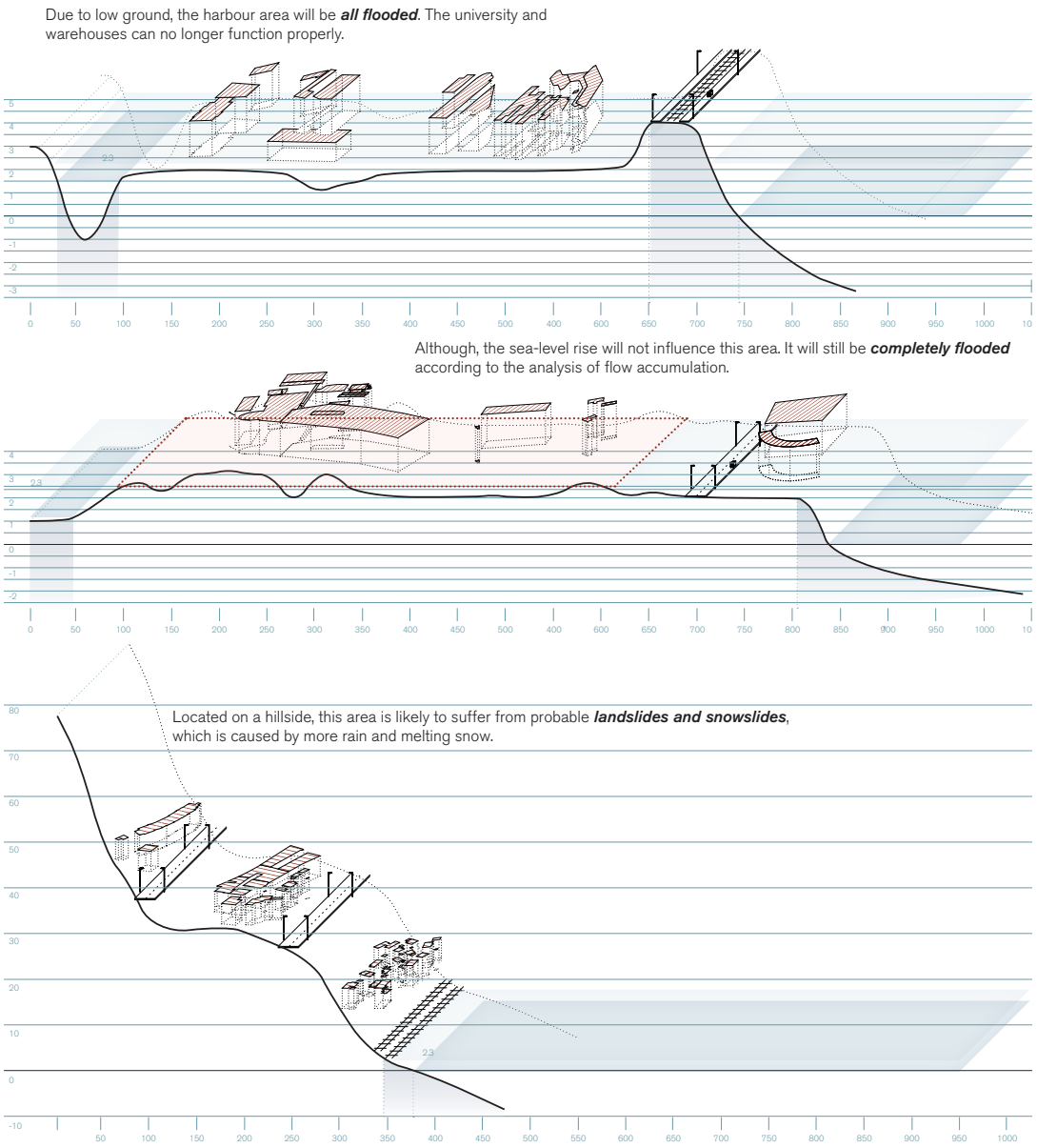


Fig. 76. Strategies of 3 main axises and coastal region
By author

3.3
RESILIENCE INITIATIVES STRATEGIES

To reverse the risks into opportunities, we must make cities more liveable and vibrant on the basis of ensuring urban safety. There are six **resilience initiatives principles** to follow when uptdating the city.

- Work in layers for independently effective solutions.

- Support multiple benefits with each activities.

- Develop adaptive and flexible strategies.

- Minimise impact on energy consumption and natural resources.

- Define a responsive urban form.

- Incorporate local involvment in design and decision-making.

So, here introduce four **resilience initiatives layers:** protected shores, resilient infrastructure, adapted buildings and intergrated actors and governance. Each of them can work in layers for independently effective solutions, but meanwhile, the combination of them forms a responsive urban form, incorporating to develop adaptive and flexible strategies.

Also, there are four **initiative process** steps to reach the goal of evolutionary resilience, firstly minimizing the possibility of risks, then reducing the influence for preparation, enhancing the robustness of urban systems for persistence and recovery and transforming the urban systems to adapt to new conditions and probably advance to a positive development.

1. Minimize the possibility of risks

Extreme precipitation and high water levels can lead to various flood hazards, which take into account the performance of the natural and built flood protection system and the urban drainage system.

Also, landslide and snowslide are on account of the lithology type and geographic and geomorphic conditions. External factors and effects can change the basic conditions of the landslide and induce the landslide.

Fig. 77. Resilience initiatives components
By author

Resilience initiatives principle

Work in layers for independently effective solutions

Support multiple benefits with each activities

Develop adaptive and flexible strategies

Minimise impact on energy consumption and natural resources

Define a responsive urban form

Incorporate local involvment in design and decision-making

Resilience initiatives process

Build a prepared and SAFE community

Accelerate access to reliable and clean ENERGY

Adapt to the SEASONAL change under CLIMATE

Promote shared economy and culture to advance city DEVELOPMENT

Excel at working together within URBAN GOVERNANCE to better serve the community

Build regional EVOLUTIONARY RESILIENCE SYSTEM

Preparation Persistance Recovery Transformability Mitigation

Resilience initiatives layers

- Protected shores

- Resilient infrastructure

- Adapted buildings

- Intergrated actors and governance

Responsive urban structure

2. Preparation - minimising potential disruption

There are four dimensions constitute the framework of evolutionary resilience, including preparation, persistence, recovery and transformability (Holling, 1973; Barata-Salgueiro and Erkip, 2013; Sharifi et al, 2016; Davoudi et al., 2016). Here preparation s defined as human interventions like predicting and preparing for reducing and minimising potential disruption of urban systems deriving from climate-related hazards.

Preventive actions and measures are firstly taken to prepare and protect the urban systems from climate change impacts.

3. Persistence & recovery - enhancing the robustness

Persistence carries on the definition of resilience in ecology and physics which stands for the ability of absorbing and withstanding the shocks, which enables the urban system to continually function without a great deterioration. Recovery is related to the flexibility and resourcefulness, which provide alternative options and a good management to re-operate if the systems collapse.

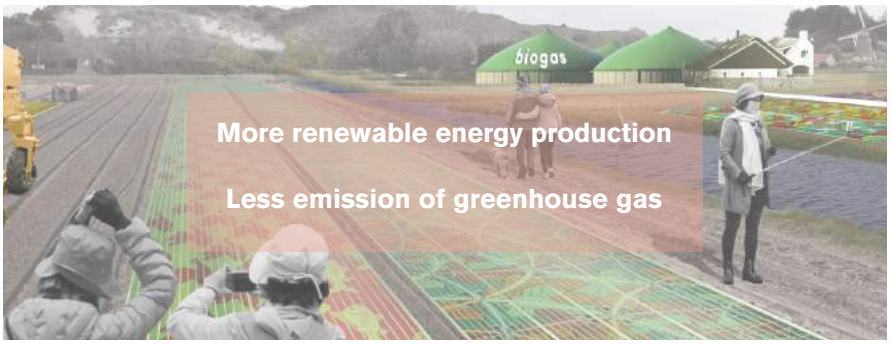
After the occurrence of hazards, the first phase of urban systems is “persistence”, in which the characteristic of robustness will retain the function as much as possible. If the system failed to persist, it will go through the next phase of recovery to the new condition by recovering from the hazards.

4. Transformability - advance to a positive development

Transformability represents that the system is able to adapt the new conditions and probably advance to a positive development.

In consideration of the unique characteristics of transformability in evolutionary resilience, the process of improvement of vulnerability towards resilience was alluded to “turning risks into opportunities” by interlinking synergetic systems and improving urban structure. Here list energetic, seasonal, dynamic as the transformability characteristics.

Fig. 78. Vision (background picture)
By POSAD


biogas
More renewable energy production
Less emission of greenhouse gas


supermarkt
Maximize local opportunity
Accelerate public enthusiasm


Increase resilience capacity
Minimize climatic risk

1. Sport + Education + Energy

This area centralized some research centers, high schools and universities. Thus, the aim is to intensify the national centre for higher education while minimize the possibility of flood risk and extreme precipitation. To take full advantage of the open green space, multi-functional service is considered, for example combine the skate park, green space and water storage underground. Meanwhile, the location is sensitive to the changing sea-level. But this can be also used to generate more energy from water.

2. Business + Ho

Due to the rapid development, this area is
scale public transportation station, parking
formation of this axis is to activate the regi
vann with more business, housing and recr
Reconnect the Lille Lungegårdsvannet and
extreme precipitation and decrease flood r
fresh water and sea water to generate mor

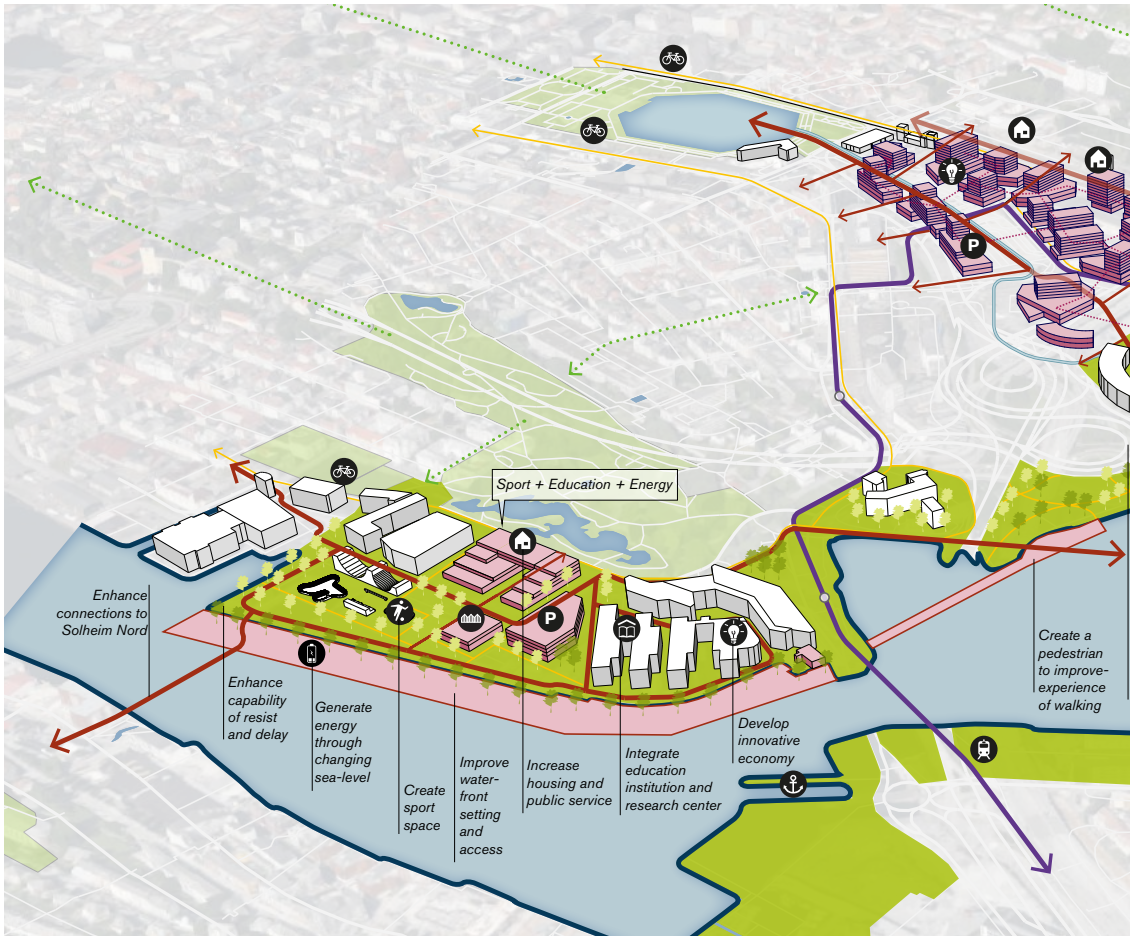


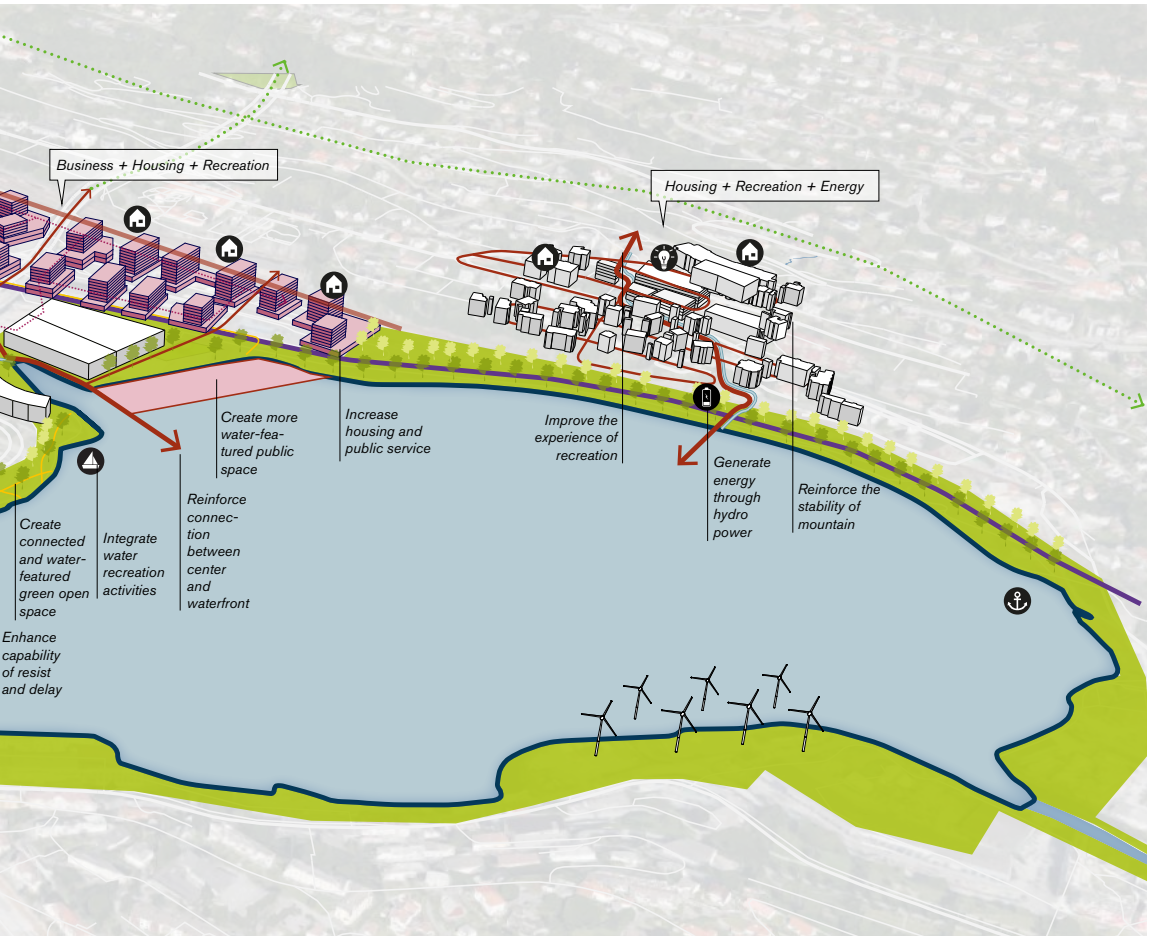
Fig. 79. New evolutionary resilience structure in local Bergen
By author

using + Recreation

quite chaotic and aggregated a lot of large- garage and logistics center. Thus, the trans- on between center and Store Lungegårds- eation and building characteristic landmarks. d Store Lungegårdsvann to better discharge isks. Meanwhile, using the meeting points of re energy.

3. Housing + Recreation + Energy

Mountains can be seen as the most distinctive features of Bergen, but it will also increase the possibility of landslide and snowslide in extreme weather, especially in winter. So this axis aims to strengthen the protection measures and utilize the advantage of altitude difference and more precipitation to generate more energy through hydropower. Also, emphasis is put on the ecological connection, recreation and housing development.



3.3.1
TO BE SAFE

Risks in Bergen area are mainly from excess water and landslides. Therefore, when it comes to safety, it mainly considers flood prevention and landslides.

In terms of flood prevention, on the one hand, the flood prevention system on the shoreline should be set up. Considering the the increasing sea-level rise and surge tide, it is needed to build a flood wall at least 0.25 meters or by other alternative prevention means. And on the other hand, the blue-green structure in the city needs to be re-designed, which should combine with the drainage system to prevent urban flooding when extreme precipitation.

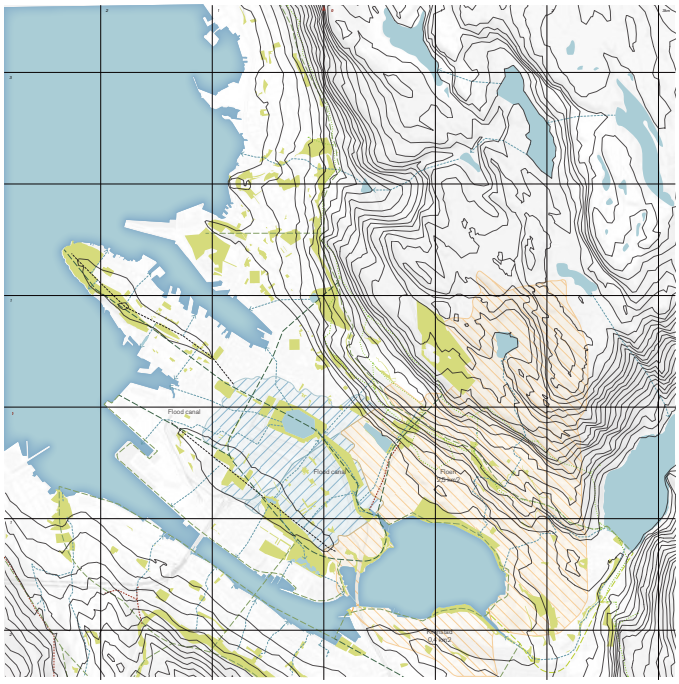
Bergen is located between seven mountains, which means the terrain plays a key role in water system. So the flow analysis is used to guide the repositioning of the drainage system. On water drainage, first consider the use of the existing blue and green space or construct green infrastructure. In the face of intractable circumstances, such as the Sentrum located in a low-lying land for infrastructure and logistic industries, then in consideration of the urban renewal function at the same time opening up new channels to solve the water problem.

Harbors in Bergen are on the one hand threatened by the waves, on the other hand threatened by the water flow inside the city due to the terrain. They can be exempted from risks by constructing coastal flood protection interventions and adding water storage and drainage projects.

In response to the possibility of landslides, stabilization of soils and protection of infrastructure through the construction of retaining wall and caisson pills and increased planting of vegetation.

Fig. 80. Blue & green corridor regarding structure combining with terrain in Bergen centre(map)
By author based on Bergen kommune

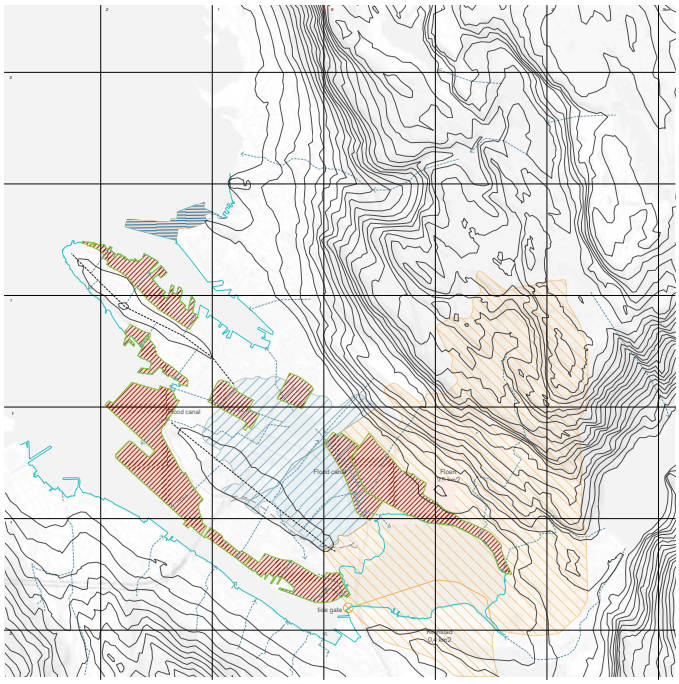
Fig. 81. Water flow regarding structure combining with terrain in Bergen centre (map)
By author based on Bergen kommune



Blue & green corridor regarding structure

- Important high backs
- Sea & surface water
- Green space
- Water flow
- Urban featured blue-green corridor connection
- Green traces
- Open waterways
- Ecological corridor

80



Water flow regarding structure

- Important high backs
- Sea & surface water
- Urban transformation considering water catchment
- Folw direction of rivers & steams
- Important meeting between valley and sea
- Catchment with gentle sloop
- Catchment with steep sloop
- Tide gate

81

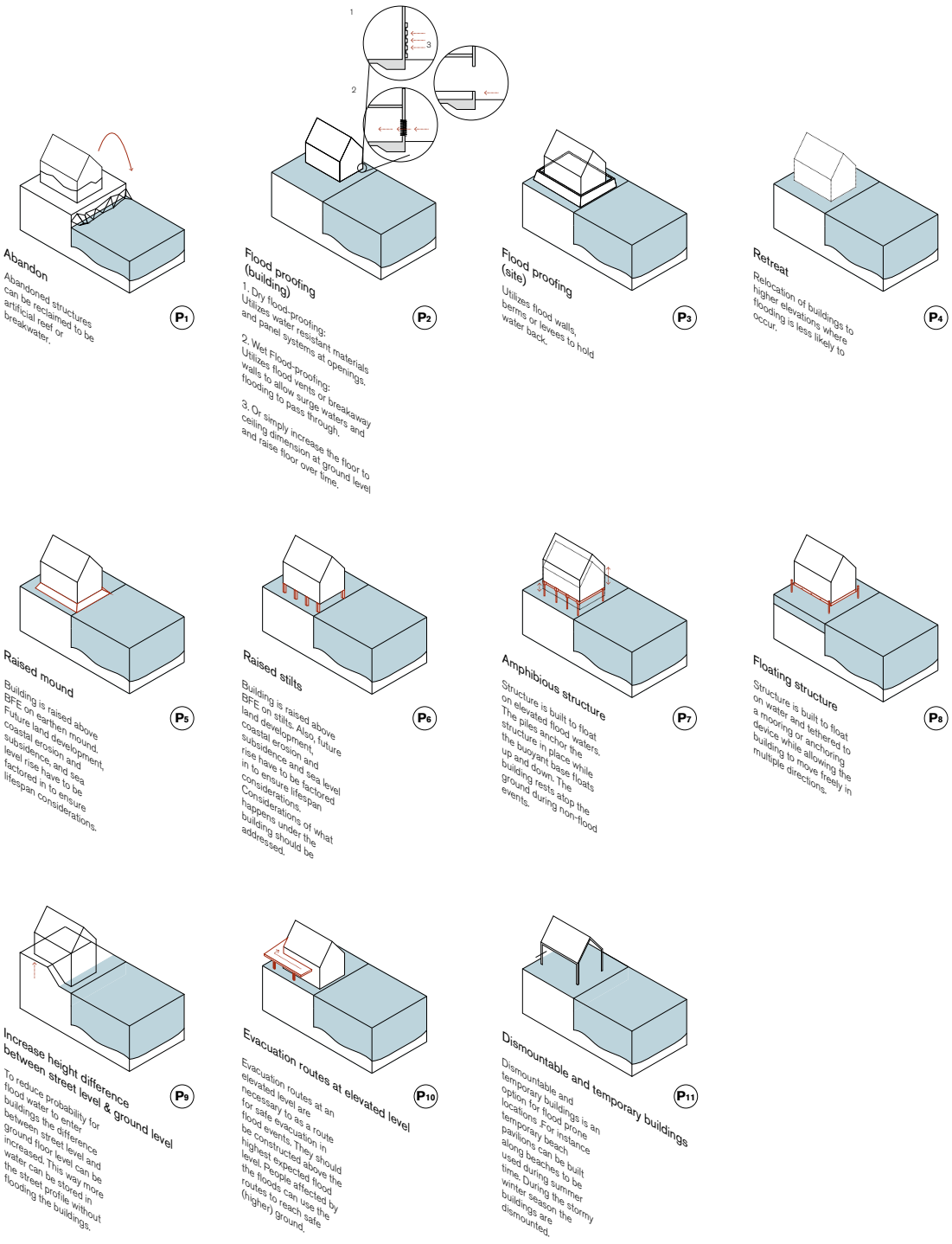


Fig. 82. Precaution measure of buildings in the high risky area
By author

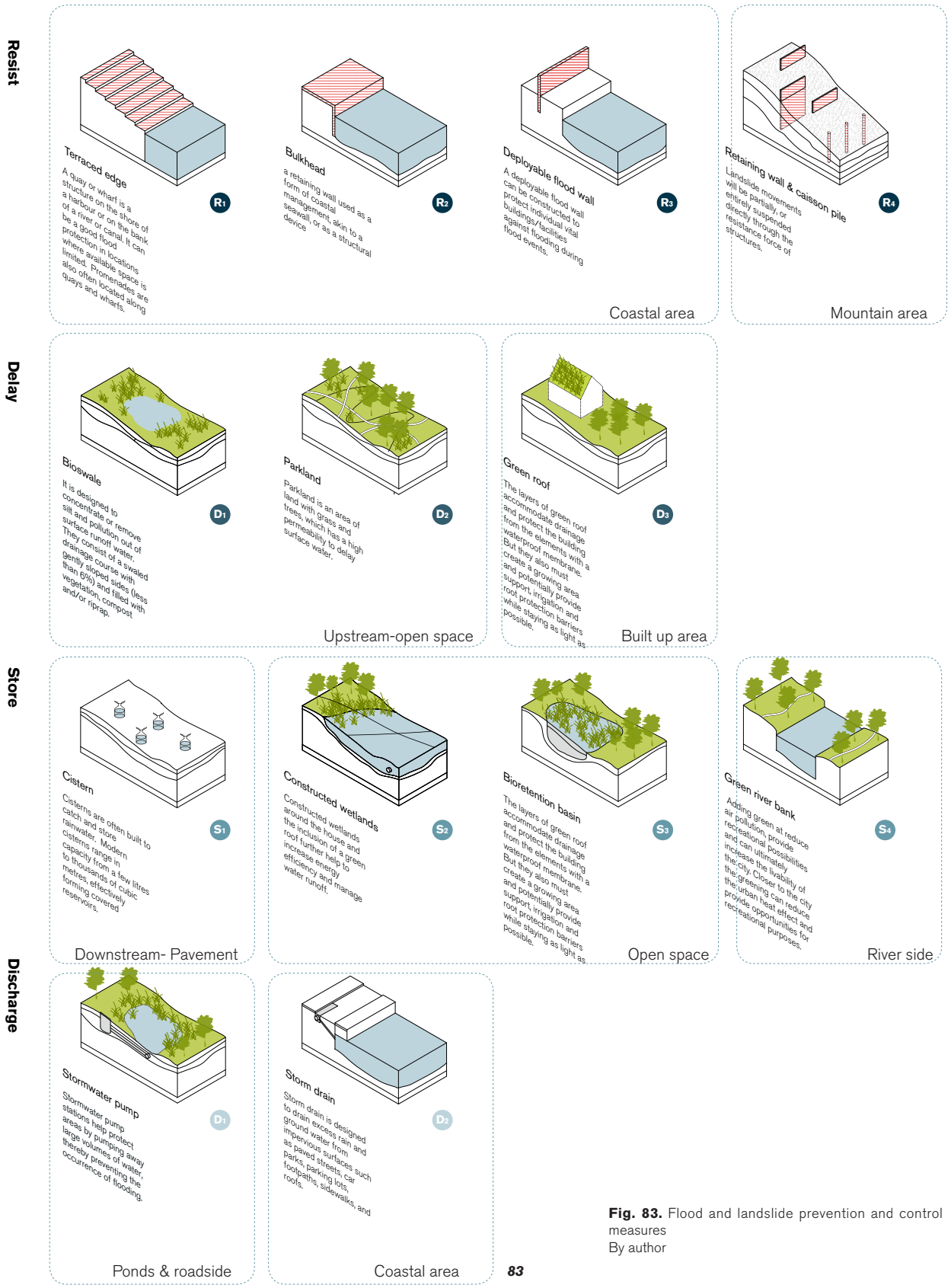


Fig. 83. Flood and landslide prevention and control measures
By author

146

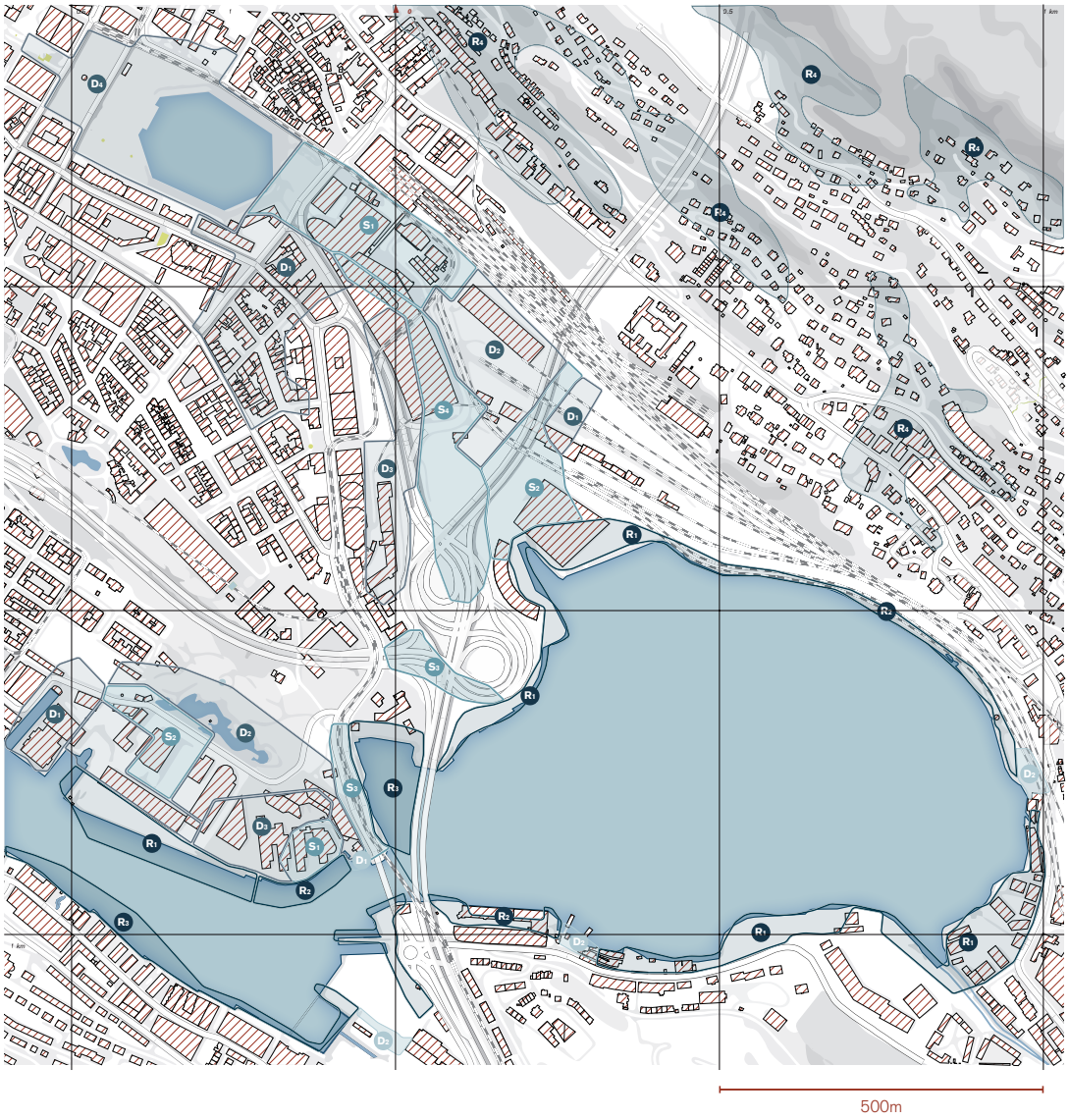


Fig. 84. Application of risk prevention and control (map)
By author

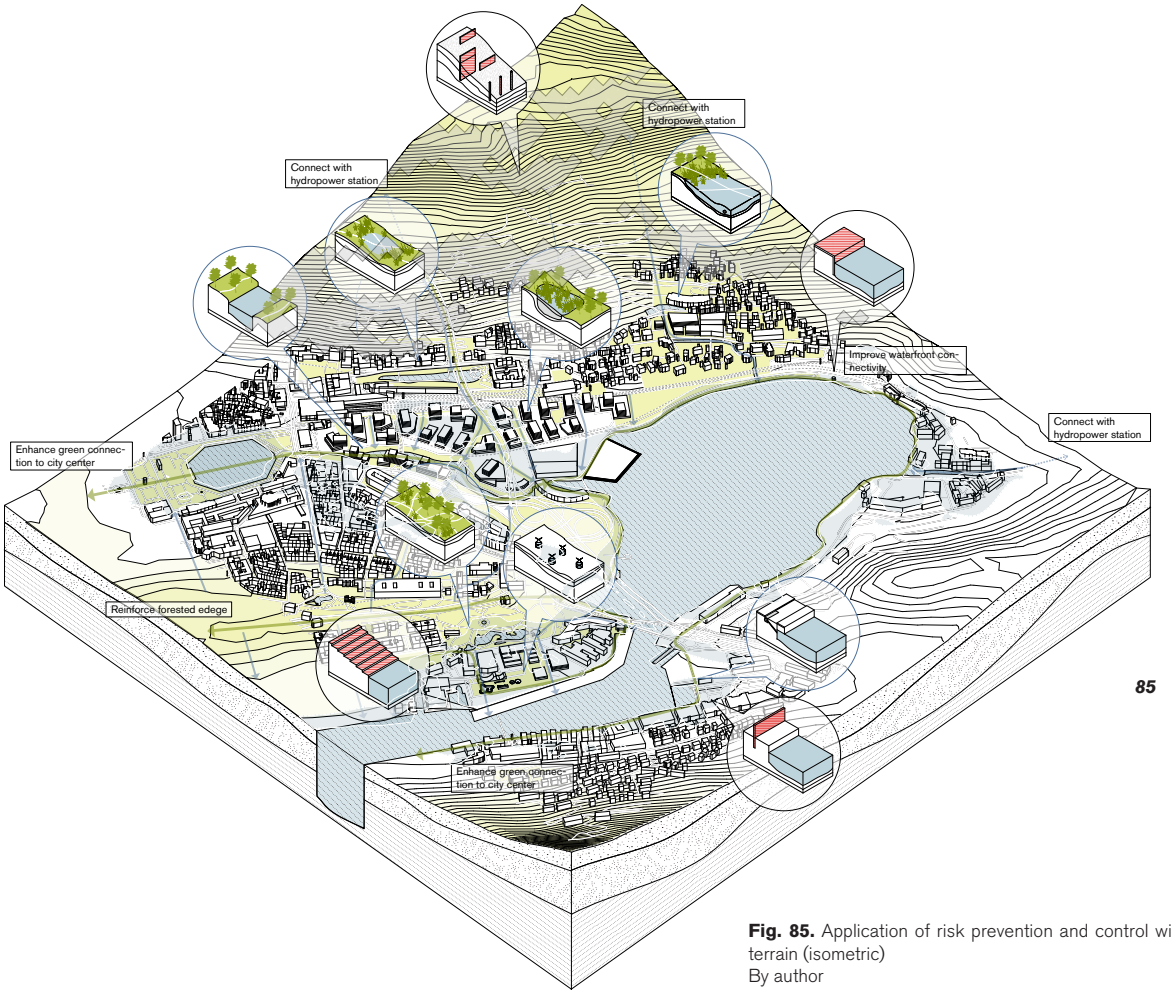


Fig. 85. Application of risk prevention and control with terrain (isometric)
By author

The blue and green connection will be restructured according to the flow accumulation and surrounding conditions. In the harbour area, more attentions need to be paid on flood prevention and water discharge. In addition, due to the low land situation, water storage is quite important, which could store flood peak flow and extreme precipitation and discharge or recycle after the peak time.

The same as other coastal region. In the central area, more water will accumulate due to two high back besides. Thus, a new canal will be constructed between Lille Lungegårdsvannet and Store Lungegårdsvann to store and discharge more water. In mountain area, the capacity of reservoirs will be expanded and the rivers and headwaters will be improved.

Also, through the projection of potential landslide and snow slide, the high-risk areas will be reinforced by retaining wall and caisson pile. Meanwhile, trees and vegetation play the crucial role of preventing landslides, which cannot only reinforce and dry soil, but also in directly obstructing rock fails.

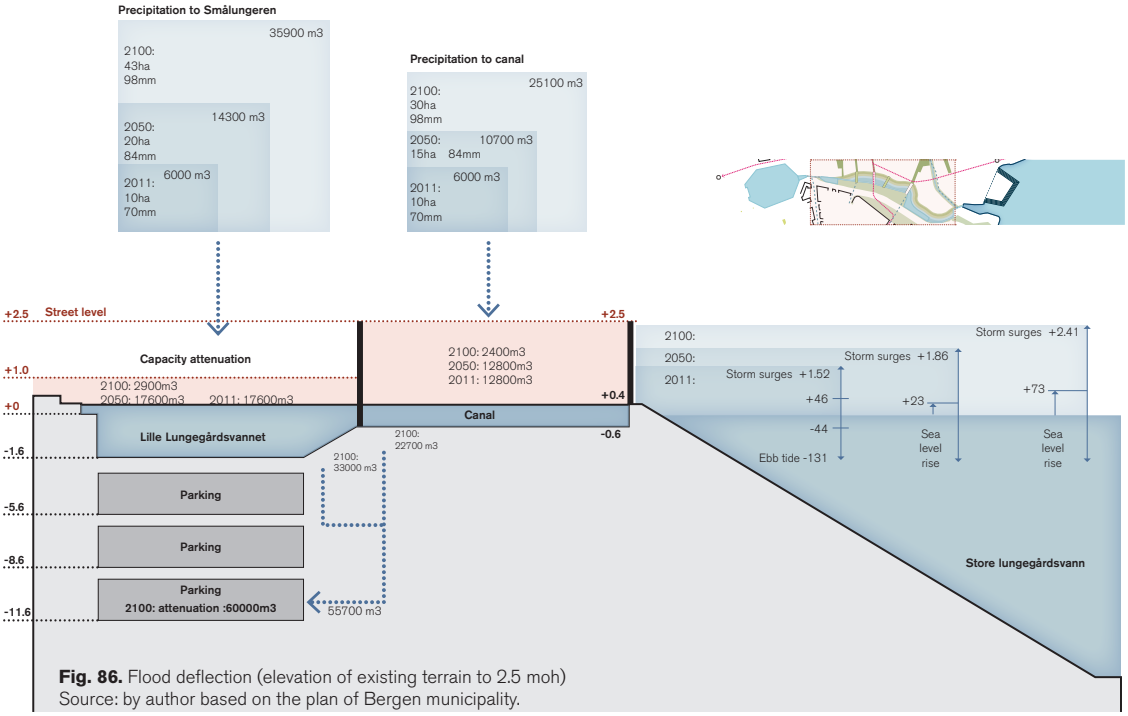
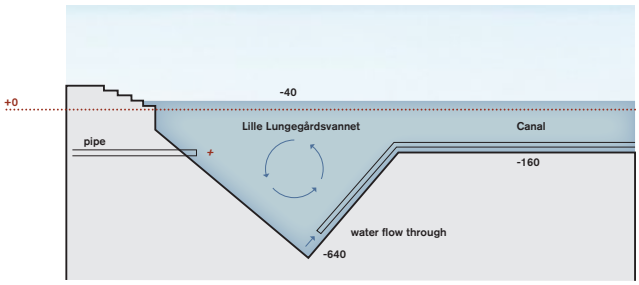


Fig. 86. Flood deflection (elevation of existing terrain to 2.5 moh)
Source: by author based on the plan of Bergen municipality.

148

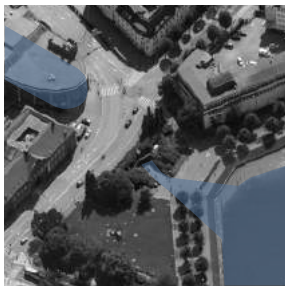
				2011		2050		2100	
Sea-level rise						0.30		0.90	
Precipitation intensity,% of 1982 - 2002				100%		120%		140%	
Main feature	**width m**	**length m**	**bottom moh**	**Start level (moh)**	**volum (m3)**	**Start level (moh)**	**volum (m3)**	**Start level (moh)**	**volum (m3)**
Distribution volume									
Smålungeren	171	171	-2.00	0.4	17600	0.4	17600	0.9	2900
Lungegårdkanalen		565		0.4	12800	0.4	12800	0.9	2400
Sum					**30400**		**30400**		**5300**
Precipitation - drainage Smålungeren									
Precipitation field Smålungeren				10 ha		20 ha		43 ha	
Duration				6 timer		6 timer		6 timer	
Precipitation 6 hours. 100 years of flood				70 mm		84 mm		98 mm	
Average water flow to Smålungeren, 6 hours - 100 years flow				0.3 m3/s		0.7 m3/s		1.7 m3/s	
Level Smålungeren				0.6 mol		0.9 mol		>2.0 mol	
Volume of dislocation				6000 m3		14300 m3		35900 m3	
Available displacement volume				17600 m3		17600 m3		2900 m3	
Need for additional volume of digestion				**0 m3**		**0 m3**		**33000 m3**	
Precipitation - drainage Lungegård Canal				10 ha		15 ha		30 ha	
Nedbørfelt Lungegård Canal				6 timer		6 timer		6 timer	
Duration				70 mm		84 mm		98 mm	
Dimensional rainfall 6 hours. 100 years of flood				0.3 m3/s		0.5 m3/s		1.2 m3/s	
Average water supply to Lungegård Canal, 6 hours - 100 years flow				1.4 mol		2.2 mol		>2.5 mol	
Largest level Lungegård Canal				6000 m3		10700 m3		25100 m3	
Volume of dislocation				12800 m3		12800 m3		2400 m3	
Available displacement volume				**0 m3**		**0 m3**		**22700 m3**	
Need for additional volume of digestion									

On the basis of the calculation, it can be concluded that Smålungeren withstand up to 30 cm sea level rise of contour 1.00 (2050).



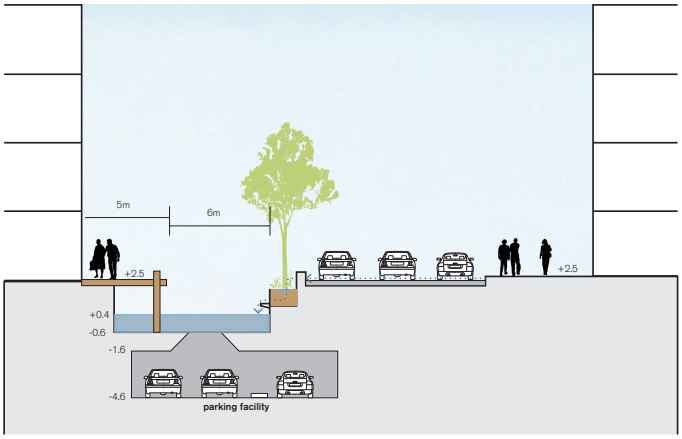
87

Fig. 87. Principle of the water in Lille Lungegårdsvannet
Source: by author based on the plan of Bergen municipality.



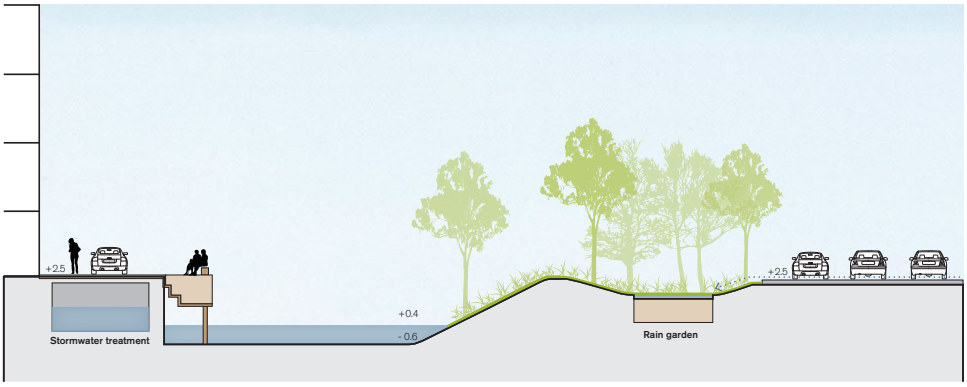
88

Fig. 88. Pedestrian walkway can be "reused" as a channel.
Source: by author based on the plan of Bergen municipality.



89

Fig. 89. Principle of canal and underground parking facility between Lille Lungegårdsvannet and Store Lungegårdsvann.
Source: by author based on the plan of Bergen municipality.



90

Fig. 90. Principle of water management along canal.
Source: by author based on the plan of Bergen municipality.



Fig. 91. Master plan of centre axis (map)
By author



92

Screen A - The water connects Lille Lungegårdsvannet the canal, which provides a quiet and comfortable atmosphere.

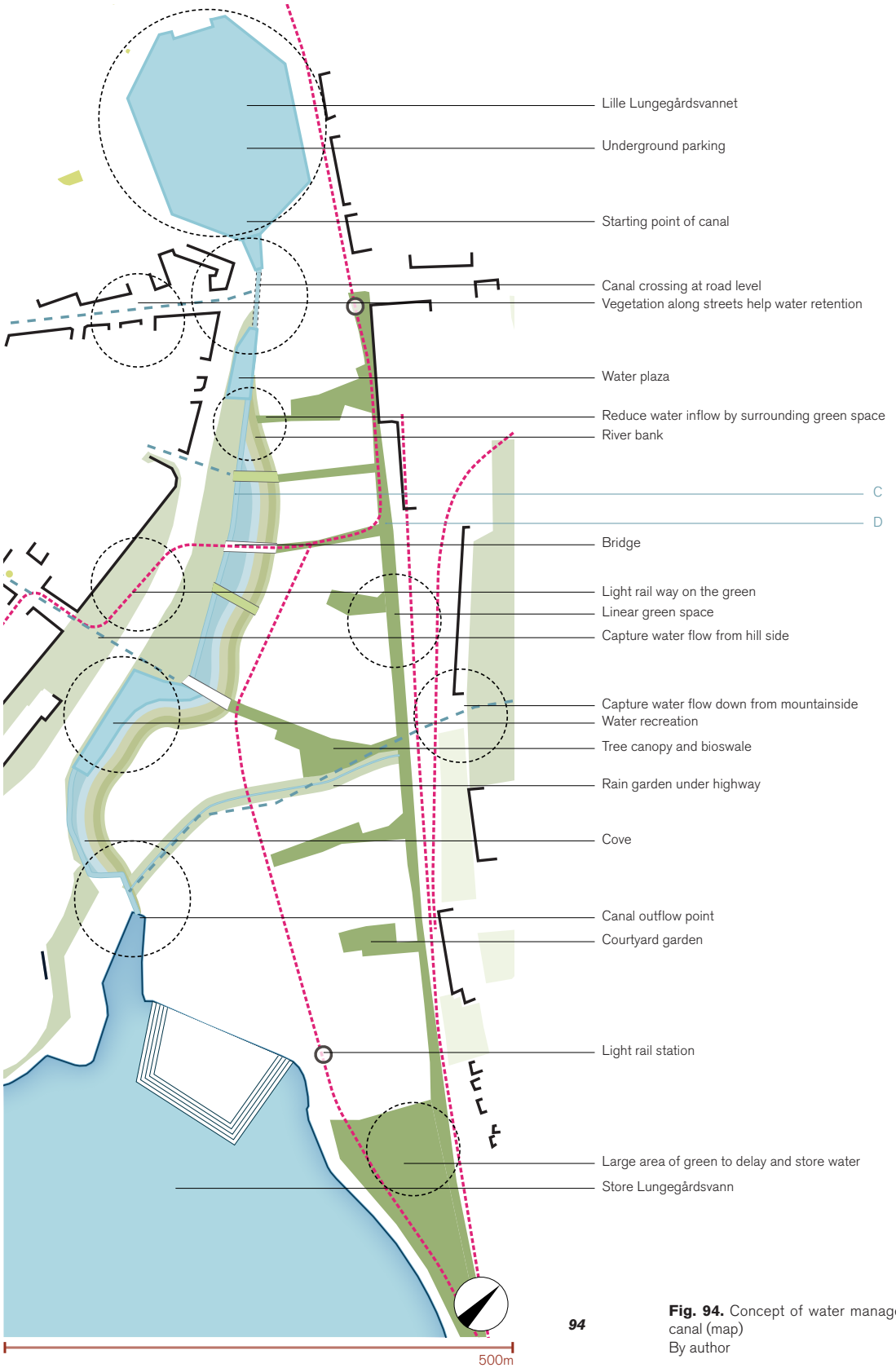
Fig. 92. Screen A - Water level along the main road (perspective)
By author



93

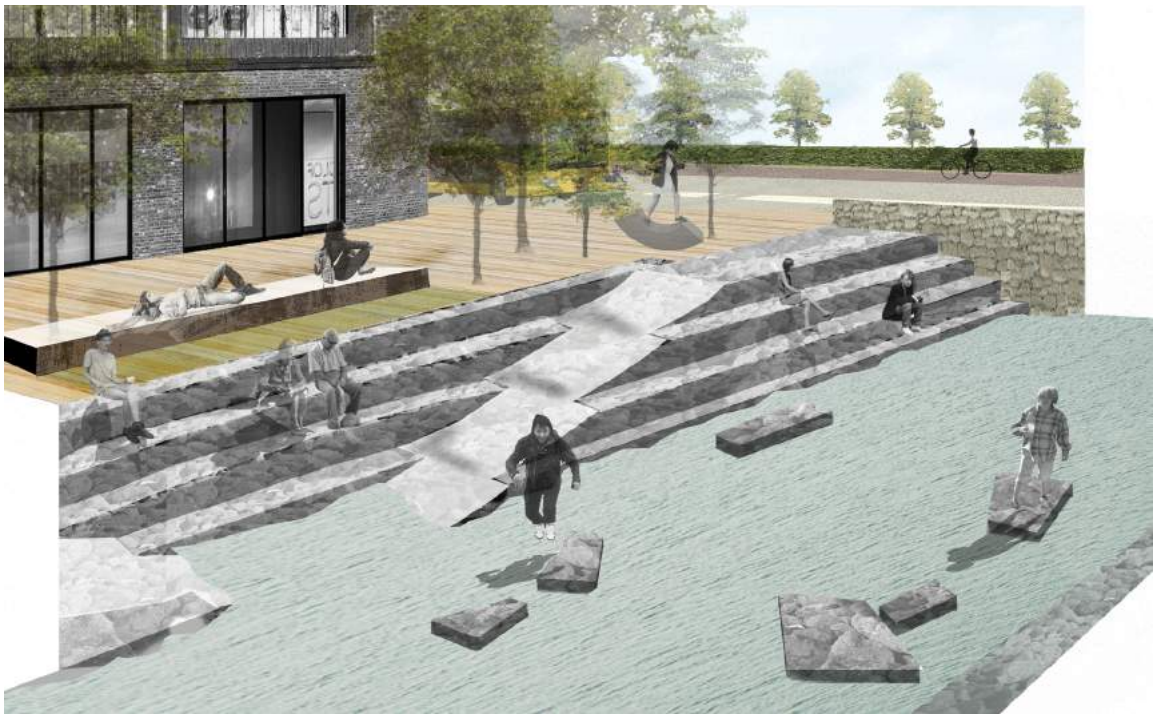
Screen B - Along with the canal, one side is the linear plaza and shopping street and another side is the open green space.

Fig. 93. Screen B - linear plaza along canal (perspective)
By author



94

Fig. 94. Concept of water management along central canal (map)
By author



95

Screen C - Water square provides leisure and recreation space.

Fig. 95. Screen C - Water square (perspective)
By author



96

Screen D- New light rail way on the green connects the built environment and green open space.

Fig. 96. Screen D - Light rail way on green (perspective)
By author



Fig. 97. Detailed design of risk prevention and control in local scale (isometric)
By author


Green river bank
S4
Permeable pavement
Roof garden
Canal
Linear park
Bioswale
Rain garden
Water deck
Stormwater filter
Parkland
D2
Retaining wall & caisson pile
R4
D3
River
Green roof

155

3.3.2
TO BE ENERGETIC

Current district heating in Bergen

District heating has replaced polluting oil boilers and makes a substantial contribution to cleaner air in Bergen. Increasing energy recovery from waste as a substitute for fossil fuel is a national goal. The heat from waste is regarded as renewable because it is waste heat.

A district heating system is a centralised heating system that supplies a city district or multiple buildings with heat and hot tap water. District heating is a flexible platform. Regardless of which energy source produces the most surplus heat or is the most environmentally friendly to use in the future, all of them will be able to heat water.

Bergen is aiming to continue to expand the district heating network in Bergen and are planning for further growth.

City of the future

According to the International Energy Agency (IEA), the whole city Bergen has a high potential for energy efficiency. By using modern, available technology, energy equivalent to 29 per cent of the city's stationary energy consumption can be saved within the following areas:

Bergen Municipality

- Housing	*731 GWh*
- Commercial properties	*496 GWh*
- Industry	*145 GWh*
- Street lighting	*14 GWh*
- Upgrading the electrical grid	*53 GWh*
Total	*1339 GWh*

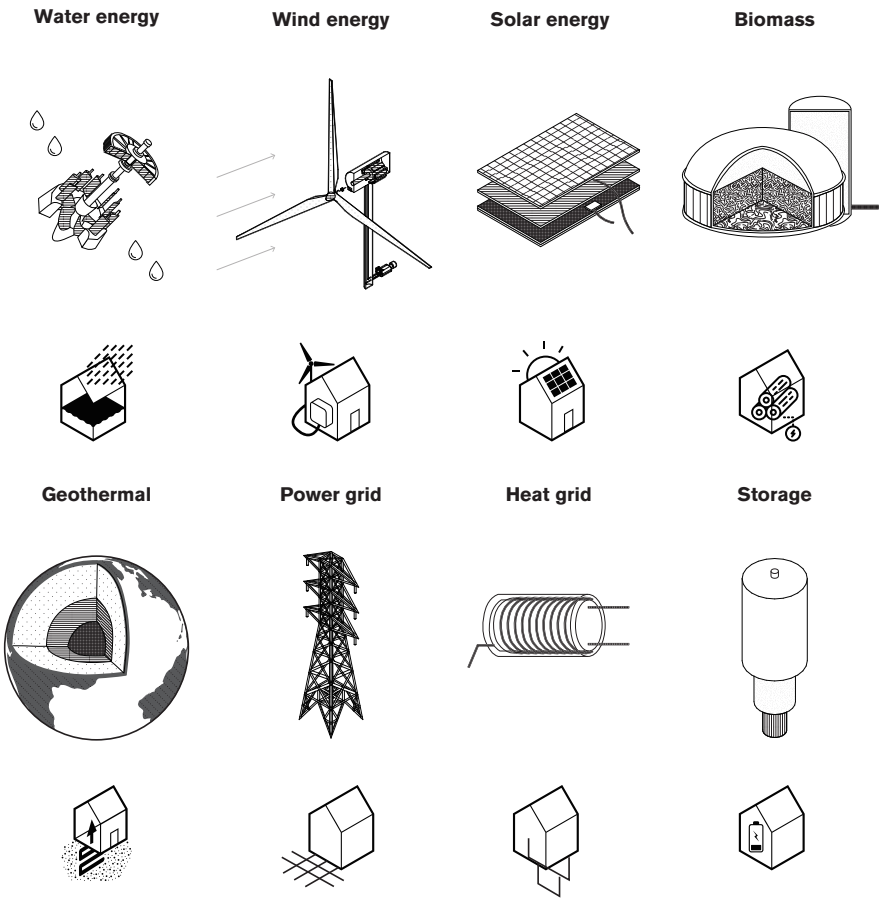
Based on the estimation of IEA, the local area of Bergen has the potential save energy consumption in:

Local area of Bergen (selected area)

- Housing	*21 GWh*
- Commercial properties	*81 GWh*

By accelerating access to reliable and clean energy, there is more potential to be self-efficient.

Fig. 98. Renewable energy tools
By author based on POSAD


Water energy
Wind energy
Solar energy
Biomass
Geothermal
Power grid
Heat grid
Storage

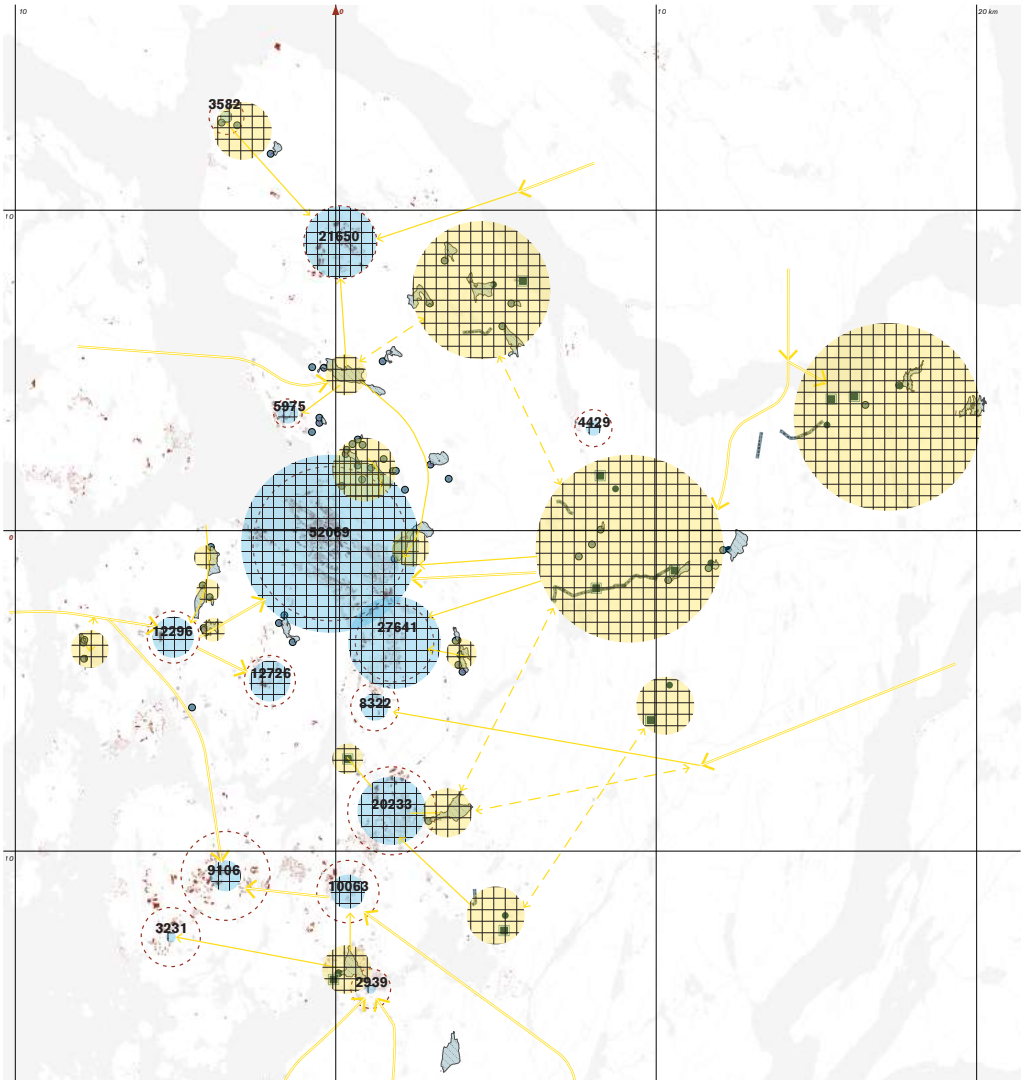
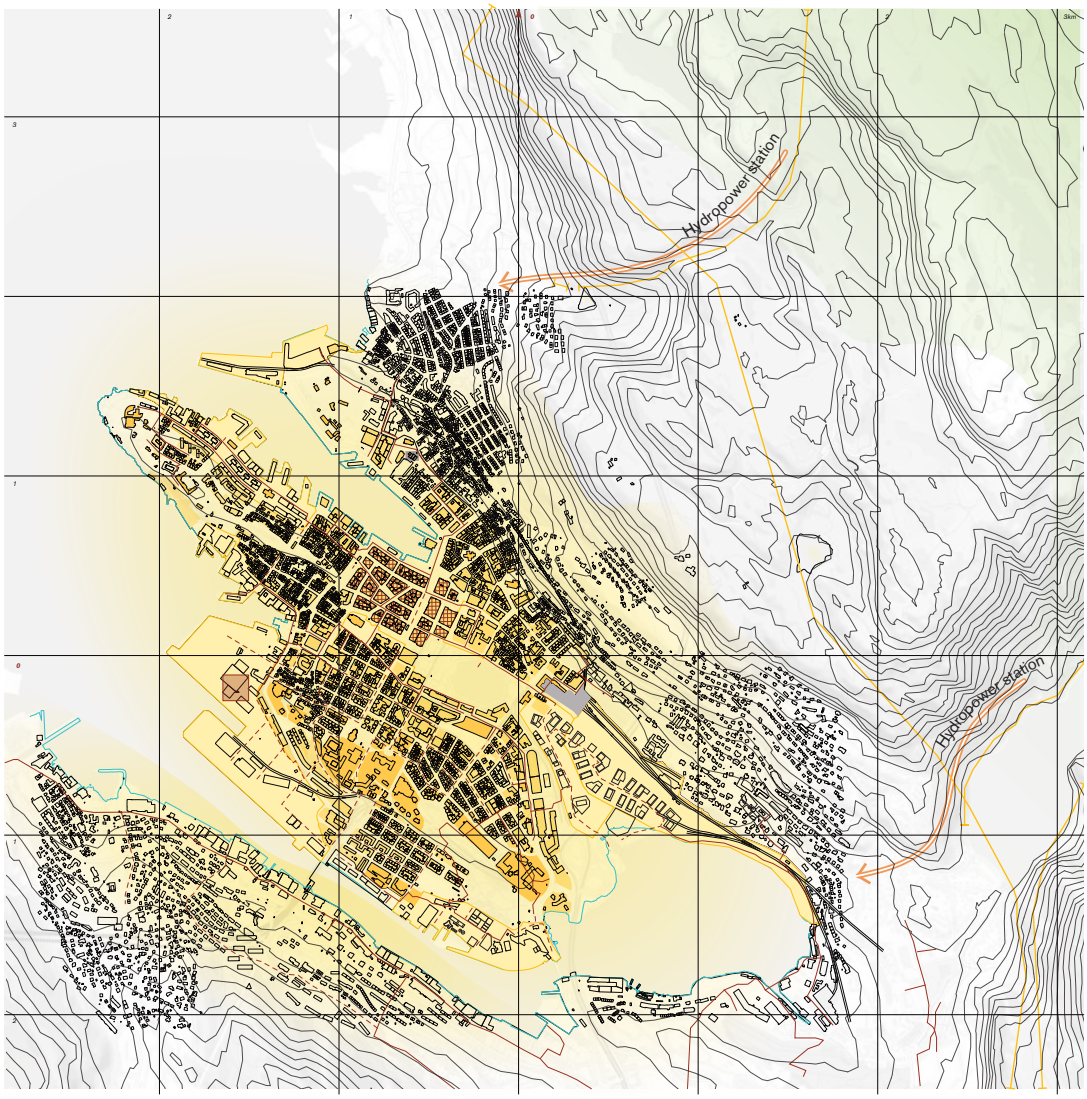


Fig. 99. Energy system combining with terrain in Bergen centre (map)
By author based on Bergen kommune

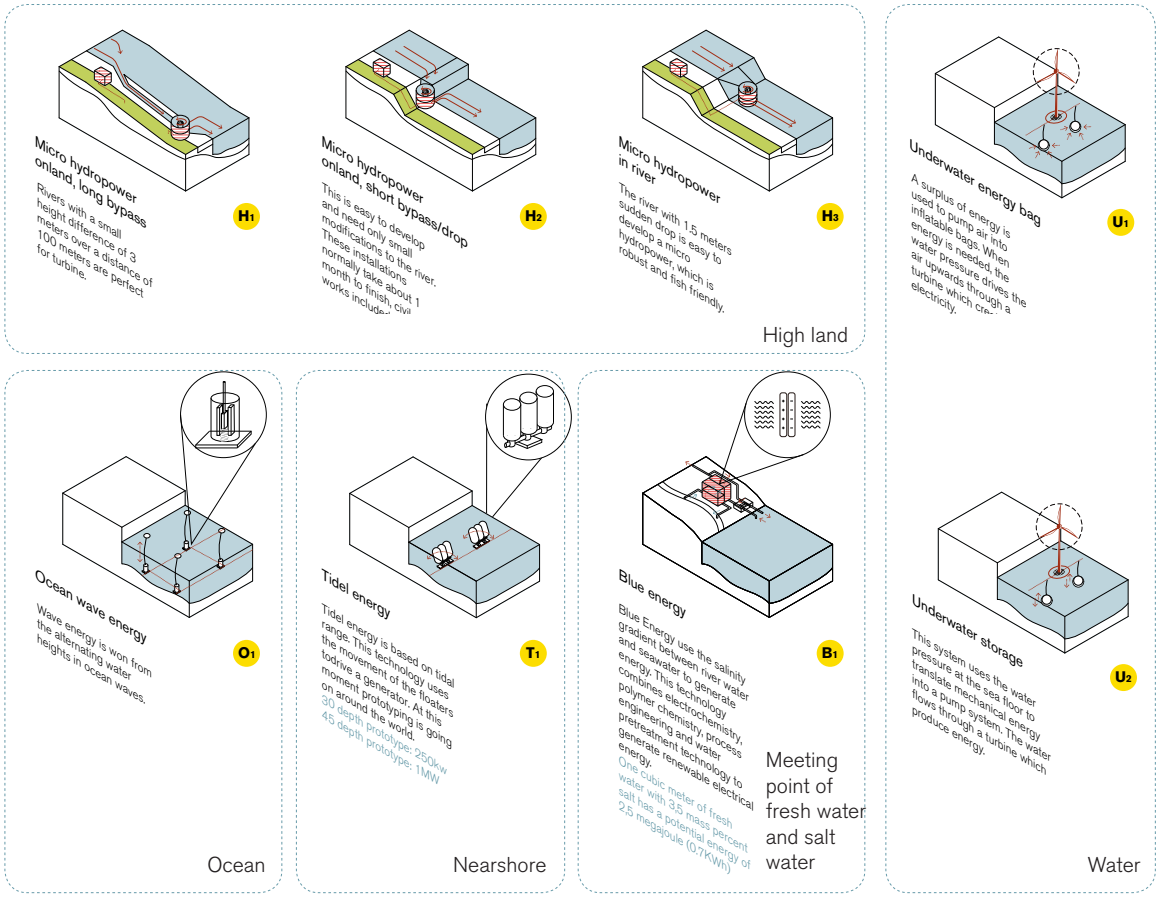
Fig. 100. Energy balance in Bergen municipality (map)
By author based on SSB



Energy consumption and generation structure

- High voltage power line
- Imported energy from hydropower station
- Hydropower location (between mountains)
- Centralized energy consumption
- High efficiency buildings (transformation area)
- Energy saving buildings (residential)
- Energy saving buildings (public buildings)
- District heating system in progress
- District heating system in future
- Power station

Water energy



Other energy

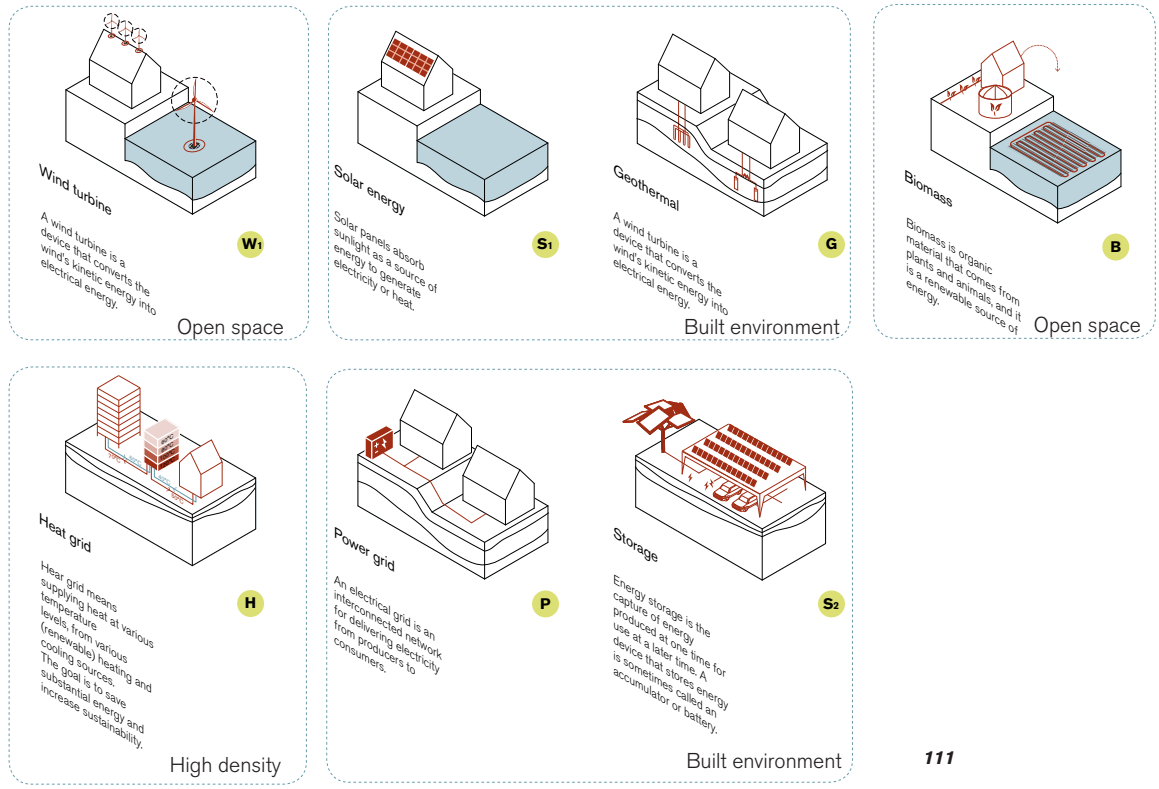


Fig. 111. Water & other renewable energy production interventions
By author

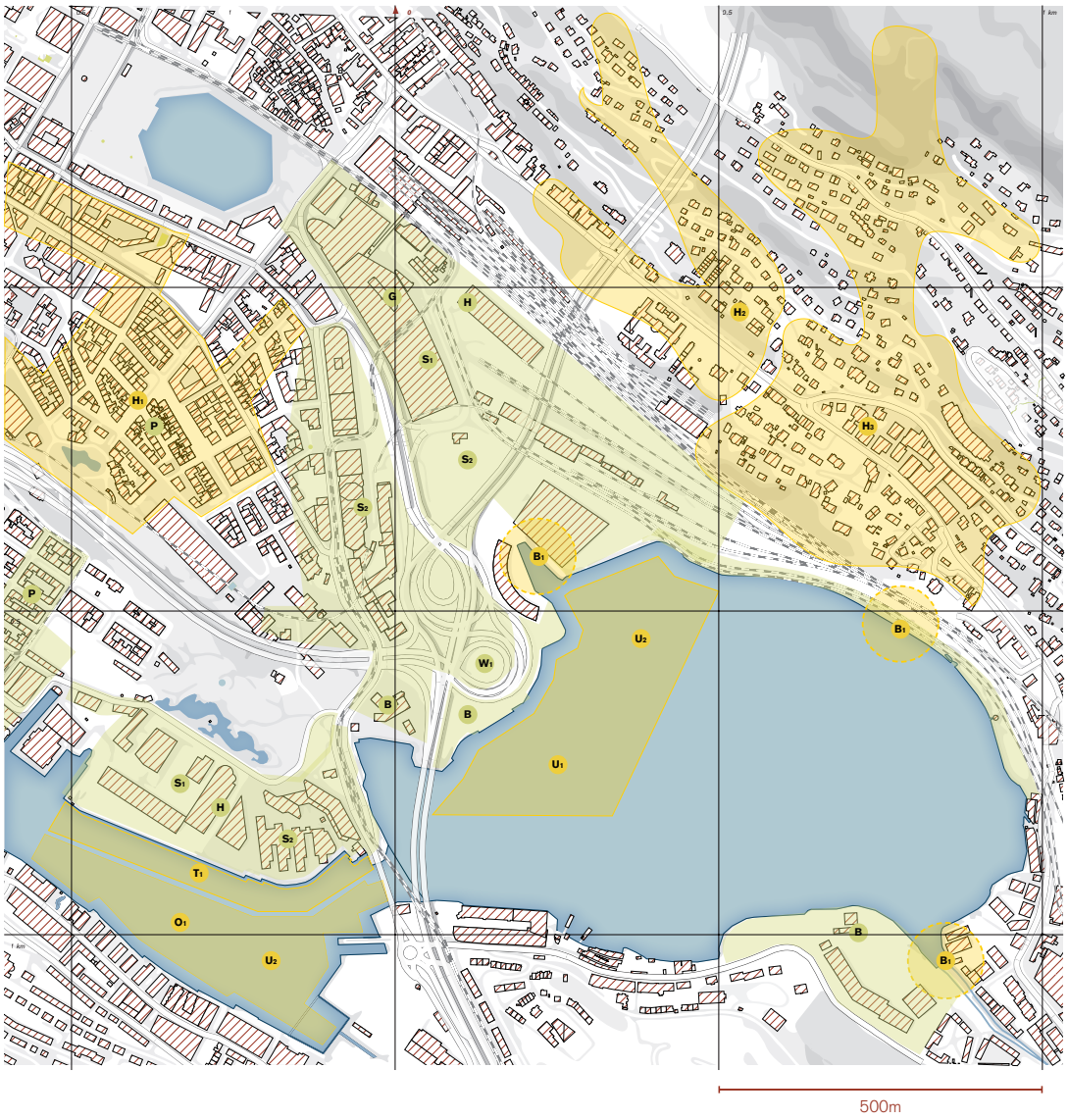


Fig. 112. Application of energy production interventions (map)
By author

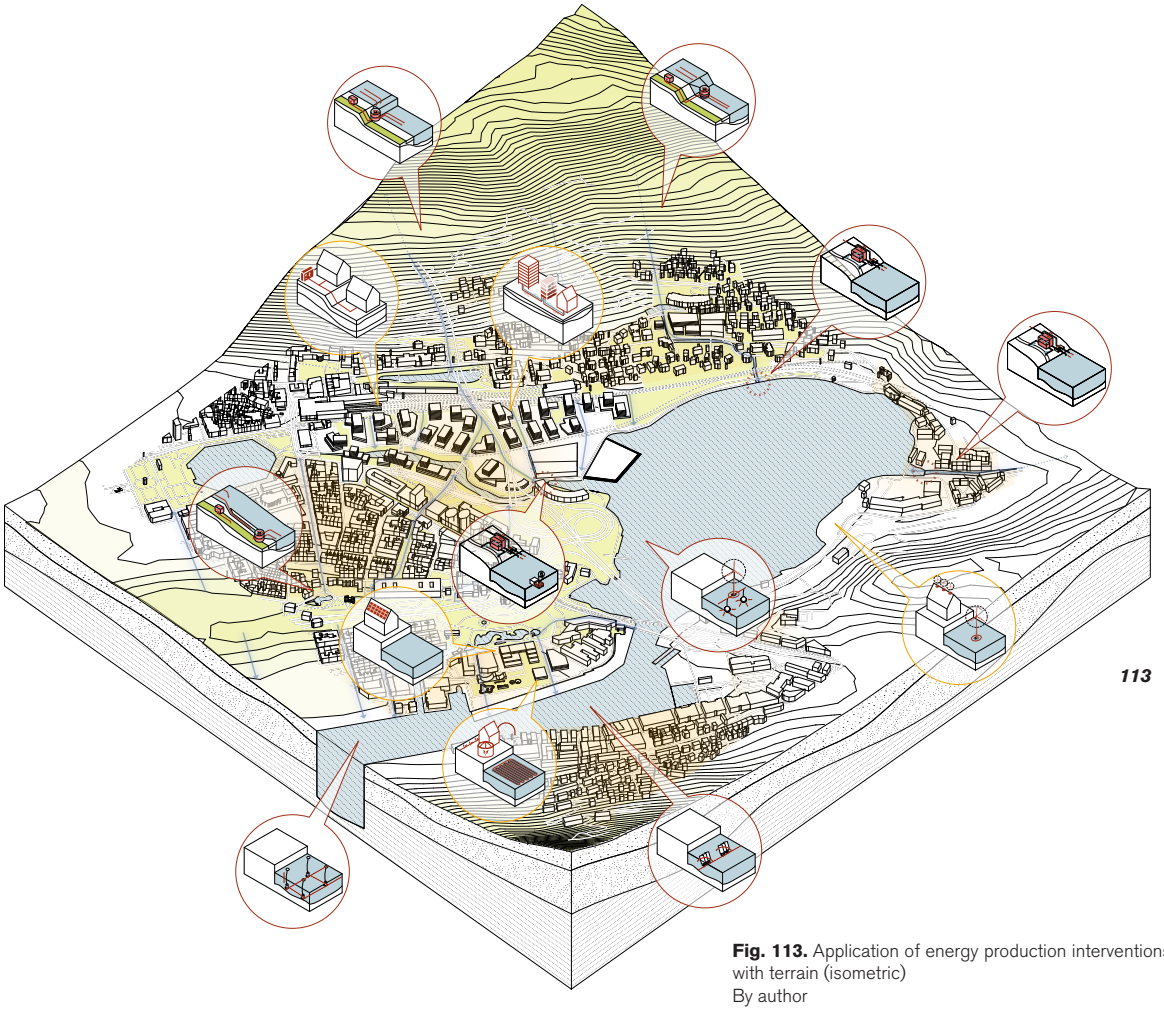
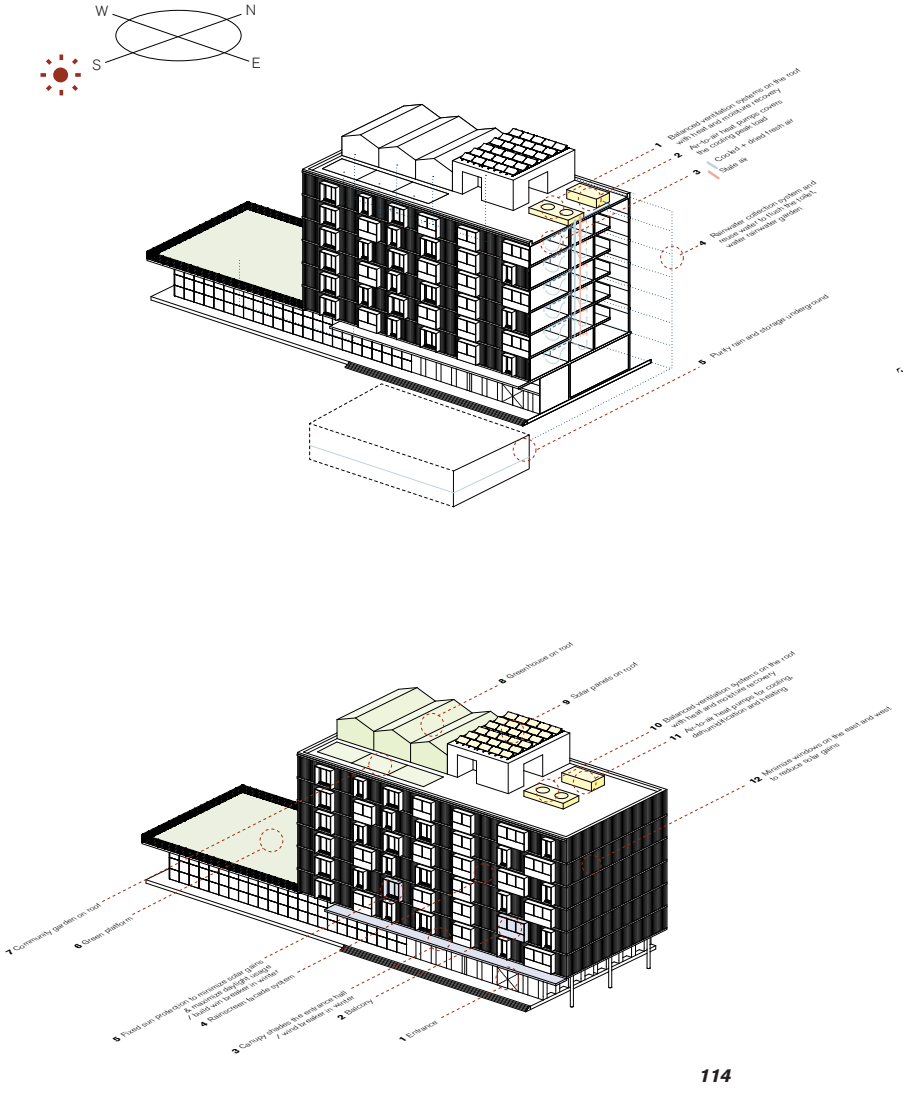


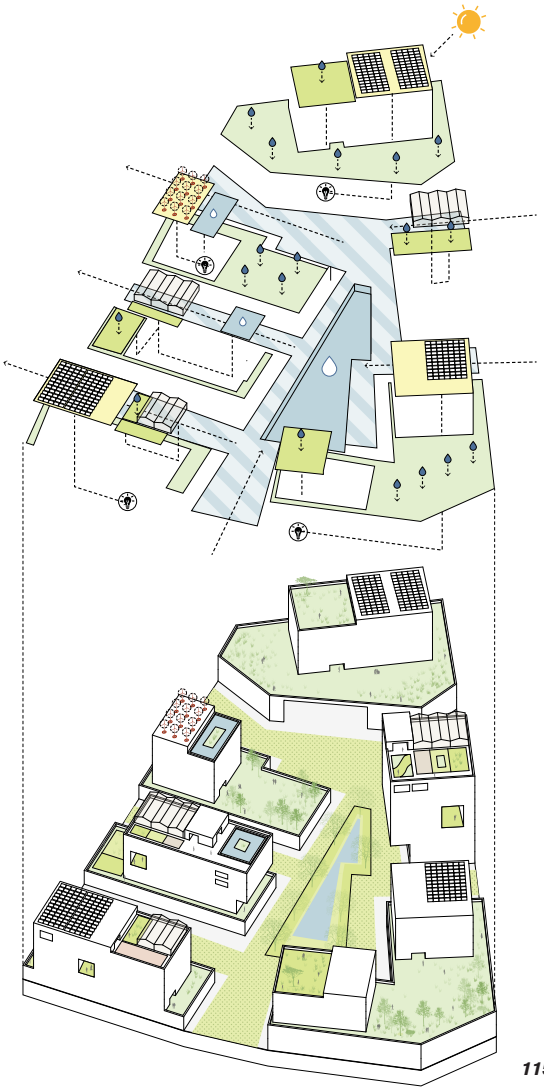
Fig. 113. Application of energy production interventions with terrain (isometric)
By author

According to the new structure of water management, more water-energy-production intervention can be applied to generate more energy from the sea level rise and increasing rainfall. For example, in the sea water and near-shore area, more ocean wave energy and tidal energy can be achieved to generate electricity. In terms of the hydro power, more micro hydro power plants can be placed along the water flow which only needs a small height difference of 3 meters over a distance of 100 meters or 1.5 meters sudden drop and will not harm the local ecosystem by using low-pressure design. The existing reservoir and hydro power station will be enhanced and expanded. And the whole hydro power system will collaborate together to serve people. Finally, these water will flow to sea which could also be utilized to generate energy by blue energy at the meeting point of fresh water and salt water. Other tools will also be applied to assist, like solar energy, wind energy and biomass.

In addition to generate more energy from the changing climate, a lot of energy can be saved from concentrated energy-consumption area by using the heat grid and the power grid in the built up area.



114



115

Fig. 114. Zero-emission passive building
Source: by author refer to Peter Ruge Architekten.

Fig. 115. Energy and water flow in a block
Source: by author refer to DELVA Landscape Architects.

Energy can be saved from the building (insulation / replacement of roof, walls and doors), sanitation (showers / fittings), heating (adjustment of heating system in combination with water purification, heat pump and etc.), cooling (automatic external sun shades, cooling system), ventilation (heat exchanger for ventilation, ventilation system), lighting, control and regulation (Energy management system, Central operational control unit, Precipitation control of snow melting system, Thermostat and time-controlled electric heating, Automatic time control of water-based heating,Reduced internal temperature).

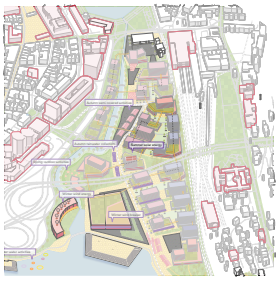




Fig. 116. Detailed design of energy production in local scale (isometric)
By author


Energy storage
Pasive building
Power grid
Heat grid
Solar energy
Wind energy
Blue energy
Heat grid
Hydropower
Solar energy
Blue energy

165

3.3.3
TO BE SEASONAL

Although climatic changes under the general trend towards 2050 is to become more drastic, the trends in different seasons might deviate.

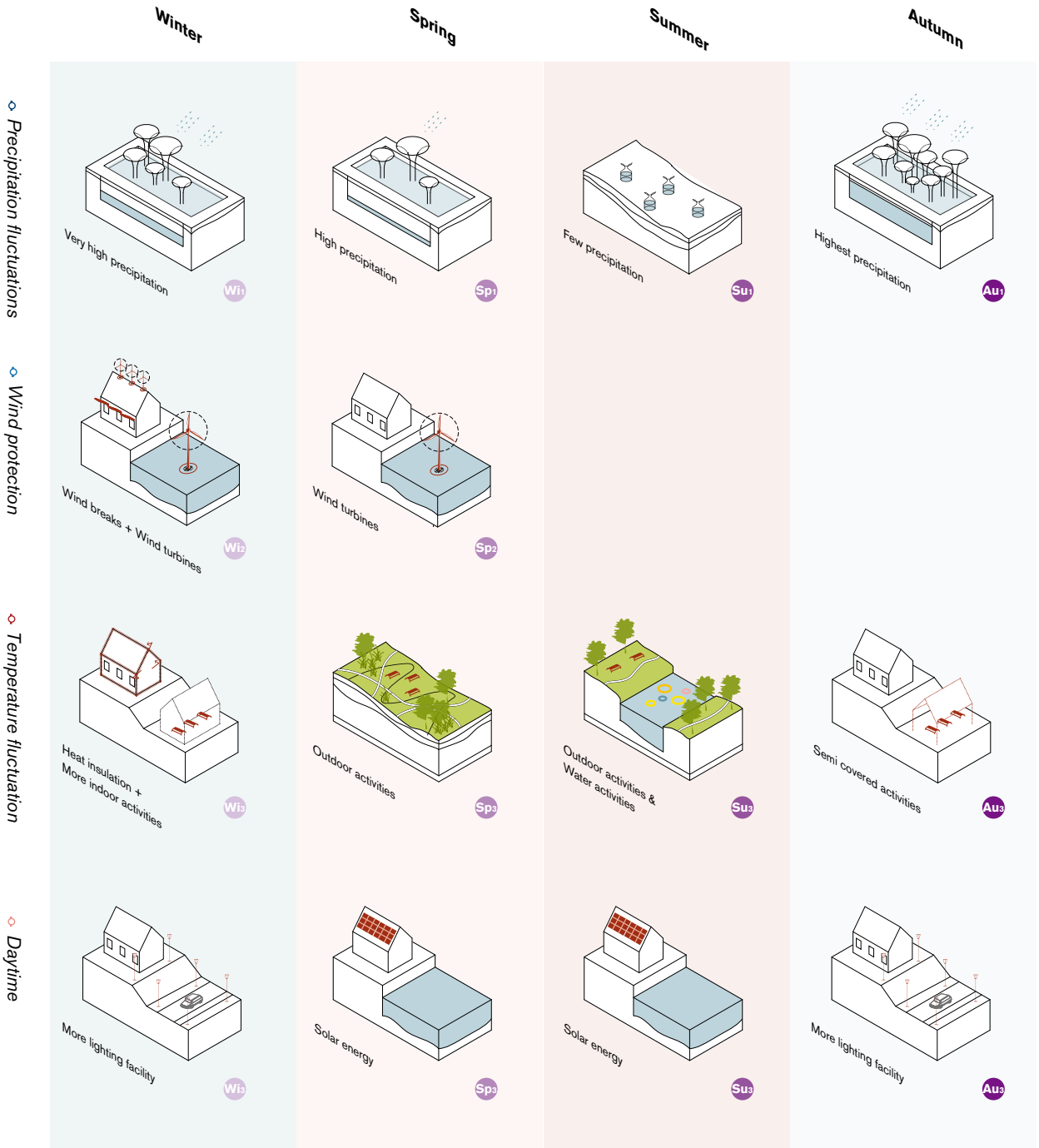
In winter, there is more precipitation. Thus more rainwater collections can be applied. And, due to the strong wind, more wind turbines can be put in the open space. But meanwhile, more attentions need to be paid on wind protection like the wind breaker attached to the buildings. Considering the low temperature, more gas will be used to keep the house warm. Heat insulation measures can be applied to save the energy. More lights are needed due to the short daytime.

In spring, more rainwater, solar energy and wind energy can be collected. The temperature, wind intensity is quite suitable for people to go outside. So, more outdoor activities can be organized.

In summer, there is less rain and wind, which can hardly generate energy. But longer daytime offers more solar energy. And, the high temperature makes the water activities popular. So the riversides, shorelines, water, sea need more attention.

Autumn is season which has the most precipitation during a year. More rainwater collection measure should be applied to store and generate energy. Also, the temperature is quite pleasant to have outdoor activities. Thus semi open temporary pavilions are suitable. But considering the short duration of day light, more lights are needed.

Fig. 117. Seasonal interventions considering climatic variation
By author


Winter
Spring
Summer
Autumn
Precipitation fluctuations
Wind protection
Temperature fluctuation
Daytime
Very high precipitation
Wi1
High precipitation
Sp1
Few precipitation
Su1
Highest precipitation
Au1
Wind breaks + Wind turbines
Wi2
Wind turbines
Sp2
Heat insulation +
More indoor activities
Wi3
Outdoor activities
Sp3
Outdoor activities &
Water activities
Su3
Semi covered activities
Au3
More lighting facility
Wi3
Solar energy
Sp3
Solar energy
Su3
More lighting facility
Au3

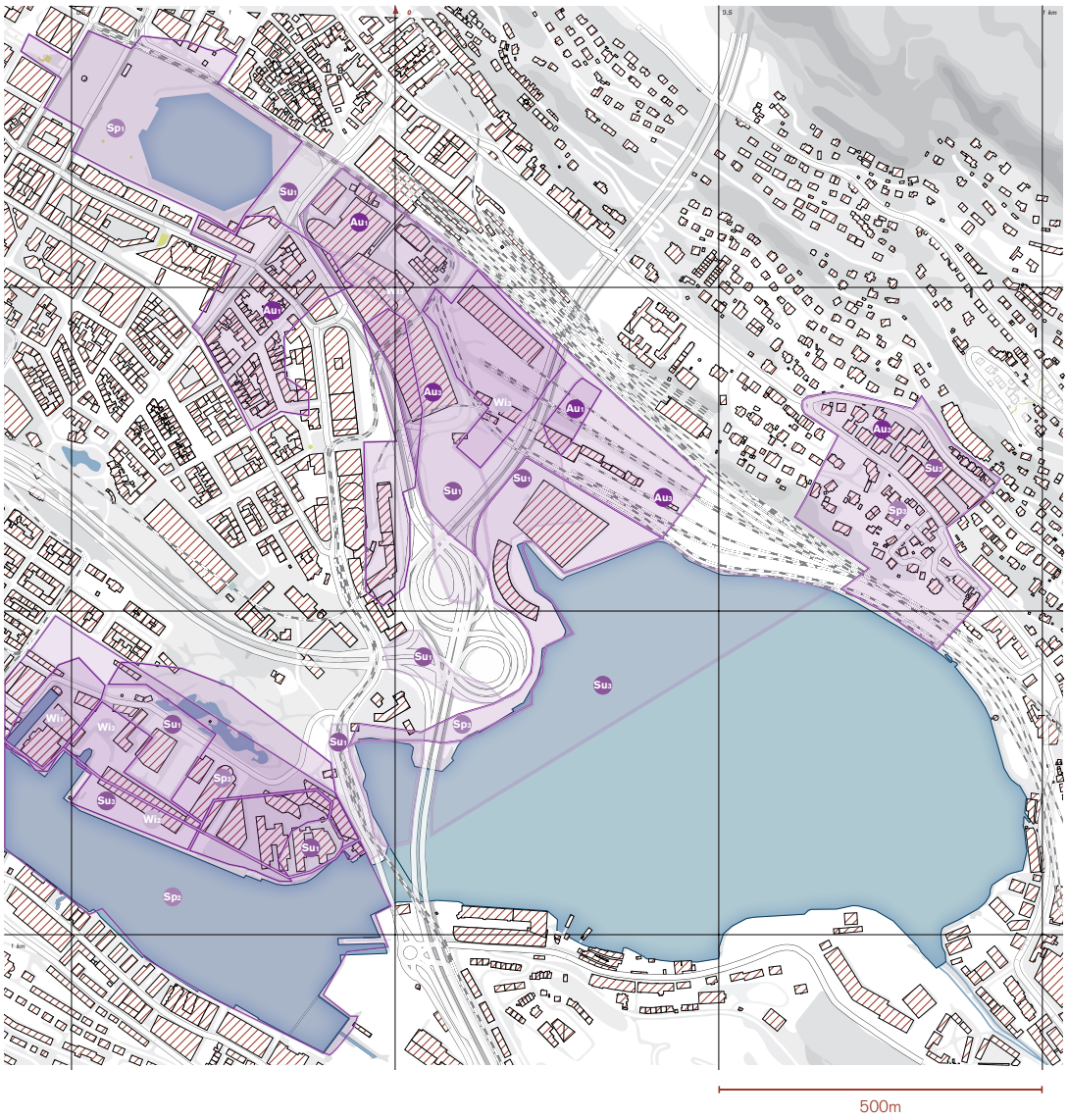
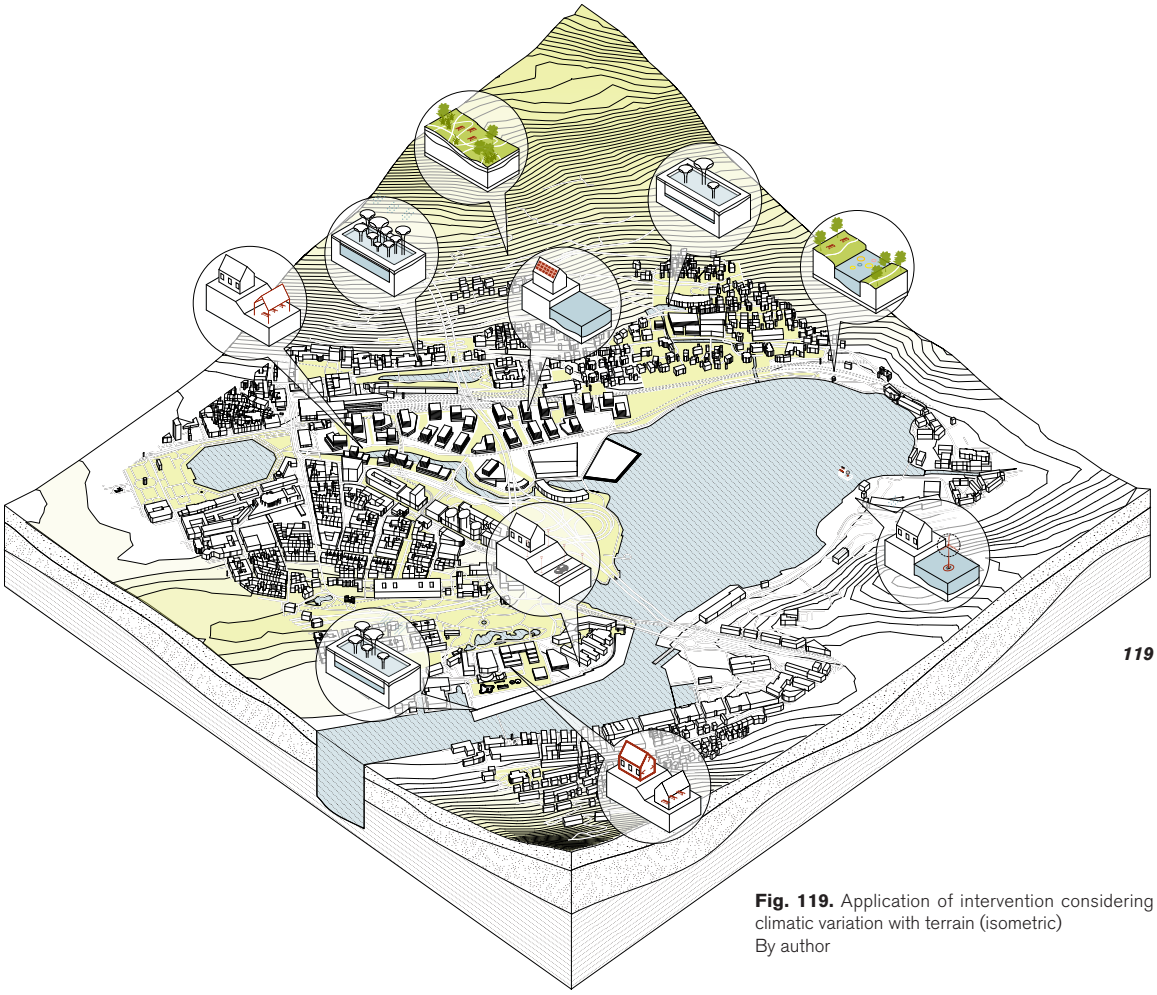


Fig. 118. Application of intervention considering climatic variation (map)
By author



119

Fig. 119. Application of intervention considering climatic variation with terrain (isometric)
By author

Due to the complex topography, there is limited space to develop. Thus, it is useful to change different intervention on the limited space according to different environmental conditions in a year. For example, in winter, more rain-water can be collected by water storage underground and temporary collection system. While in summer, the underground storage is sufficient. So more space can be provided for other facilities or urban activities.

In addition, in winter, more energy consumption will happen like lightning and heating. But more wind energy and rainfall can be ge collected to make ends meet in the energy balance. In summer, it is important to minimize solar gain and maximize daylight usage by fixing sun protection in order to reduce energy consumption to cool the house and meanwhile to gather more solar energy through solar panels and solar field.

Devices that can be flexibly mobilized provide efficient and reasonable allocation of resources for limited space.



Fig. 120. Detailed design of climatic variation in local scale (isometric)
By author


Autumn-semi covered activities
Autumn-rainwater collection
Summer-solar energy
Spring-outdoor activities
Winter-wind energy
Winter-wind breaker
Summer-water activities
Spring
Spring-outdoor activities

171

3.3.4
TO BE DYNAMIC

Compare with other places in the city centre, this chosen area is less popular for both tourists and residents, but it has plenty services and educational institutions. Thus, the ambition of this place for future urban development is to become more popular when providing enough housing and services for the future population.

Due to different functions of the three main axises, the building typology, the function of buildings and the relation with the street are quite different.

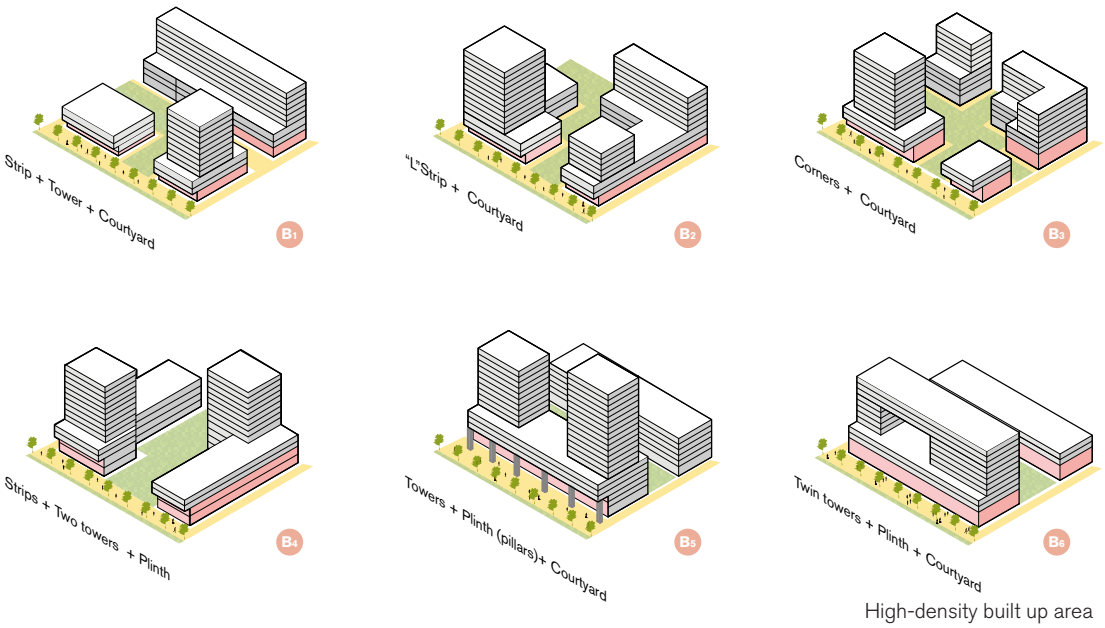
In the harbour area, there are more educational intuitions, research centers and universities. Thus, more public functions like sports space and educational public activities can be applied. In addition, housing might be scarce in the future when more scholars, students, intellectuals, workers, merchants come to the city. And meanwhile, according to the guidance of the municipality, the new buildings along the shoreline should be lower than 16m. Thus, the cascade building is the best, which has a nice view of the waterfront.

In the centre of this area, there were a lot of big-scale but disordered buildings, which hindered the movement of pedestrian and cyclists. Thus, the new plan is to remove the logistics and freight railway and rebuild new public buildings, housing and office to activate this area. Due to the complex topography of Bergen, there is limited space for development. If this large-scaled buildings can be reorganized and to be more compact, more place can be provided for future development. And meanwhile, it is also essential to minimize the potential risk from precipitation and sea-level rise by opening the surface water system and increase permeability of the pavement.

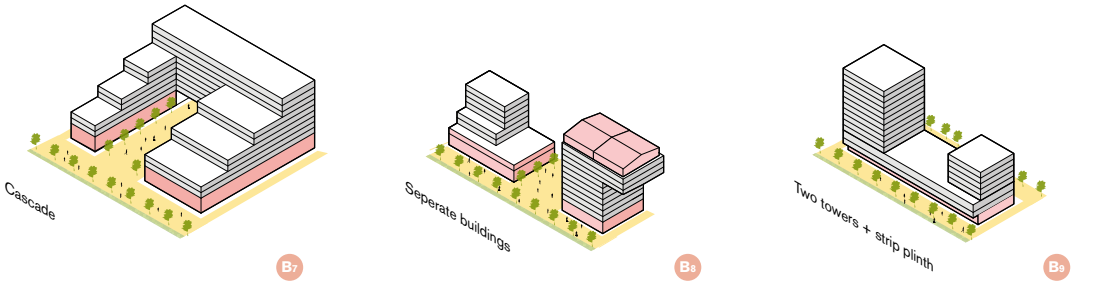
In the mountain area, there are many characteristic houses. To provide a better hiking route and living environment, more public buildings will be built.

Fig. 121. Building typologies concerning the density, layout and interaction with the street and green space
By author

Building type

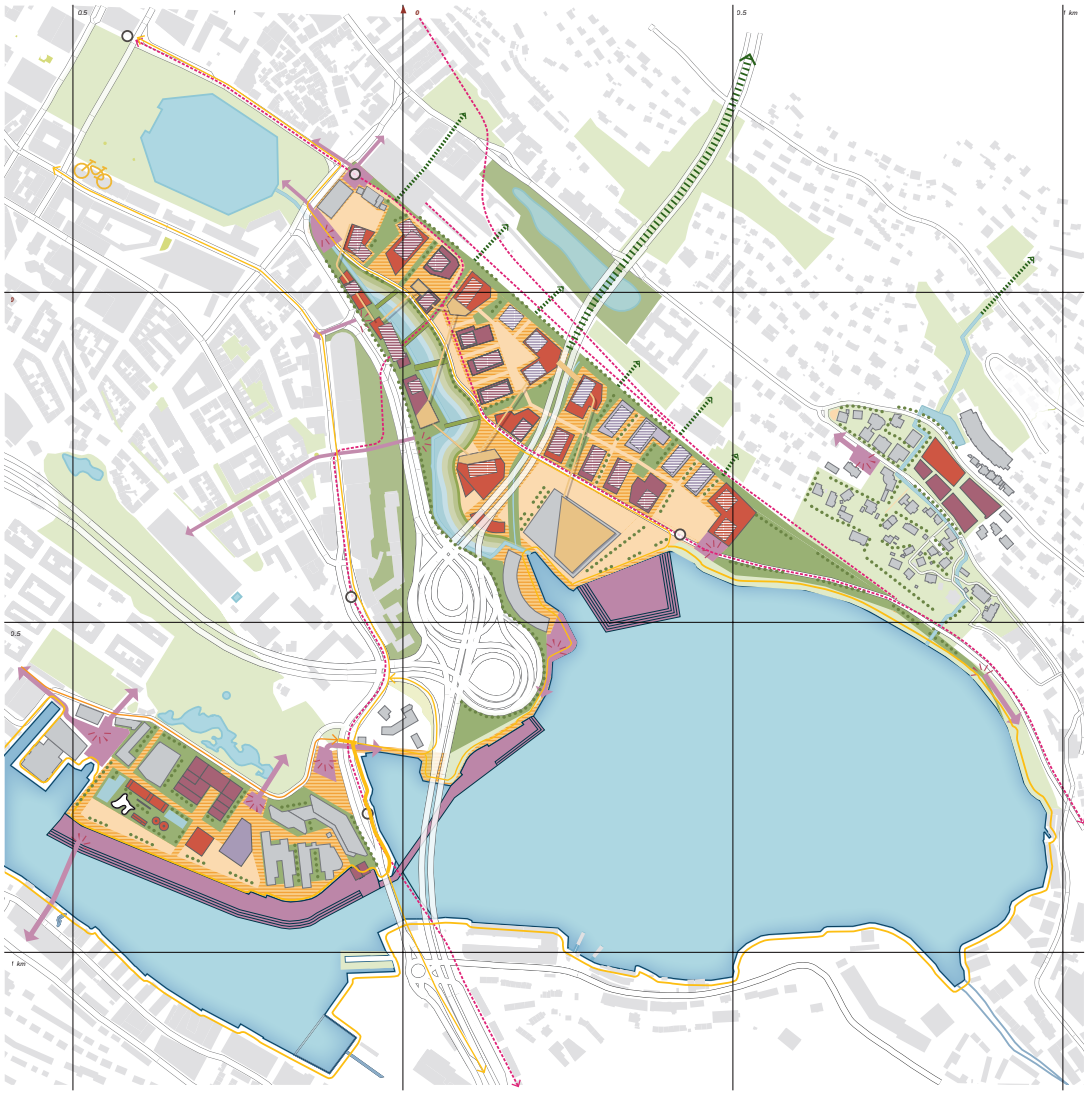


High-density built up area



Harbour / low-density built up area

173



Evolutionary resilience structure

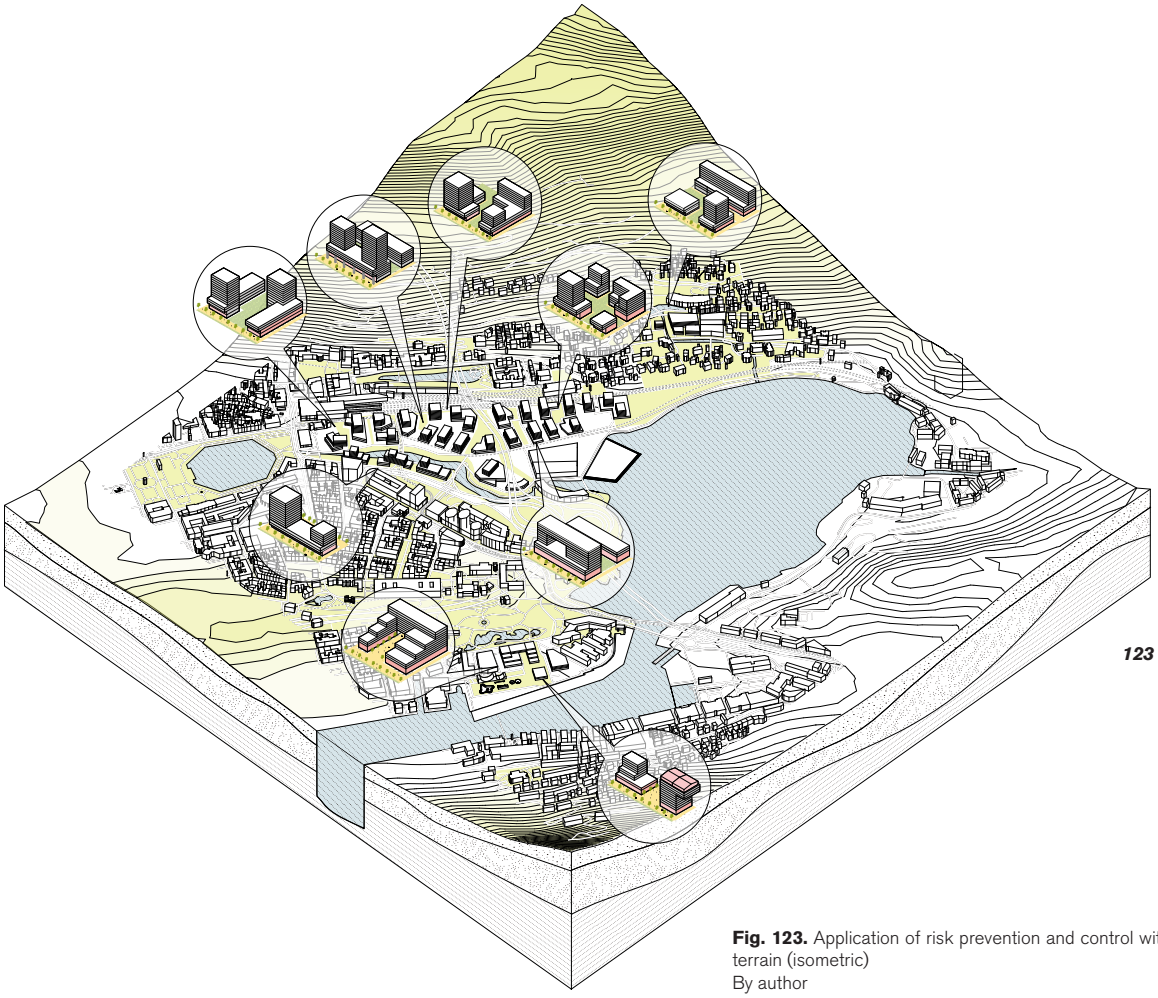
- Preserved

- Existing characteristic buildings
- Other existing buildings

- New structure

- Link with surroundings
- Entrance
- Main characteristic axies
- Special squares
- Connected green paths
- Green over road
- Vegetation
- Important slow traffic route
- Fly-over
- Light rail stop
- Light railway
- Bike highway
- Open surface water
- Office
- Office with high density
- Public service
- Public service with high density
- Residential
- Residential with high density
- Extended floating plate

Fig. 122. New evolutionary resilience (map)
By author



123

Fig. 123. Application of risk prevention and control with terrain (isometric)
By author

In order to meet the city's rapid development requirements within limited land resources, the central axis area is expected to become a new high-density Central Business District and residential area. The height is greater than 12 meters and less than 40 meters. But the layout of the building should be in line with the new blue-green structure, so this will allow better water storage and discharge and to reduce the possibility of flooding. In addition, the construction of air corridors in the central area on the one hand provides a new experience for urban leisure landscapes, on the other hand, this corridor can play a good evacuation role in case of floods or landslides.

The height of the harbour and coastal areas should be less than 16 meters, providing a better view of the waterfront and the gradual change of the city skyline from the centre to the edge. The building function is based on education, research, and entertainment. These combine with advanced energy generation and storage facilities to motivate the public's awareness and enthusiasm. Hillside buildings are mainly scattered buildings, and there are public service buildings such as schools and community centres within a certain range. On the basis of protecting the ecology, it actively develops hydroelectric power and encourages tourism.



Fig. 124. Detailed design of risk prevention and control in local scale (isometric)
By author


Historic church
Department store
Fly-over
Shopping mall
Residential
Ofiice
Open market
Museum
Exhibition
Indoor sports center
University
Light rail station
Open-air concert
Shopping mall
School
Small plaza
Open market
<40m
>12m
<16m

177

3.4
INTERLINKING SYNERGETIC SYSTEMS TO IMPROVE THE URBAN STRUCTURE

Through protected shorelines, resilient infrastructure and adaptive buildings, Bergen is becoming safer, more energetic, more seasonal adaptive and more dynamic. The next step is to improve the urban structure by interlinking synergetic systems, through energetic, climatic and dynamic aspects to finally reach evolutionary resilience by 2050.

- To be Safe - prevent Bergen from flooding and landslide

- To be Energetic - generate more energy from changing climate

- To be Seasonal - be adaptive to daily, monthly and yearly climate change

- To be Dynamic - meet future population and infrastructure and provide a liveable city

There are no risks concerns in climate change. And the changing climate even provides a huge potential to generate more energy if advanced technology can be embedded in the urban structure during the period of urban planning. This kind of renewable energy is clean and unlimited, which can help accelerate the energy transition and have less emission of greenhouse gas.

When considering the urban resource during urban development, it is always limited. But, if we take the fluctuation of climate change during hours, days and months, for example the sea-level, wave height, temperature, precipitation, wind, we can re-allocate urban resources reasonably and effectively, which can fully revitalize without wasting any facilities.

In addition, during the development, the first essential is to meet the demand for housing, infrastructure and service. In the future, a large number of people will rush into the city including residents, workers, students, immigrants and tourists. Meanwhile, it is important to accelerate public enthusiasm and maximize local opportunity. It is encouraged to share economy and culture.

The synergetic action of urban systems and coordinated development will make the city further to evolutionary resilience.

Fig. 125. Evolutionary resilience structure (map)
By author



Evolutionary resilience structure

- Integrated waterfront axis
- Continuous waterfront routes
- Radius of shoreline
- Main characteristic aixes
- Connected paths
- Corrider in the air
- Light railway
- Light rail stop
- Railway
- Bike highway
- New open surface water
- Redeveloped area
- New constructions
- Green space
- Water
- Improve water management


potential surge of tide -2.3m
Sea & water
Pedestrians
Semi-public pedestrains
Infrastructure
Green space
Risk prevention projects
Energy projects
Urban development projects
Phase1 (2017-2025)
Phase1 (2025-2040)
Phase1 (2040-2050)
a
b
2.5
2.3
Phase 1
Tide & wave energy
Terraced edge
Phase 2
Improving the roadway
Phase 3
Upgrading pedestrian & public space
c
2.5
2.3
Phase 1
Tide & wave energy
Terraced edge
Park land
Phase 2
Skate park
Improving the roadway
Phase 3
Upgrading public space
Upgrading pedestrian
d
2.5
2.3
Phase 1
Tide & wave energy
Terraced edge
Bioswale
Phase 2
Skate park
Cascade residential
Improving the roadway
Phase 3
Improving public space
Roof garden& solar panel
2.5
2.3
Phase 1
Tide & wave energy
Terraced edge
Phase 2
Improving public space & pedestrian
Improving the roadway
Phase 3
Public service building
e
2.5
2.3
Phase 1
Terraced edge
Phase 2

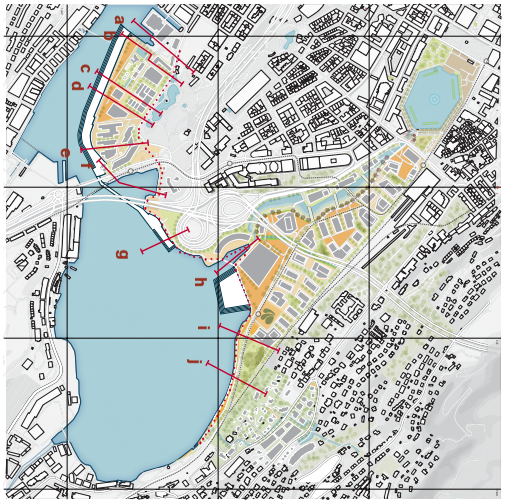
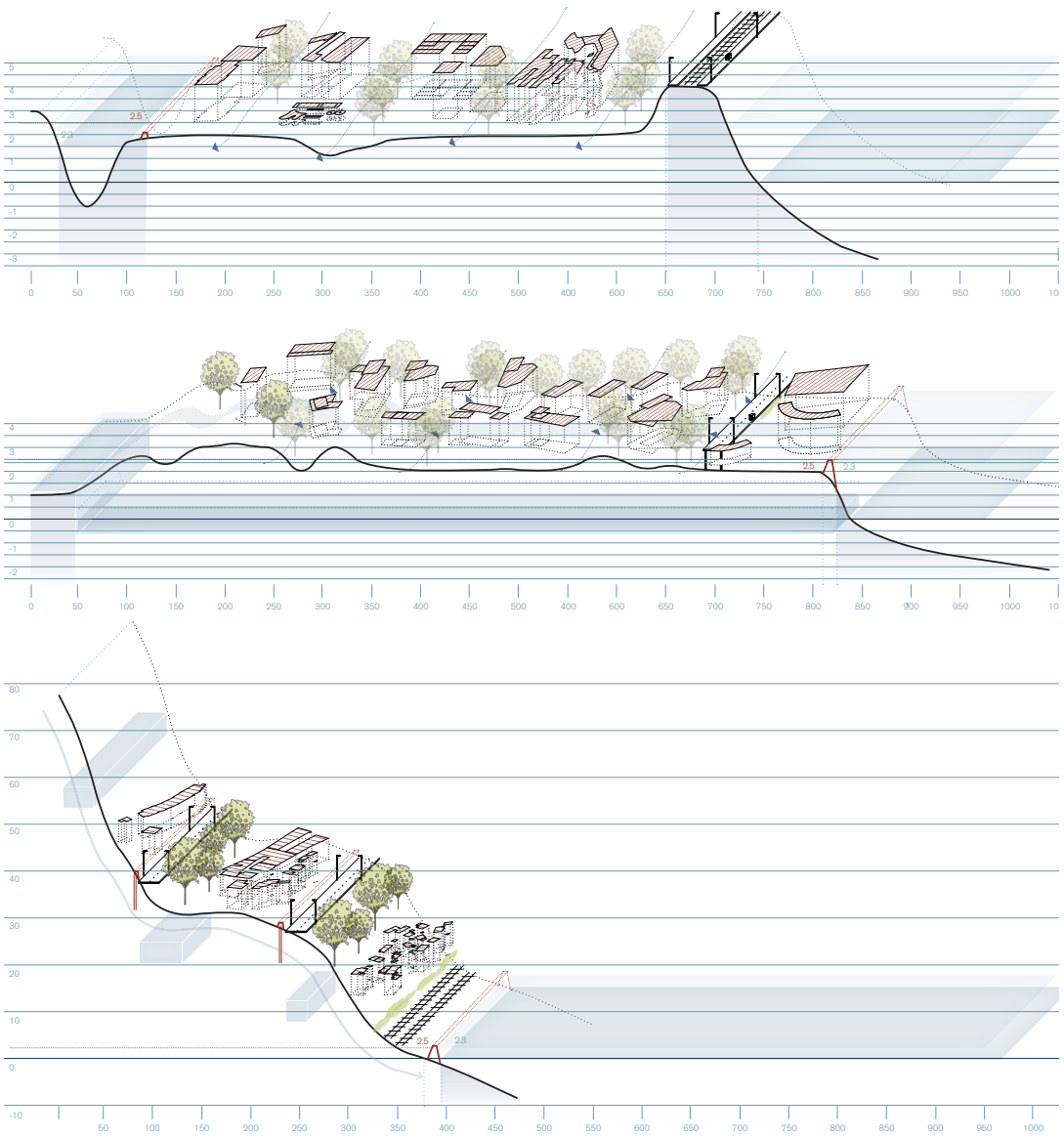




Fig. 126. Shoreline sections after transformation
By author



182

Fig. 127. Sections of three main axes after intervention
By author

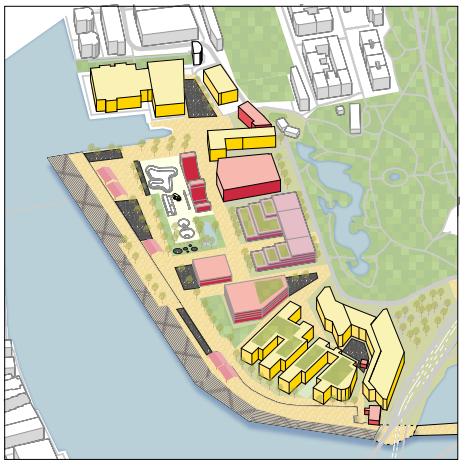
Evolutionary resilience structure

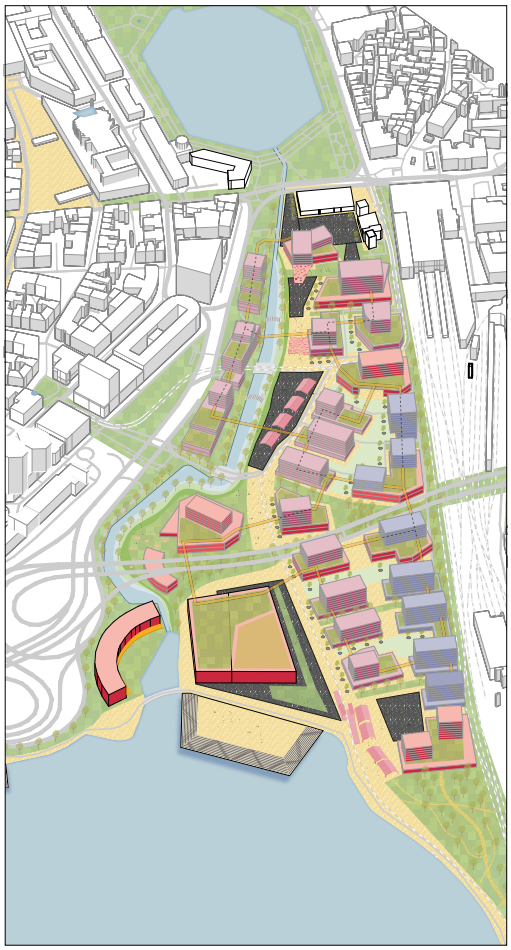
- Preserved

Existing surrounding buildings

- New structure

Educational building
Public building
Residential
Office
Pathway
Fly-over
River
Light railway
Special square
Pavement
Open green space
Roof garden
Semi-public green space
Green basement
Water





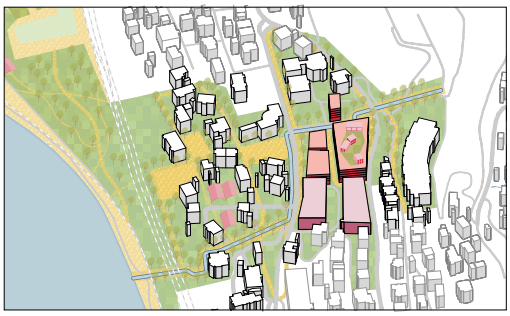


Fig. 128. Detailed design of three axes (isometric)
By author

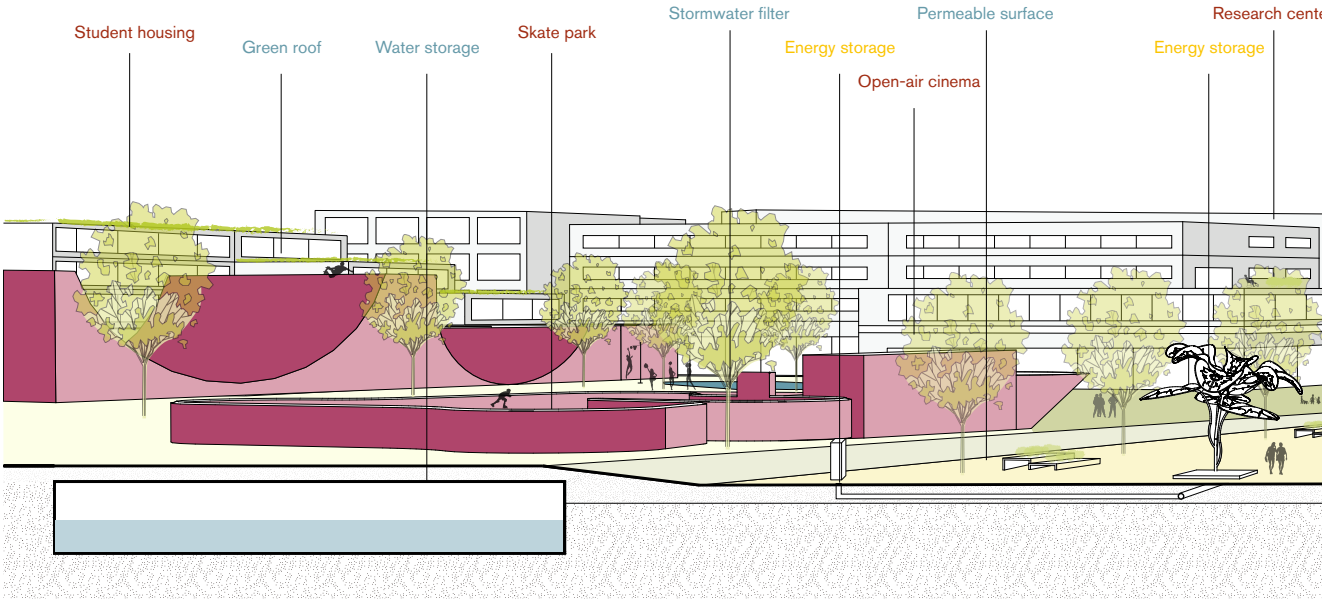


Fig. 129. Harbour boulevard (sectional perspective drawing)
By author.

This section shows a new picture of the port area. Since the no
drainage and flood control. Thus, based on the urban functions
storage tanks), a city avenue, centralized educational institutes

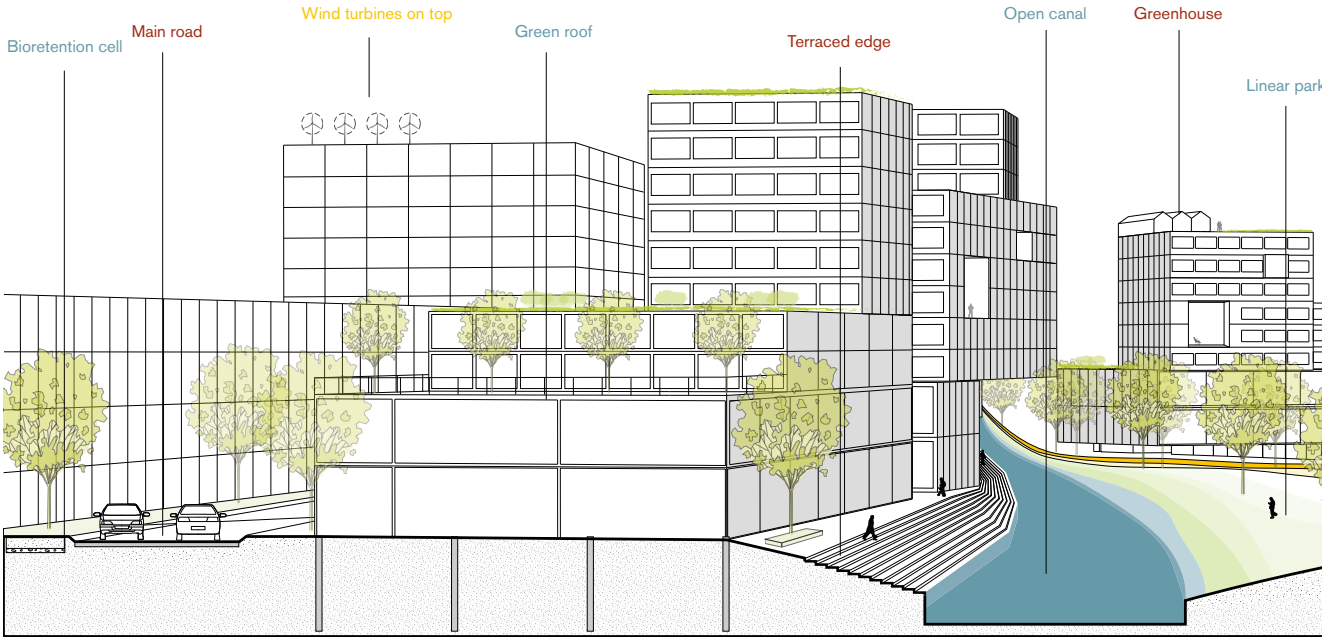
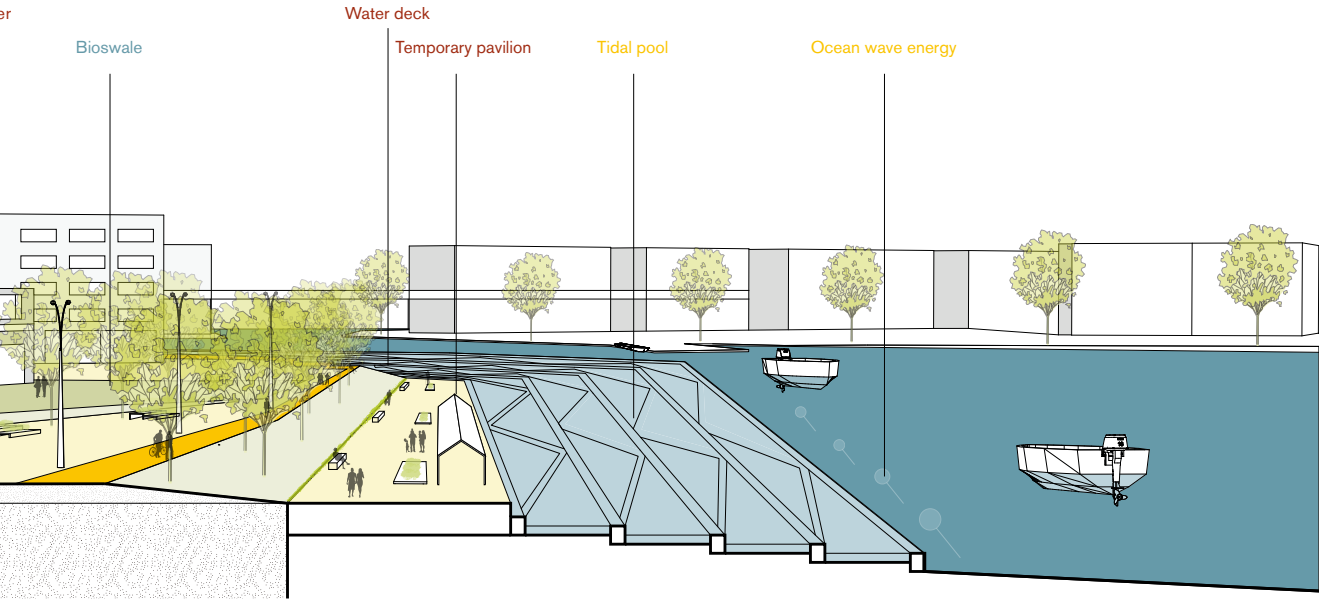


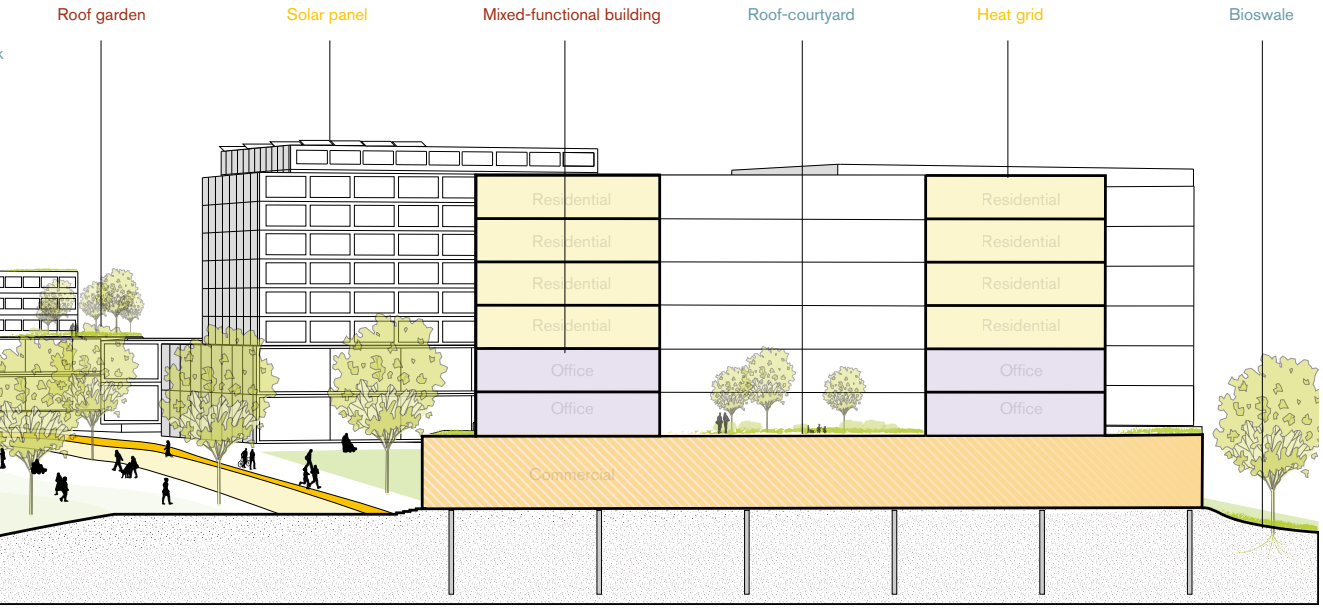
Fig. 130. Central canal (sectional perspective drawing)
By author.

Considering that a large amount of water will be concentrated
purification of water in Lille Lungegårdsvannet. The river is con
height is between 27 and 40 meters, which is well-matched with
by greenery and vegetation. Connected to the linear park are the



129

rth is a high back and the south is directly connected with seawater, this low-land area needs to be well-equipped for water storage, and the blue-green structure, a multifunctional city park (combined with a skate park, an open-air cinema, and underground water and a terraced edge is set up. In addition, solar panels, tidal pool and wave energy facility are applied to generate more energy.



130

on the central axis, a new river channel has been established for better water storage and drainage, as well as for the renewal and trolled to be 6-12 meters wide and 1 meter to 0.5 meters deep. On one side is hard paving and commercial activities. The building n the architectural skyline on the other side of the main road. On the other side are linear parks and recreational activities surrounded e main roads in the center area (including fast bicycles) and the mixed-function block with an inner courtyard.

This profile shows the relationship between the complex terrain and the urban structure of the entire Bergen Center.

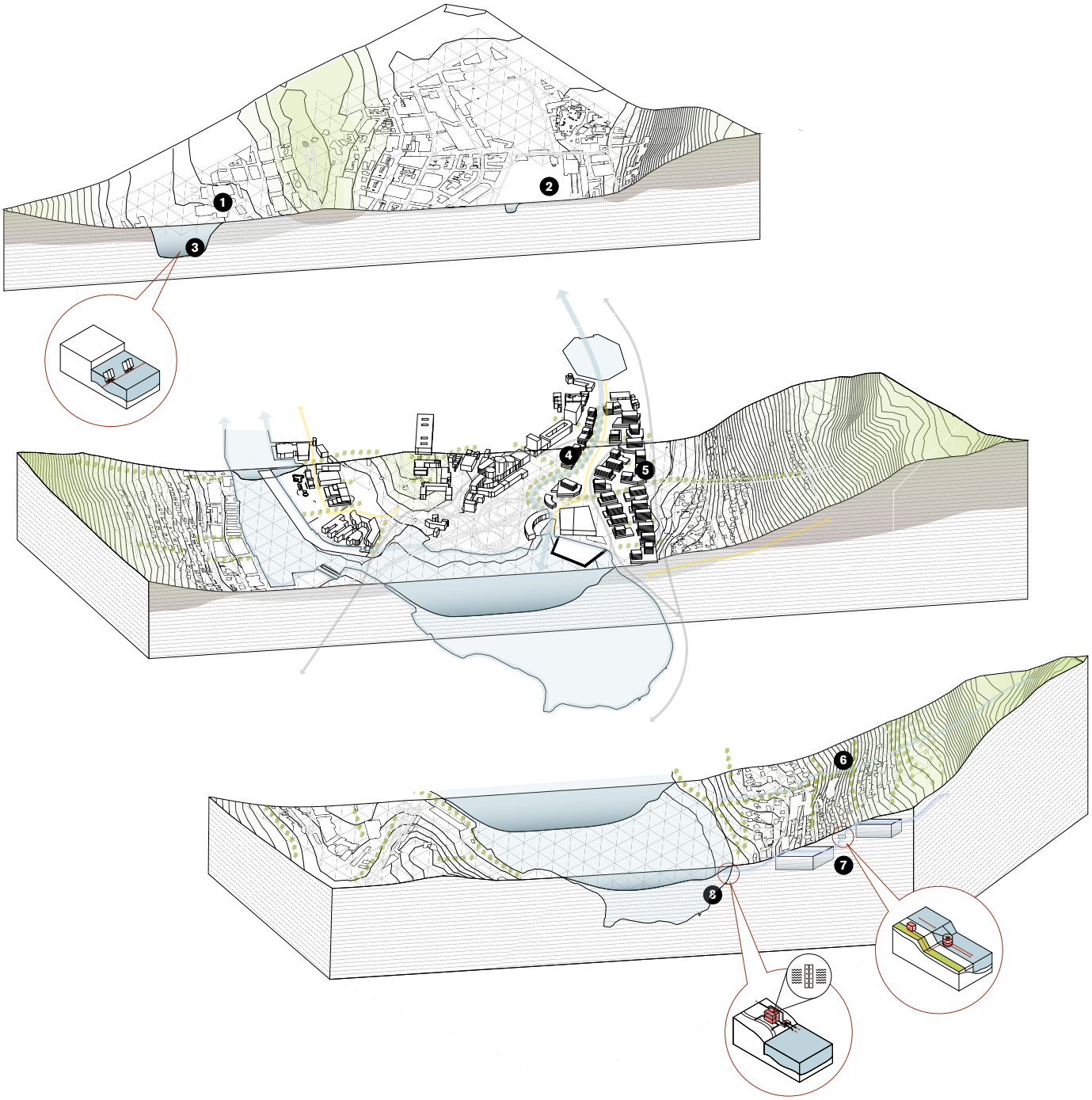
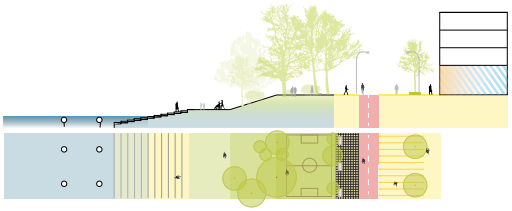
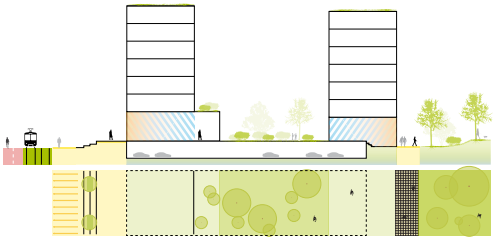


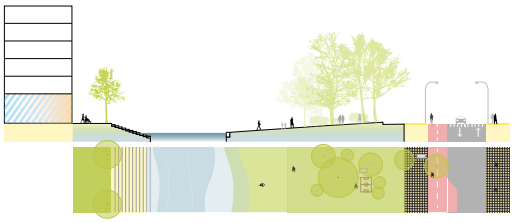
Fig. 131. Profiles of Bergen center with terrain (isometric)
By author



1.This section shows the use of natural resource to produce energy through ocean wave facility and tidal pool. The combination with the terrain edge helps to prevent floods, and meanwhile providing people with recreational space. The harbour boulevard has been improved and runs through the entire coastal area, which provides a continuous routes for public. Renewal in this area will be education, research, leisure, sports as the main function to activate and promote regional development.

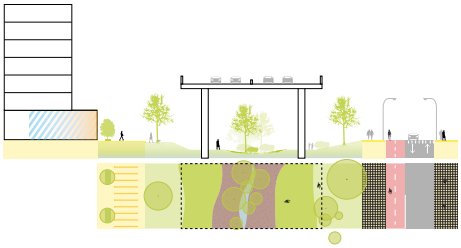


2. Second section shows a general block in the center of the city. Since this area is located in the middle of two hills, it is likely to gather more water. In addition, the high back in the northeast may bring landslides. Therefore, neighborhoods in this area are mainly of strip-shaped buildings facing southeast, which could minimize the thrust surface in case the risk happens. And there is a courtyard to store and delay the water flowing from the mountain, and provide semi-public space for people to use. The courtyard can be raised half or one floor and use the underground space as a parking lot.

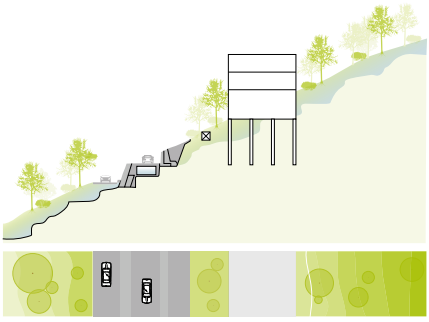


4. More precipitation in the future might lead to a landslide and snow slide. Thus interventions like retaining wall and caisson piles are taken to protect infrastructure and trees are planted to dry and strengthen the soil in order to minimize the possibility of land rocks.

187



5. The elevated road in the Bergen Center is an important and busy road. The space under the viaduct can be used as a green corridor and a relaxing space for public. The space around the original negative elevated road is now activated and brings more popularity.



6. In order to better store and evacuate the water left on both sides of the hillside and purify water in Lille Lungegårdsvannet Water, a new canal was built. On one side is hard paving and commercial activities, on the other side is the linear park.

3.5
PARTICIPATORY URBAN REGENERATION

Urban regeneration process links the renewal of urban structure and blue-green corridor, redesign of public space, upgrade of infrastructure and their results in terms of environmental, economic and social improvement in the participatory process led by different actors and institutions.

This kind of process enables the most efficient and effective management of material, resources and information to embrace urban environment and nature and provide a safe and sustainable living condition with better quality. So, the participatory process and the specific actors should be defined.

In this project, the actors and institutions related to environment, energy and regeneration are listed by the range of influence. International actors are mainly some institutions devoting to mitigate the influence of human activities on the environment. Some universities and research centers are also dedicated to this and have huge impact over the world. These important actors serve as the bridge between research and practice, technology and application. National actors are the norwagian goverment, concil and institutions who manage the resources and plan the future development of Norway. Regional actors are the Bergen municipality and some public or private institutions who has the political power and economic power to implement the urban regeneration. And the citizens are the people who have the local power.

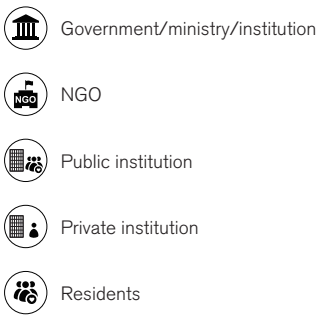
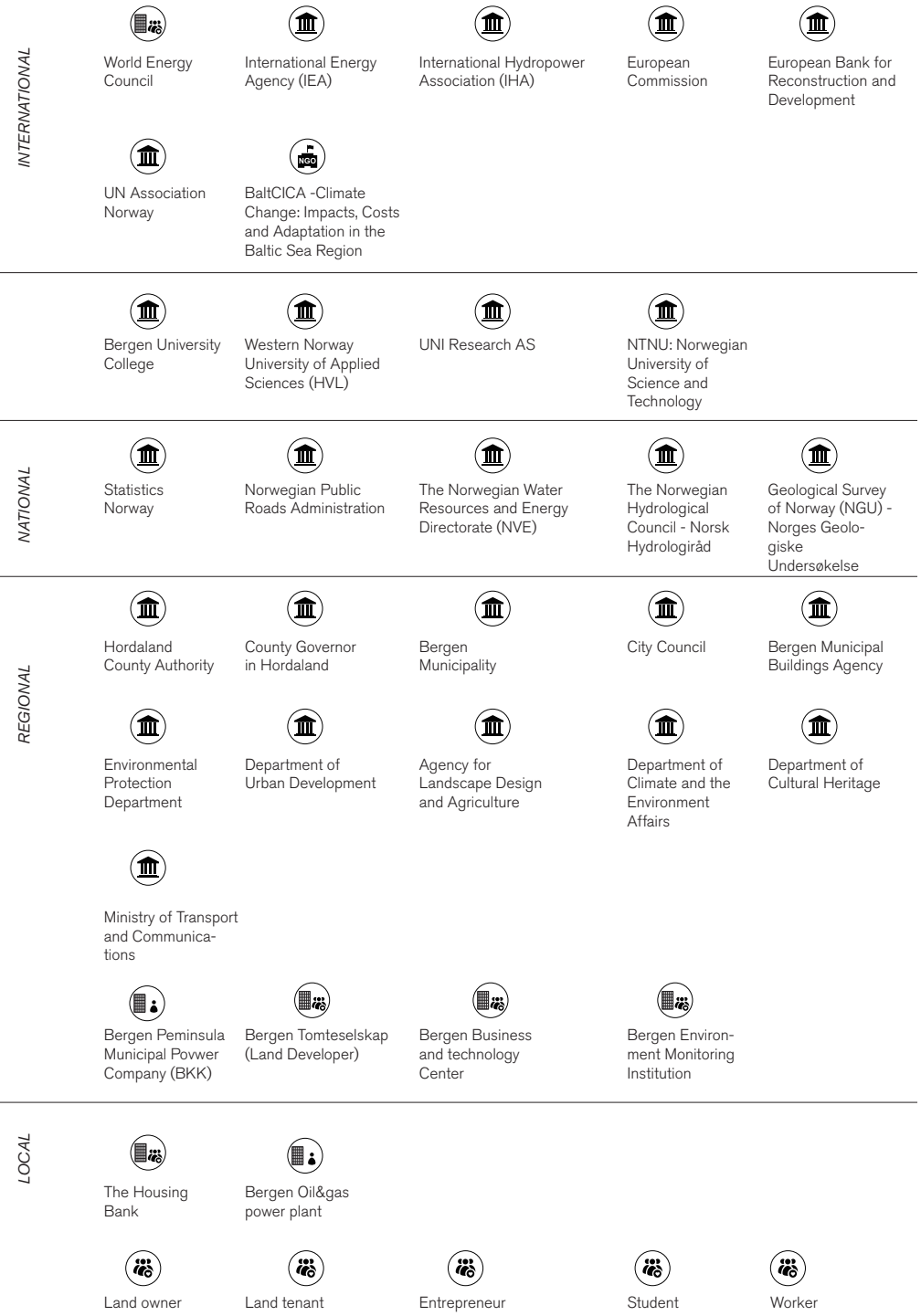


Fig. 132. Actors in participatory regeneration
By author


INTERNATIONAL
World Energy Council
International Energy Agency (IEA)
International Hydropower Association (IHA)
European Commission
European Bank for Reconstruction and Development
UN Association Norway
NGO
BaltCICA -Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region
Bergen University College
Western Norway University of Applied Sciences (HVL)
UNI Research AS
NTNU: Norwegian University of Science and Technology
NATIONAL
Statistics Norway
Norwegian Public Roads Administration
The Norwegian Water Resources and Energy Directorate (NVE)
The Norwegian Hydrological Council - Norsk Hydrologiråd
Geological Survey of Norway (NGU) - Norges Geologiske Undersøkelse
REGIONAL
Hordaland County Authority
County Governor in Hordaland
Bergen Municipality
City Council
Bergen Municipal Buildings Agency
Environmental Protection Department
Department of Urban Development
Agency for Landscape Design and Agriculture
Department of Climate and the Environment Affairs
Department of Cultural Heritage
Ministry of Transport and Communications
Bergen Peminsula Municipal Povwer Company (BKK)
Bergen Tomteselskap (Land Developer)
Bergen Business and technology Center
Bergen Environment Monitoring Institution
LOCAL
The Housing Bank
Bergen Oil&gas power plant
Land owner
Land tenant
Entrepreneur
Student
Worker

189

3.6
IMPLEMENTATION ROADMAP & SYNERGIES BETWEEN DIFFERENT PROJECTS

When introducing the actors into this project, we can have a basic knowledge about which intervention is the most urgent, how much capacity do we really need and how much can these interventions bring about.

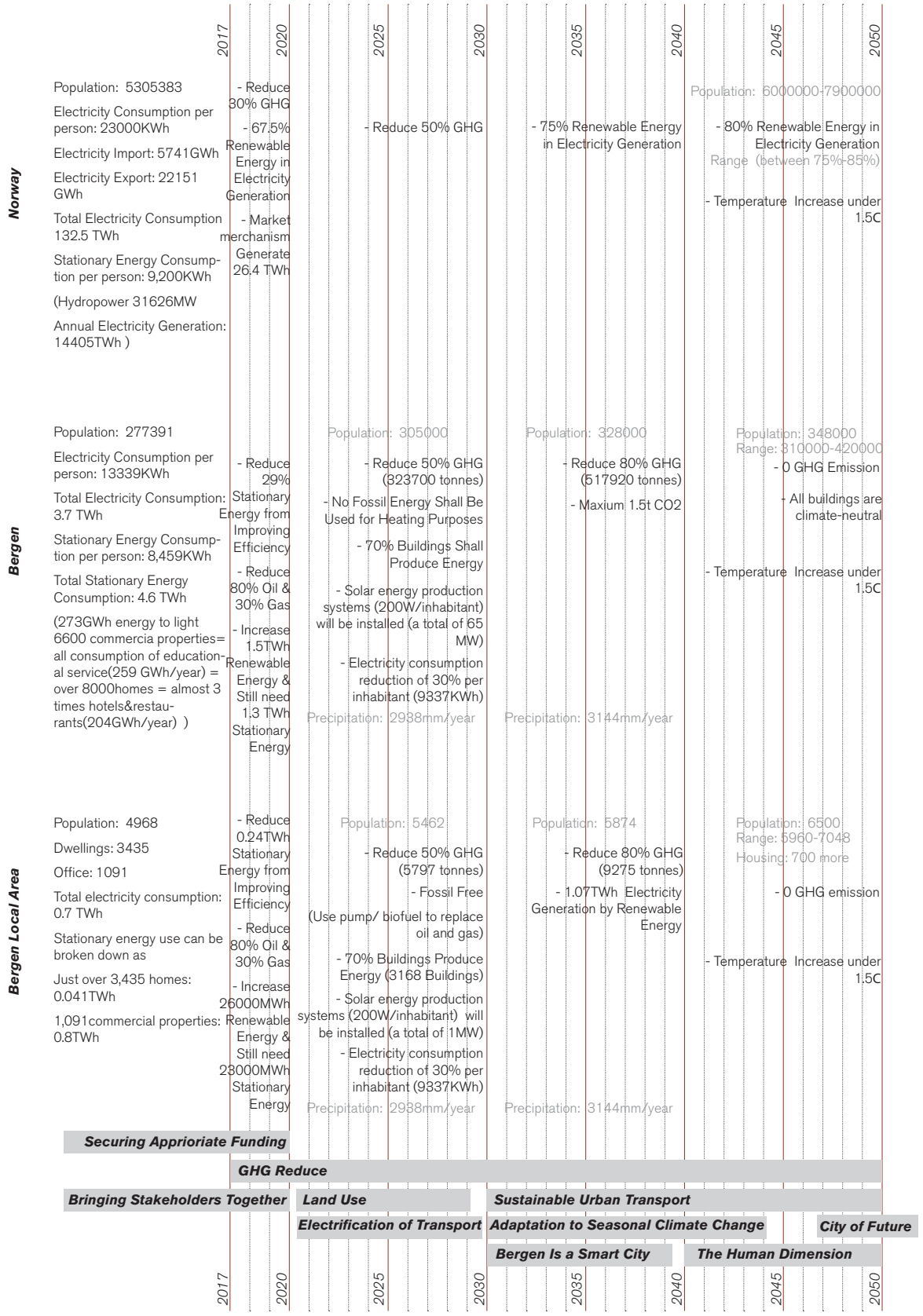
The first essential is prevent Bergen from probable risks caused by climate change. The biggest problem is exceeded water from sea-level rise and extreme precipitation. The biggest benefit of this urban update is the natural resource and extra energy from the changing weather. Also, the limited resource is the city will be redistributed in an efficient way according to different characteristics of four seasons. In addition, some areas will be re-defined in terms of the function and responsibility in a city and a region, which are no longer suitable for current and future situation during the development.

The first stage would be the transformation of the shorelines and harbours. Although these areas will not be flooded in a short time, the tide and wave energy are ready. The earlier transformation is, the more energy can get. Meanwhile, these can be part of the research topic for the universities and research centers around. The knowledge flow promotes two sides. In addition, the connectivity of harbour regions will be improved.

The second phase would be energy consumption reduction and energy gain maximization. Upgrading the old buildings, electrification of transportation, construction of district heating system will greatly save energy. And more rain collection, water energy, solar energy, wind energy generators will be applied widely and connect into the power system.

The final phase aims to provide more space, more activities, more jobs to accommodate increasing population in the future. Transformation of logistic industries, bus stations and parking garage into mixed function building provides more possibilities and redefine the urban structure. The synergetic systems work together to building a safe, green, smart and vibrant Bergen.

Fig. 133. Implementation map towards 2050
By author


2017
2020
2025
2030
2035
2040
2045
2050
Norway
Population: 5305383
Electricity Consumption per person: 23000KWh
Electricity Import: 5741GWh
Electricity Export: 22151 GWh
Total Electricity Consumption 132.5 TWh
Stationary Energy Consumption per person: 9,200KWh
(Hydropower 31626MW
Annual Electricity Generation: 14405TWh)
- Reduce 30% GHG
- 67.5% Renewable Energy in Electricity Generation
- Market merchanism Generate 26.4 TWh
- Reduce 50% GHG
- 75% Renewable Energy in Electricity Generation
Population: 6000000-7900000
- 80% Renewable Energy in Electricity Generation
Range (between 75%-85%)
- Temperature Increase under 1.5C
Bergen
Population: 277391
Electricity Consumption per person: 13339KWh
Total Electricity Consumption: 3.7 TWh
Stationary Energy Consumption per person: 8,459KWh
Total Stationary Energy Consumption: 4.6 TWh
(273GWh energy to light 6600 commercia properties= all consumption of educational service(259 GWh/year) = over 8000homes = almost 3 times hotels&restaurants(204GWh/year))
- Reduce 29% Stationary Energy from Improving Efficiency
- Reduce 80% Oil & 30% Gas
- Increase 1.5TWh Renewable Energy & Still need 1.3 TWh Stationary Energy
Population: 305000
- Reduce 50% GHG (323700 tonnes)
- No Fossil Energy Shall Be Used for Heating Purposes
- 70% Buildings Shall Produce Energy
- Solar energy production systems (200W/inhabitant) will be installed (a total of 65 MW)
- Electricity consumption reduction of 30% per inhabitant (9337KWh)
Precipitation: 2938mm/year
Population: 328000
- Reduce 80% GHG (517920 tonnes)
- Maxium 1.5t CO2
Precipitation: 3144mm/year
Population: 348000
Range: 310000-420000
- 0 GHG Emission
- All buildings are climate-neutral
- Temperature Increase under 1.5C
Bergen Local Area
Population: 4968
Dwellings: 3435
Office: 1091
Total electricity consumption: 0.7 TWh
Stationary energy use can be broken down as
Just over 3,435 homes: 0.041TWh
1,091commercial properties: 0.8TWh
- Reduce 0.24TWh Stationary Energy from Improving Efficiency
- Reduce 80% Oil & 30% Gas
- Increase 26000MWh Renewable Energy & Still need 23000MWh Stationary Energy
Population: 5462
- Reduce 50% GHG (5797 tonnes)
- Fossil Free (Use pump/ biofuel to replace oil and gas)
- 70% Buildings Produce Energy (3168 Buildings)
- Solar energy production systems (200W/inhabitant) will be installed (a total of 1MW)
- Electricity consumption reduction of 30% per inhabitant (9337KWh)
Precipitation: 2938mm/year
Population: 5874
- Reduce 80% GHG (9275 tonnes)
- 1.07TWh Electricity Generation by Renewable Energy
Precipitation: 3144mm/year
Population: 6500
Range: 5960-7048
Housing: 700 more
- 0 GHG emission
- Temperature Increase under 1.5C
Securing Appriorate Funding
GHG Reduce
Bringing Stakeholders Together
Land Use
Sustainable Urban Transport
Electrification of Transport
Adaptation to Seasonal Climate Change
City of Future
Bergen Is a Smart City
The Human Dimension
2017
2020
2025
2030
2035
2040
2045
2050

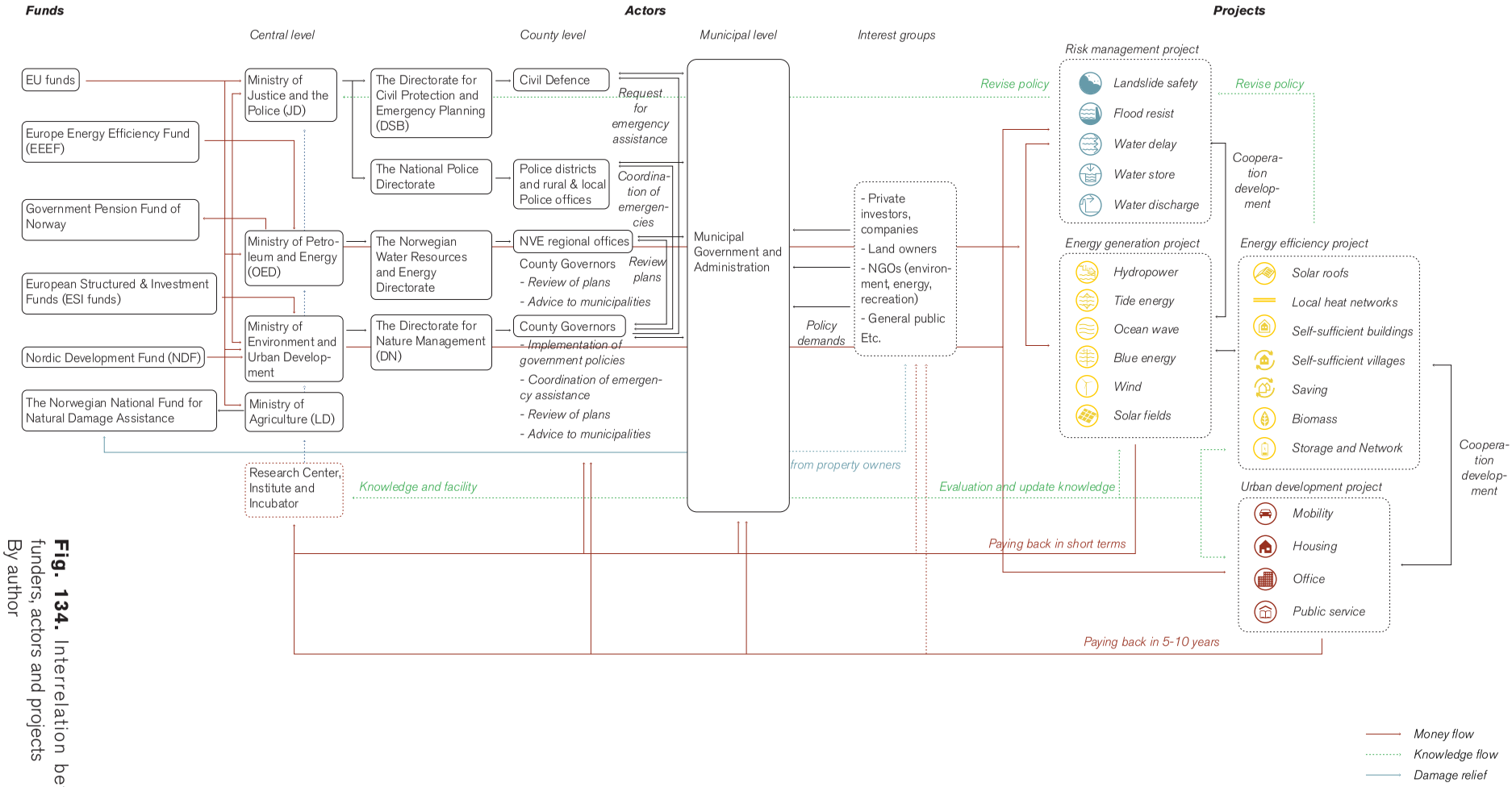


Fig. 134. Interrelation between funders, actors and projects
By author

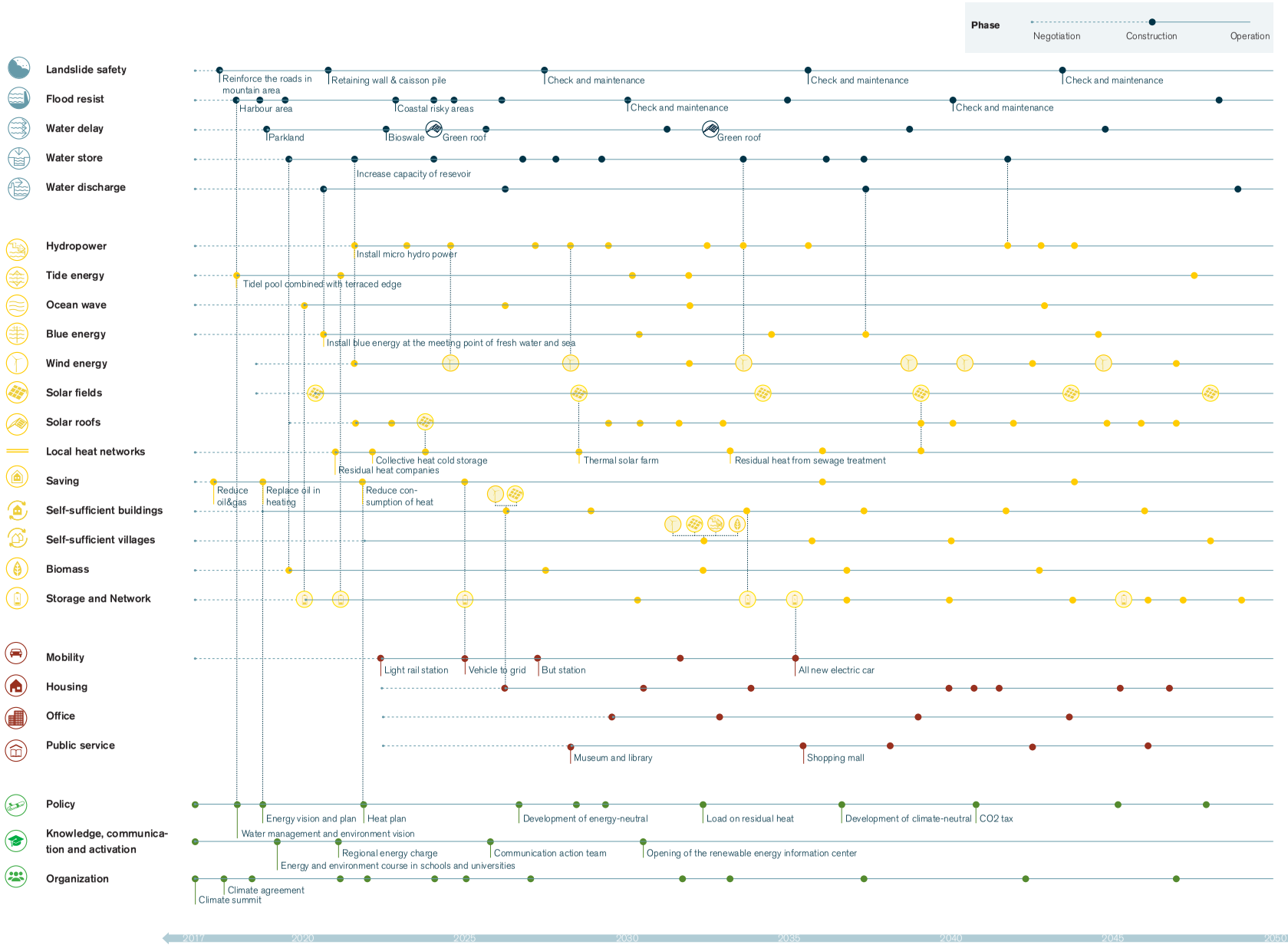


Fig. 135. Synergies between different project
By author

3.7
CONCLUSION OF DESIGN STRATEGIES

In this project, the main strategy is to reduce the possibility of risks caused by climate change, and to make full use of the changing weather (for example, to obtain more water energy through increased rainwater and elevated sea level and to obtain more wind energy through the increase of wind power) and re-examine the existing urban spatial structure and resource allocation for urban regeneration.

In terms of risk prevention and reduction, measures are formulated based on the prediction of possible risks. Set the retaining wall and caisson pile in places where landslides are most likely to happen, and plant trees and vegetation to dry and reinforce the soil, and obstructing rock fails. According to the analysis of flow accumulation, reorganize the blue-green connection. In the port, it is equipped with terraced edge, bulkhead and deployable flood wall. Make full use of the existing conditions, set delay and transfer water intervention in the upstream of the river, and set up facilities for water storage and drainage in the downstream. However, when the functional layout of the city is not conducive to the blue structure, it is necessary to re-examine the urban structure. In the central axis area of the city, a large number of logistics and transport industries are built to block the surrounding areas of the city, and the terrain is low and water is easy to accumulate. Therefore, consider establishing a new canal for better water storage, discharge, purification of Lille Lungegårdsvannet Water and open it to the public.

On the basis of ensuring that cities will not be suffered by risks, cities can use climate changes as a turning point for better development. For example, using more rainwater conditions, setting more micro hydro power at the river and increasing the capacity of the existing hydro power, using increased sea level and tide wave to collect more tidal energy, meanwhile using wind energy, solar energy to produce increases energy production in this area. Taking into account that more people will flow into cities in the future, cities need more residences, offices, business and supporting facilities to meet future needs. Combined with the demand for energy saving and emission reduction, a large number of negative space are redesigned to activate surroundings.

Fig. 136. Conclusion of resilience components
By author

Resilience components

1. Climate consensus
- *Coastal flooding*
- *Pluvial flooding*
- *Landslide and snowslide*

2. Vulnerability assessment
- *Exposure population*
- *Exposure infrastructure*

3. Resilience initiatives

Principle

- Work in layers for independently effective solutions
- Support multiple benefits with each activities
- Develop adaptive and flexible strategies
- Minimise impact on energy consumption and natural resources
- Define a responsive urban form
- Incorporate local involvment in design and decision-making

Process

- *Build a prepared and safe community*
- *Accelerate access to reliable and clean energy*
- *Adapt to seasonal change under climate*
- *Promote shared economy and culture to advance city development*
- *Excel at working together within urban goernance to better serve the community*
- *Build regional evolutionary resilience system*

Layers

- Protected shores

1) District flood defenses

2) Harbor-wide protection

- Protected shores

- Resilient infrastructures

1) Common planning, agendas and design standards

2) Green infrastructure protection & expansion

3) Energy system redundancy and renewal

4) Adaptation of existing infrastructure systems

- Water and sewer

- Transportation

- Resilient infrastructure

- Adapted buildings

1) Support for building retrofits

2) Standards for new buildings

3) Risk insurance reform

- Adapted buildings

Responsive urban structure

- Intergrated actors, agendas and governance

1) Climate projection consensus

2) Engagement of at-risk stakeholders

3) Preparedness planning and agendas for vulnerablility

4) Small businesses and institution support

5) Economic development through resilienc

- Intergrated actors and governance

4. Implementation roadmap
- *Revise agenda*
- *Promote synegies between different projects*

4 PHASING

4.1
SHORT TERM DEVELOPMENT PLAN - 2020

In the short term development plan towards 2020, the emphasis is put on flood prevention and discharging, restructuring the blue-green corridor according to the calculation of flow direction and flow accumulation based on precipitation prediction and sea-level rise, landslide prevention and reduction of energy consumption. And the relevant actors will be invited to negotiate about the action plan and execution.

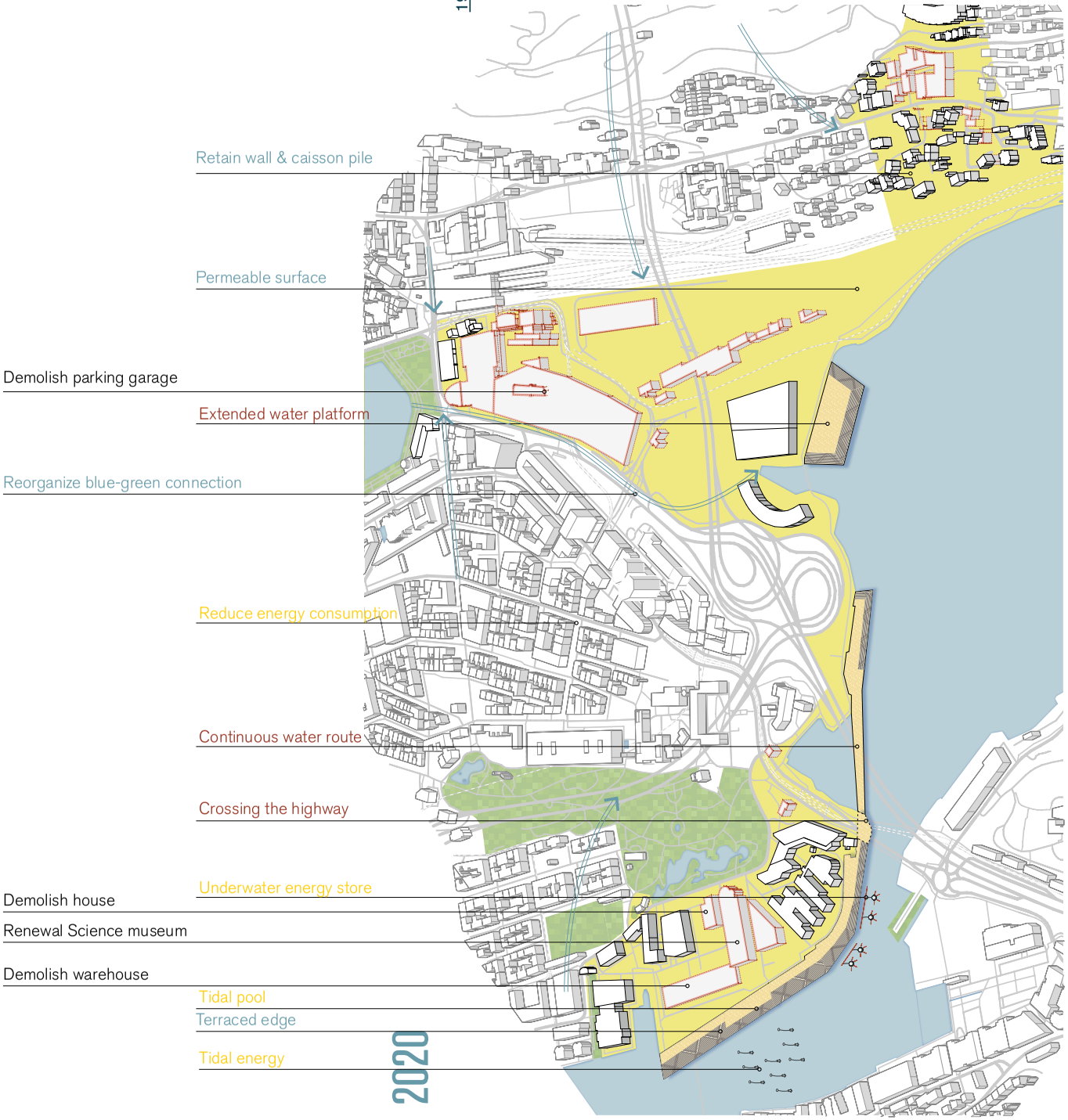
Due to the low land, the coastal region around Store Lungegårdsvann is susceptible to be flooded by sea-level rise. Thus, terraced edge, bulkhead, deployable flood wall are applied to prevent potential flood. In addition, the middle part of the city is also low-lying and surrounded by mountains which will be flooded when extreme precipitation happens. So according to the prediction of flow amount and accumulation, a new blue-green structure which can help to delay, store and discharge water will be prepared.

But on the other side, the additional water from sea and sky brought a new opportunity to generate more renewable energy. So combined with the terraced edge in the harbour area, the interventions which can generate energy from sea wave and tide will be placed.

Besides the water-related problem, the change of precipitation pattern will also cause the land slides in the mountain area. The interventions like retain wall and caisson pile will help to strengthen the construction of mountain and protect infrastructure.

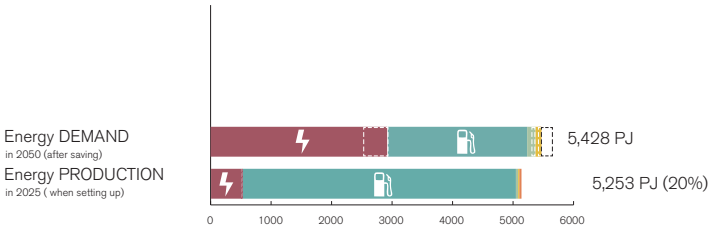
Meanwhile, according to the risk range and a new structure of blue-green corridor to decide the demolish and transformation. For example, the location of the current parking garage is a gathering place of water flow which is preferable to be an open canal to store and discharge water in the future. In terms of public service, the harbour is closed and negative now because of many ware house, which has a huge potential to activate the coastal region if it opens and service for the public.

Fig. 137. Short-term development by 2020 of Bergen center (isometric)
By author

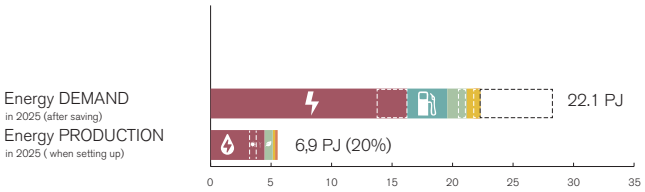

Retain wall & caisson pile
Permeable surface
Demolish parking garage
Extended water platform
Reorganize blue-green connection
Reduce energy consumption
Continuous water route
Crossing the highway
Underwater energy store
Demolish house
Renewal Science museum
Demolish warehouse
Tidal pool
Terraced edge
Tidal energy
2020

4.2
MEDIUM TERM DEVELOPMENT PLAN - 2025

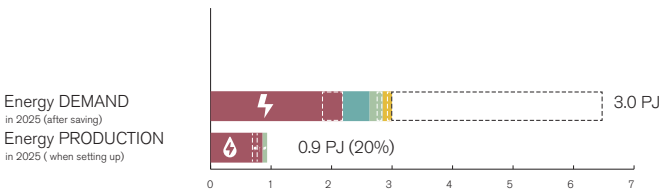
Norway



Bergen



Bergen -
Local area



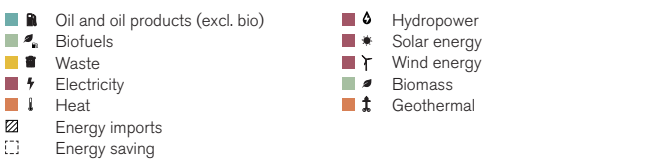
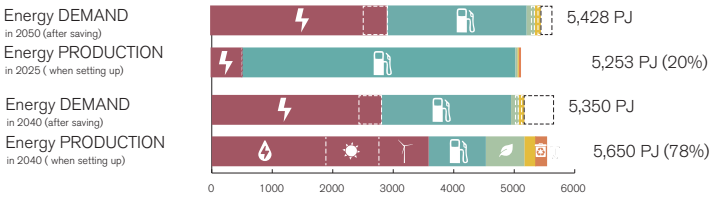


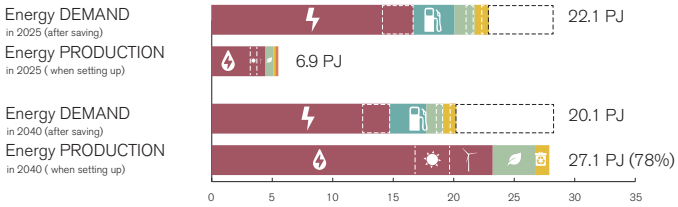
Fig. 138. Medium-term development by 2025 of Bergen center (isometric)
By authr

4.3
MEDIUM-LONG TERM DEVELOPMENT PLAN - 2040

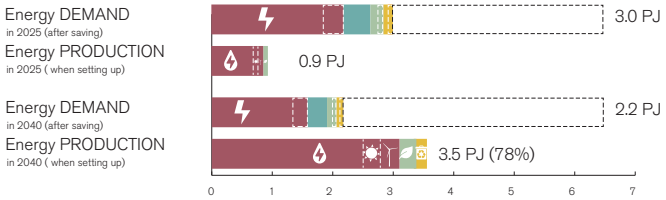
Norway

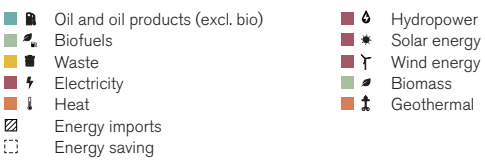


Bergen



Bergen -
Local area





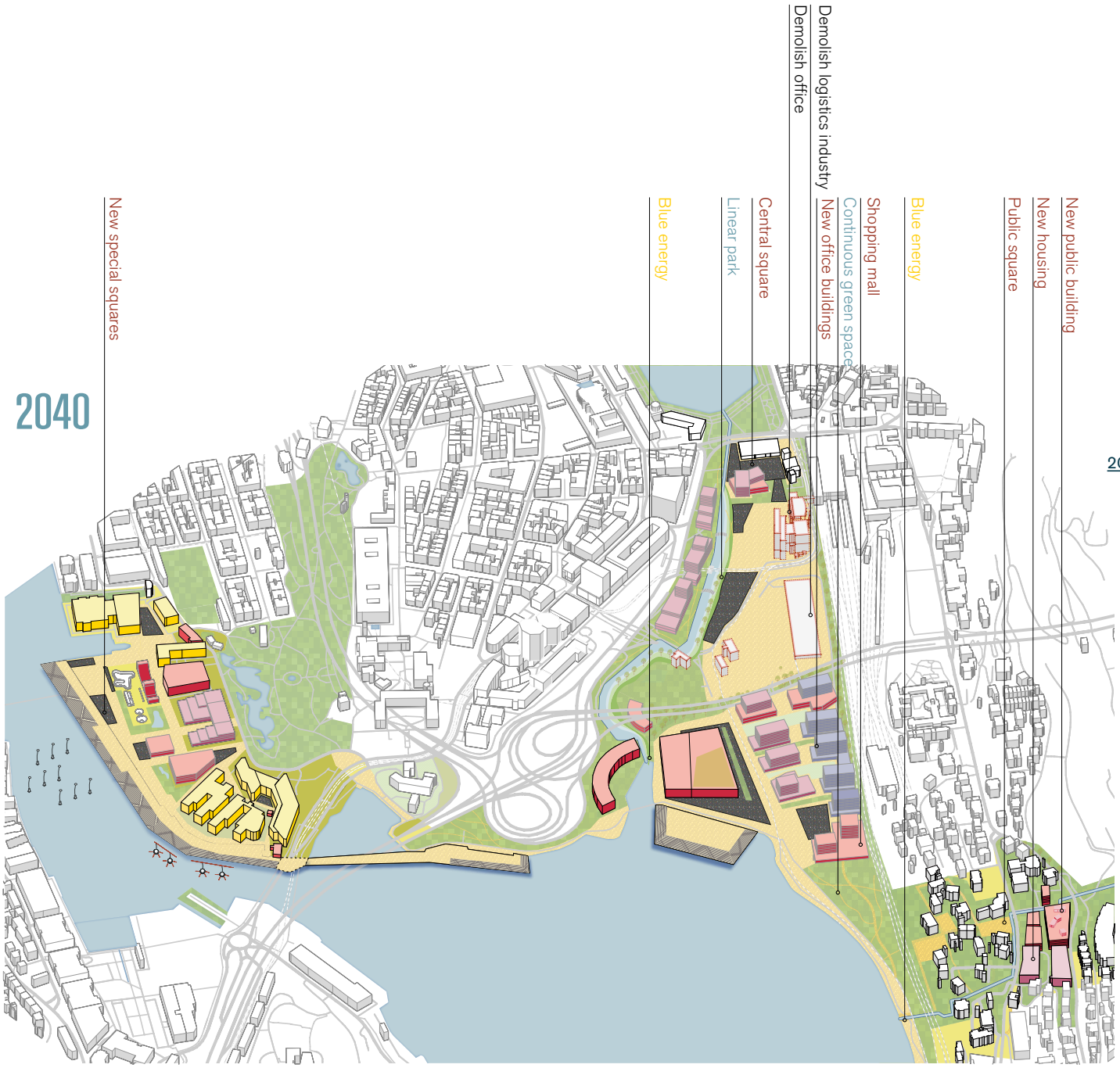
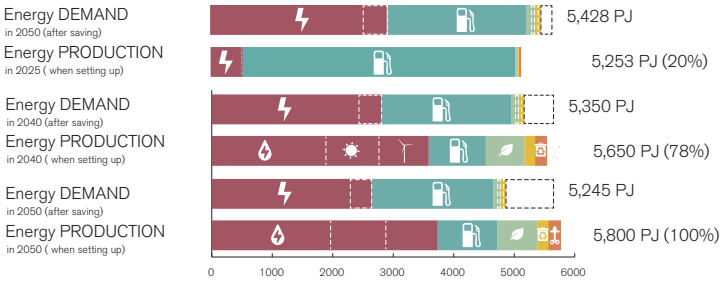


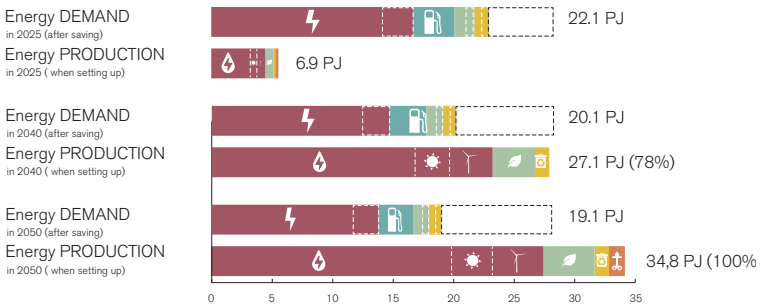
Fig. 139. Medium-long term development by 2040 of Bergen center (isometric)
By author

4.4
LONG TERM DEVELOPMENT PLAN - 2050

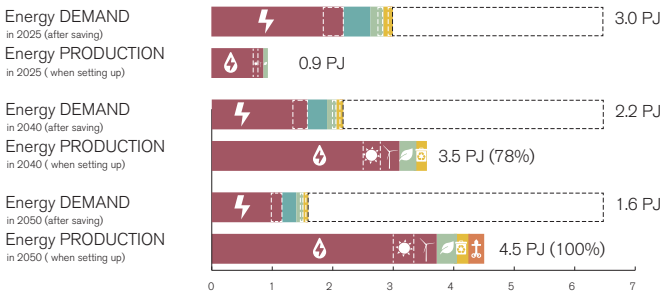
Norway



Bergen



Bergen - Local area



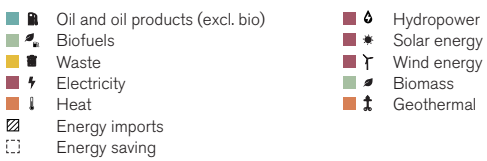


Fig. 140. Long-term development by 2050 of Bergen center (isometric)
By author

4.5
CONCLUSION AND BENEFITS

For Bergen and Norway, besides prevent ion of possible risks like floods and landslides, the greatest advantage of this project is the successful transformation from carbon-based energy to green energy, and even become the green battery for the North Sea region.

The first phase of disaster prevention measures made the city safe. The second stage on this basis is to completely prohibit the use of oil for heating and to become a fossil free city. Combined with the expansion of regional thermal systems, upgrading of energy levels in housing, etc., the use of electricity is greatly reduced.

With the transformation of the shoreline, tidal energy can begin to generate a small amount of income (reaching 20% by 2020, comparing with the energy production in 2050). These energy sources are enough to provide street lights and public transportation.

Between 2020 and 2040 is a period of maximizing energy production (78% when comparing with the energy production in 2050). In addition to the benefits brought by the coastal water energy, a large number of newly-added micro hydropower facilities, wind energy, solar energy, and algae farms have developed in synergy for energy production. They will be connected into energy system to support daily use in housing, commercial, office, recreation.

Between 2040 and 2050, new multi-functional buildings were built to provide more people's lives. At the same time, these passive new buildings are energy-balanced and can even store excess energy. During this period, Bergen can reach an energy balance, and Norway can transfer the rich energy to neighboring countries.

Fig. 141. Conclusion of energy potential of Bergen and Norway
By author

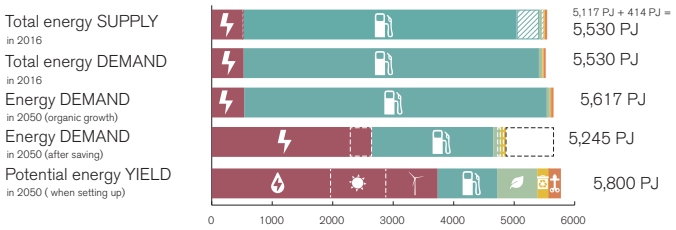


Norway

Population
5 258 000 (2016)
6 691 000 (2050)

Area
385 203 km²

Households
2 316 600



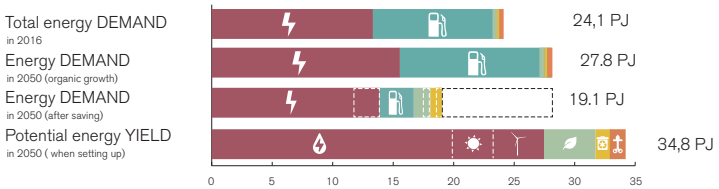


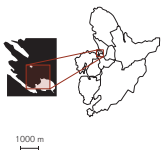
Bergen

Population
277 391 (2016)
348 000 (2050)

Area
445.1 km²

Households
120 000



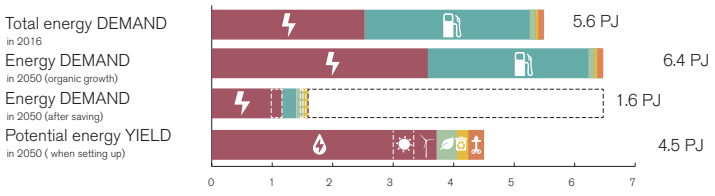


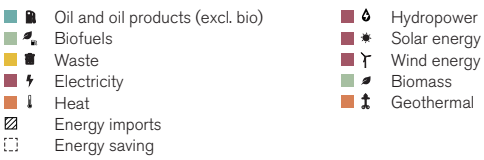
Bergen -
Local area

Population
4968 (2016)
8000 (2050)

Area
3.24 km²

Households
3435







	Total
Policy	
- Water management and environment vision	
- Energy vision and plan	
- Heat plan	
- Development of energy-neutral	
- Load on residual heat	
- Development of climate-neutral	
- CO2 tax	
Knowledge, communication and activation	
- Energy and environment course in schools and universities	
- Regional energy charge	
- Communication action team	
- Opening of the renewable energy information center	
- Load on residual heat	
Organization	
- Climate agreement	
- Climate summit	
Landslide safety	
- Retaining wall & caisson pile	
Flood resist	
- Terraced edge	
- Bulkhead	
- Deployable flood wall	
Water delay	
- Bioswale	
- Parkland	
- Green roof	
Water store	
- Cistern	
- Constructed wetlands	
- Bioretention basin	
- Green river bank	
Water discharge	
- Stormwater pump	
- Storm drain	

	Total
Solar fields	**3.1 PJ**
- Solar PV meadows	0.6
- Floating solar fields	0.1
- Solar panels in agricultural area	0.4
- Solar thermal panels	2.0
Solar roofs	**0.3 PJ**
- Non-residential buildings	0.2
- Housing in cities	0.1
Local heat networks	**1.1 PJ**
- Residual heat companies	0.9
- Residual heat sewage treatment plant	0.2
- Riothermie	-
Saving	**19.1 PJ**
- Electric cars & electrification of public transport and ports	1.2
- Built environment (housing, utility, industry, agriculture)	17.9
Hydropower	**19.8 PJ**
- Hydropower (>10MW)	13.2
- Micro-hydropower (<1MW)	6.6
Tide energy	**1.4 PJ**
- 45 depth prototype (1MW)	
Ocean wave	**2.0 PJ**
- Prototype (wave height of 3 m & wave period of 8 seconds has 36 kw of power potential per meter of wave crest)	
Blue energy	**1.0 PJ**
- Prototype (One cubic meter of fresh water with 3,5 mass percent salt has a potential energy of 2,5 megajoule (0.7KWh))	
Wind energy	**3.2 PJ**
- Wind turbines (3.3MW)	2.0
- PV along infrastructure	1.2

	Total
Self-sufficient buildings	**0.6 PJ**
- Zero-emission passive building	
Self-sufficient villages	**0.7 PJ**
- Off-the-grid eco-village (eg. ReGen)	
Biomass	**1.6 PJ**
- Biomass covering	
Storage and Network	**-**
- Energy storage	-
- Low temperature heat	-
Mobility	**Total Consumption**
- Lighrail, highway and tunnel	2050 **19.1PJ**
Housing	**Total Production**
Office	2050 **34.8PJ**
Public service	
- Education	
- Shopping	
- Sports & recreation	
- Nursery & hospital	

Fig. 142. Application of new evolutionary resilience projects
By author

5 CONCLUSION & REFLECTION

5.1
CONCLUSION

This project explored and summarized a adaptive strategy towards evolutionary resilience, which is inspired by the drastic climate changes in recent years and the transformation of petroleum sector in the North Sea.

This strategy is proved to be an effective solution by using Norway and Bergen as experimental sites. It not only deal with the probable risks caused by rising sea levels, extreme precipitation and landslides, but also take this transformation opportunity to bring more natural resources and energy to the region and the country and improve the performance of various urban systems.

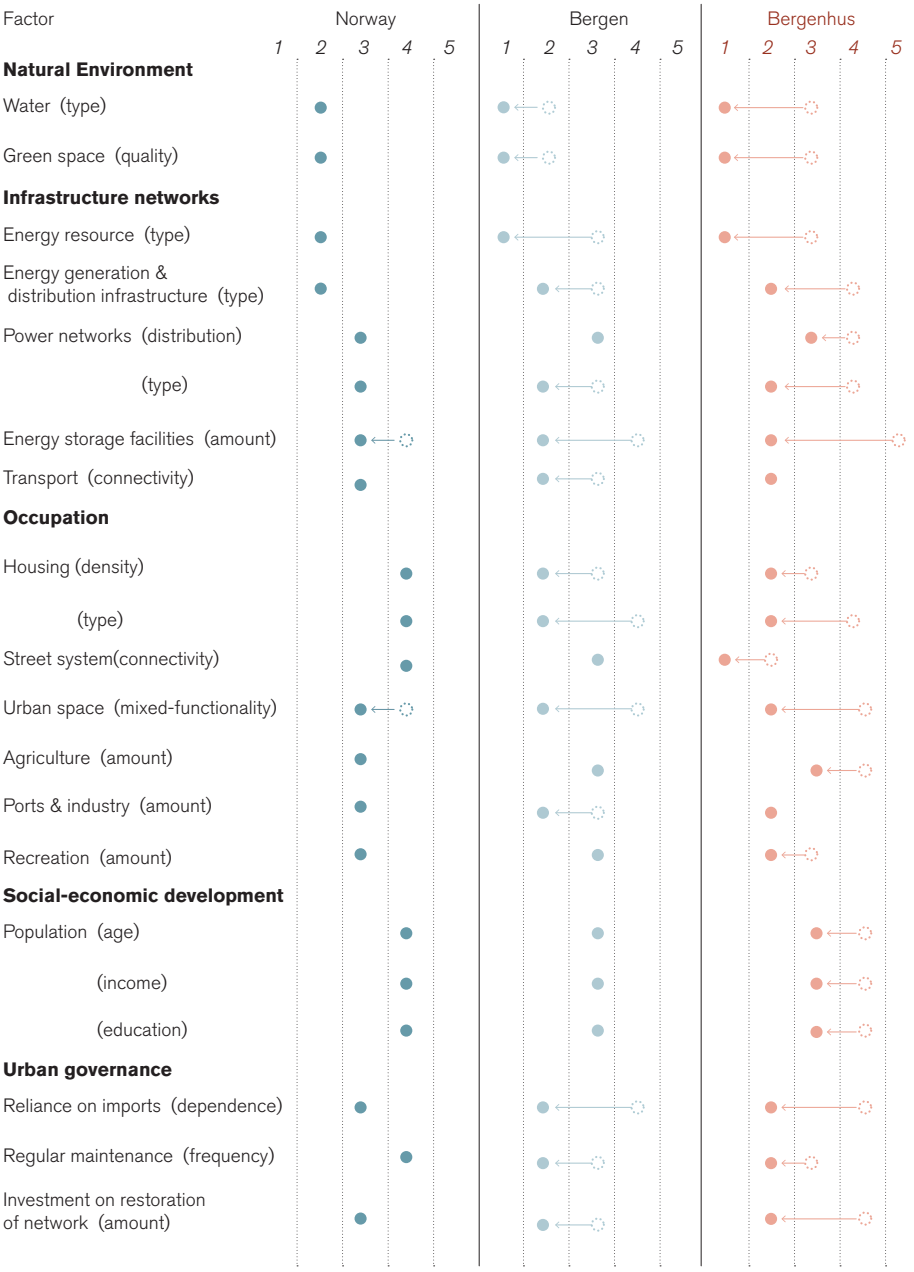
Firstly, to Norway, because of the complex terrain, the impact of climate change is even more dramatic and diverse, especially the west coast region. In addition, as an oil-rich country and a leader in renewable energy, Norway is facing a process of shifting from the carbon-based industry to new energy. How to encourage energy transitions in the face of changing weather conditions is particularly important and urgent for Norway.

So, here, take Bergen as a research object, who is the second largest city in Norway and one of the typical cities on western coast. Through deep analysis of climate change impacts and the potential risks, and assessing required energy transition goals to explore integrated resilience strategies 9that can be applied in the coastal region of Norway.

Main strategies are firstly restructuring blue-green corridor and using prevention measures to reduce potential risks, then make full use of climate change in energy production, and rationally allocate resources in limited space and finally renew space to meet future population growth needs within urban governance and reach a high level of evolutionary resilience.

The city will not be troubled by disasters and even take advantage of this opportunity to update and thus has a higher level of adaptability. It also makes full use of the resources brought about by climate change to accelerate the energy transition and re-examine the existing structure.

Evaluation of new vision



5.2
UPSCALING TO THE NORTH SEA

So far, the partnership of the North Sea region is mainly around the fossil fuel resources. It is expected that in the future, countries will share renewable energy , which is critical in the transition to a zero-carbon electricity system and keeps the temperature rise within 2 degrees.

Firstly, as a pioneer in renewable energy, Norway can share 555PJ surplus green energy by 2050 through the design and projection of this project. Considering that an undersea energy interconnector between UK and Norway has been built (a method of linking up electricity and gas networks), hydro power in Norway can replace wind energy in the UK when the wind was not blowing, which can support 30 000 000 people (based on 5130kWh energy consumption per capita in UK).

However, if it is only to share the surplus power in Norway with other countries in the North Sea region, the power is still too weak. So, a regional electricity grid in the North Sea region is needed. Applying the strategy in this project to countries with similar characteristics, the ambition of lowering the reliance on fossil fuels and improving overall energy and climate security will be achieved. For example, Iceland is experiencing the similar situation as Norway, who also has potential for hydro power and storage as well as geothermal energy.

Generally speaking, this project provides an idea to prevent climatic risks and even utilize the changing condition to generate more green energy for a country, which could benefit the region by exchanging exceed renewable energy, adding diverse energy sources and meeting the challenge of greener, affordable energy. On account of increased supplies through the regional electricity grid in the North Sea region in the future, there will be no blackouts even though the country is vulnerable to energy shocks.

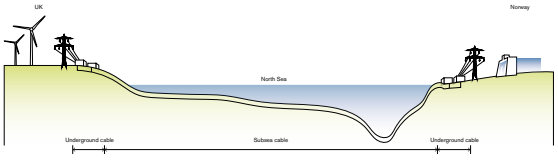


Fig. 143. Profile of the North Sea
By author refer to EU's Innovation and Networks Executive Agency (INEA) (February 2017)

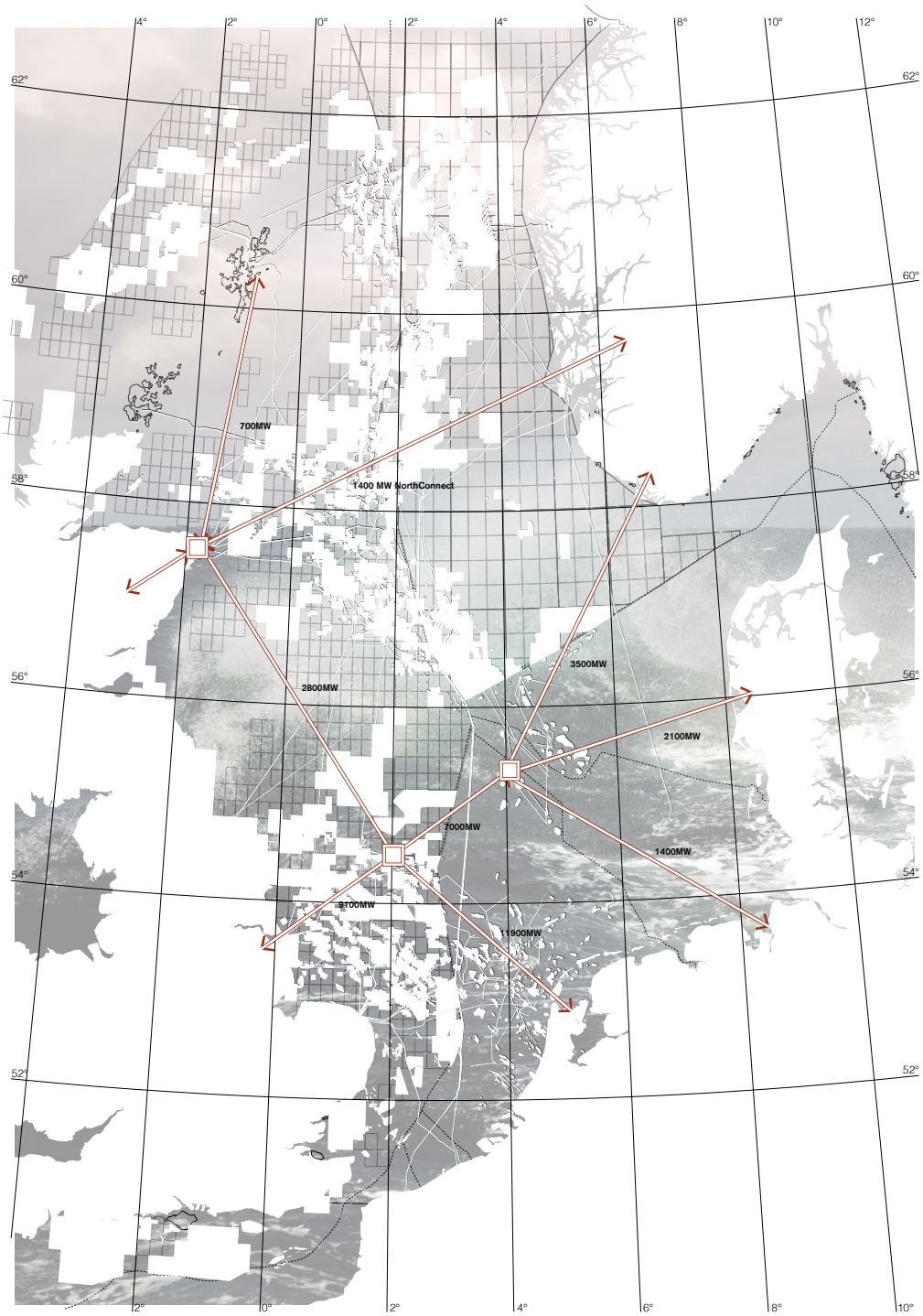


Fig. 144. Regional electricity grid in the North Sea
By author refer to Hegeman Water Expertise 2009 - 2017 & DI gourp 4

5.3
REFLECTION

The project is about the reverse of risks from changing climate and transitional energy system into opportunities to become evolutionary resilient cities.

Climate change is happening globally and is becoming more and more serious now. The temperature rise, sea-level rise, land shifting, precipitation pattern change, extreme weather increase the potentiality of risks like coastal flooding, pluvial flooding, landslide, snow slide and so on. To mitigate the climate change, energy transition is put forward which is the most effective way to control greenhouse emission. But this kind of measure requires the change of energy system also including social, economic and spatial alteration, especially the country like Norway who benefits from the petroleum sectors since the years of history. The combination of climate change and transitional energy system will threaten the whole urban systems and the people will finally become the victims.

On the other side, considering the main climatic change and geographical condition of Norway, more water from sea, river and sky brings the opportunity to accelerate energy transition. Therefore, in this project energy sector in transition is utilized as the tool to explore how to diminish the impact of climate change, meanwhile to reduce the vulnerability of urban systems and even convert the risks into opportunity of evolutionary resilience. The transitional process is proposed towards 2050.

Aspect 1

- the relationship between research and design.

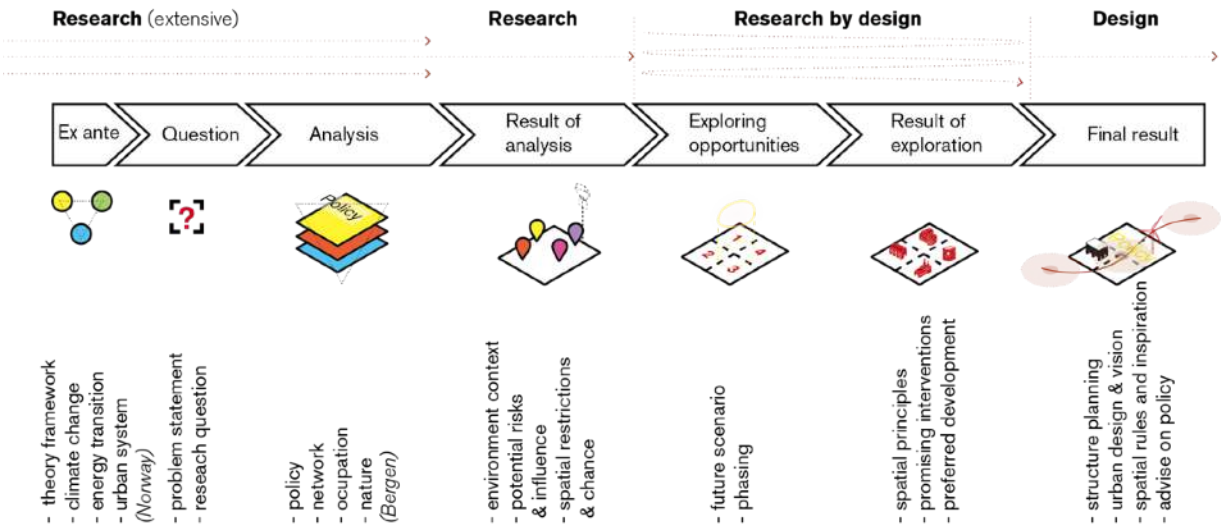


Fig.1 Research and design process.
Source: author

In the initial stage, the research provides the background for this project, including the context, the theoretical framework and the analytical framework. The original analysis of the North Sea region and Norway triggers my interest in the relation between climate change, energy transition and urban systems. The tremendous changes of climate and the strong ambition of energy transition happening on the complex urban systems led to the uncertainty of future with a high risk, and then this framed my main research question, "which adaptive strategies can be

applied in the coastal system of Norway assessing the climate change impact within the process of energy transition goals". So, as the ex ante, theories of vulnerability and risk, transformability, relevant delta urbanism, complex urban system and evolutionary resilience are constituted to the theoretical framework.

Then several research process were applied to deepen my understanding of the specific location Bergen city and build envisioned goals towards 2050 which will guid my design. By measuring the effects of climate change and evaluating the goals and possibilities of energy transition on the specific location, the risks and transitions on the urban systems which embedded in the urban structure can be concluded. A deeper understanding of possible risks in Bergen would have helped to proceed with the design easier. And scenario method helps to identify the current trends and set two extreme future situation by overlapping the low limit and high limit of temperature increase, the share of renewable energy and socio-economic growth, around which the expected situation can move and adapt. Combined with this, the research of involved stakeholders, cost and benefit are also included to propose new goals which are the guidance for spatial interventions.

Based on these research, the structure in the region scale will be reorganized. But it is quite hard to make a clear distinction between right and wrong on this level. So the urban design in the center of Bergen can be seen as the test of the ambition on the regional scale by showing how to deal with the issues of urban composition according to the climatic mitigation, energy transition and socio-economic variation. Then the evaluation of the Bergen center is also used to reflect validity of regional structure. If it works, this kind of structure and urban design can be applied more extensively to the similar-conditioned regions. Otherwise, this need to be revised. This method of formulating design strategies through research and verifying the possibility of research through field of design (research by design) helps to integrate progressive strategies and build a new vision for Norway coastal area to reach better resilience level by adapting the coastal urban system considering climate change effects integrating with the potentiality of the requested energy transition.

Aspect 2

- the relationship between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS).

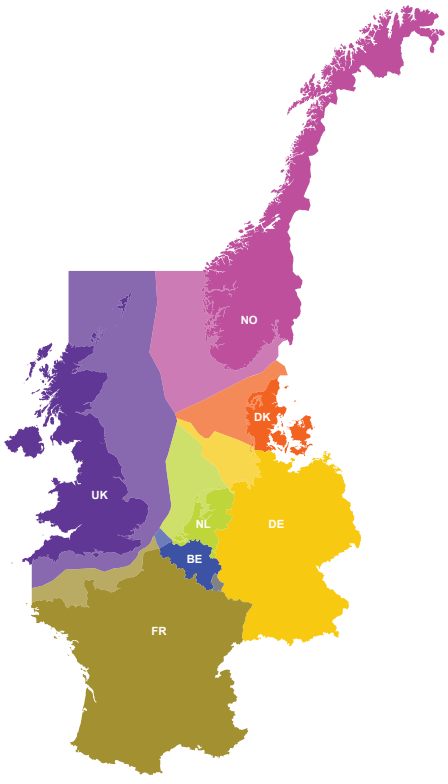


Fig.2 *Territorial entitlement*
Source: OMA

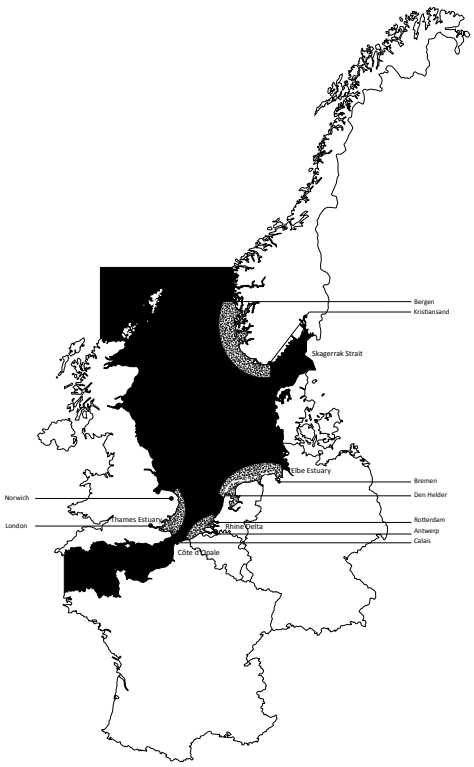


Fig.3 Important cities in the North Sea Region
Source: Delta Intervention Studio

The Delta Intervention studio concentrates on the impact of spatial interventions to the dynamic delta environment according to the global climate change. The North Sea as the chosen site for this year in the studio is greatly influenced by changing climate, with much uncertainty, where delta urban design is not only a mean of spatial improvement but also a way of research to explore the future potentials and reframe the current approaches. My graduation project was designed to find an adaptive pathway to balance dynamic natural system and manual activities corresponds well to the focus of Delta Intervention Research Group. Meanwhile, the graduation project contributes to the topic of Delta Intervention studio as well by exploring the way of using transitional energy sector to diminish the risk of climate change and reverse the risks into opportunity of reaching evolutionary resilience. The research and tentative design may be the example in the similar-condition area and build a new resilience structure in the North Sea region with low climatic risks and high share of renewable energy.

Considering the particularity of Delta Intervention studio who convene the master students in Architecture, Urbanism, Landscape and Engineering together, this graduation project is influenced by various fields. The research and design process is based on the diverse aspects. While, as a student major in Urbanism, the emphasis in put on the integrated progressive strategies towards evolutionary resilience and a new vision for the Norway coastal region even the North Sea region. However, I learnt a lot from this studio and the lectures organized. The lecture of 'Becoming-Infrastructure' by Ross Exo Adams elaborates the concept of 'Resilient Urbanism' by introducing the relation between nature, bodies and infrastructure from past to now, which help me to thinking from the aspect of the balance between environmental and infrastructural performance and the risks and opportunities brought by changing climate in Norway. The self-organized workshops also contributes to facilitate communication between different trajectories in graduation studios and support our own projects within the main scope of resilient design.

Aspect 3

- Elaboration on research method and approach chosen by the student in relation to the graduation studio methodical line of inquiry, reflecting thereby upon the scientific relevance of the work.

The Delta Intervention studio focus on integrated approach towards a balance of economy ecology and safety through works throng times, scales and layers to understand the dynamic delta region, build scenarios to deal with the uncertainties and consider design as a way of research to imagine potential futures and to reframe current approaches with the aim to find the balance between landscape and urban. Similarly, in my graduation project, I firstly analysis the climate change impacts and energy transition impacts on different layers within different scales to know the risks and potentials. Explanatory scenarios are built to define the trends and set goals, which guides the design of structure in regions and urban regeneration in small scales. Urban design in detail serves as the test of the ambition on the regional scale. Through continuous adjustment of urban composition according to the climatic mitigation, energy transition and socio-economic variation to reach the goal of controlling temperature increase under 1.5 degree and reach 80% share of renewable energy in Norway. This stimulates the research oriented approaches which is always closely related to specific site, scale and space and address urgent issues.

Aspect 4

- Elaboration on the relationship between the graduation project and the wider social, professional and scientific framework, touching upon the transferability of the project results.

The climatic control is a difficult but urgent task. According to COP21, all the countries are responsible to keep the increased temperature below 2 degree centigrades. Thus, energy transition is regarded as an efficient tool to reduce greenhouse gas and mitigate climate change. However, the high dependence on weather and environment makes the renewable energy more vulnerable. So the research project is quite essential and urgent to the society, which is trying to find a resilient solution of accelerating energy transition under the increasingly serious climate change impact while meeting the demand of future population.

In Norway, considering the main climate change impact, increasing precipitation and sea level rise, and the special geological features, there is great potential to revise the climate change risk into potential of producing more energy. Actually, Norway has already devoted himself to low-carbon energy. New tech-knowledge system are applied to energy generation for example using electricity exclusive hydropower to generate energy and access to new energy like wind power and flexible hydropower. Norway has a good beginning in the production and usage of energy in the new field and is likely to serves as a paragon that other countries can copy the success on resilience energy system under climate change. But it should be mentioned that in the new sites with similar conditions, the patterns and the solutions still need to be tested again on the location.

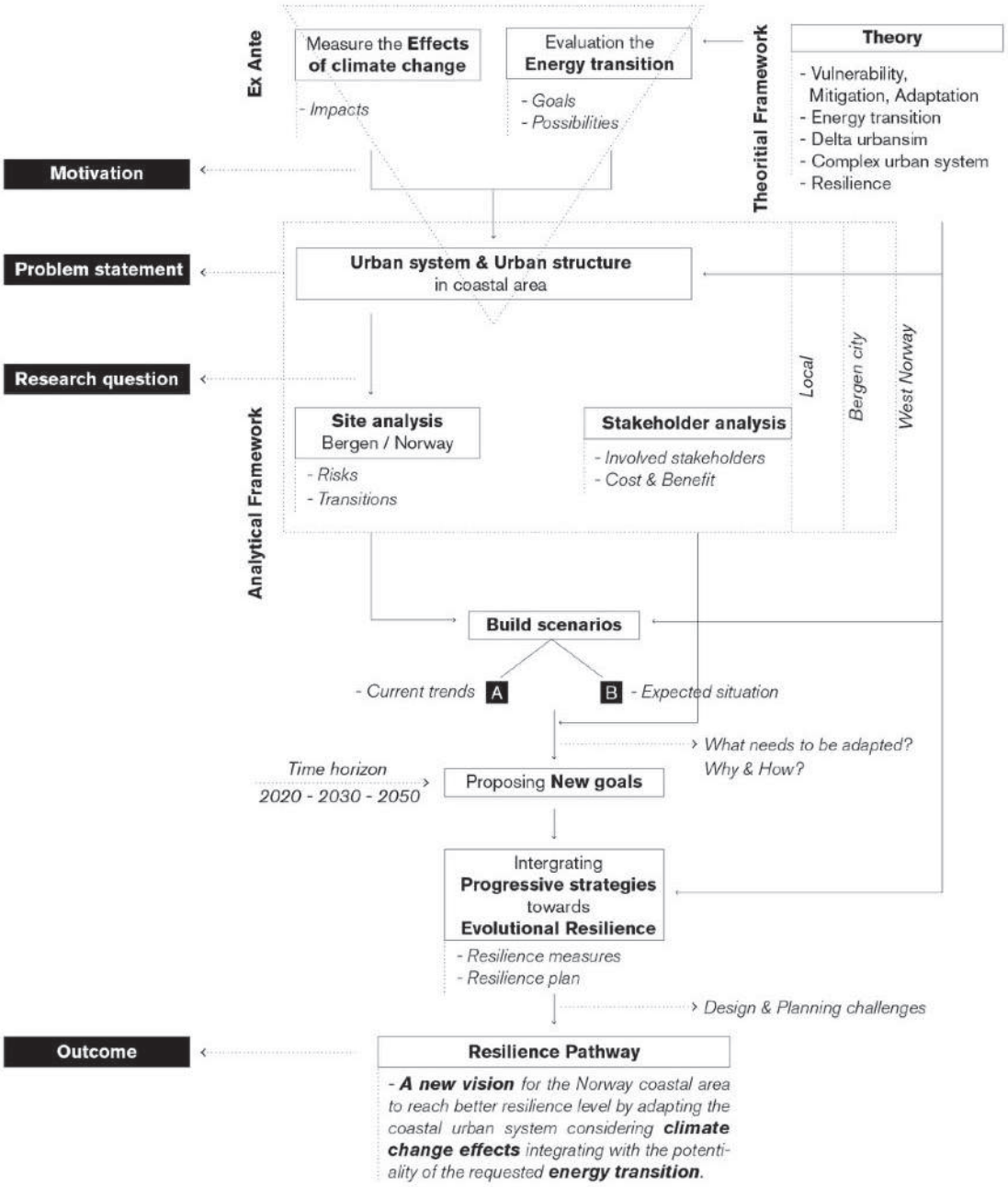


Fig.4 Methodology
Source: Author

Aspect 5

- Discuss the ethical issues and dilemmas you may have encountered in (i) doing the research, (ii, if applicable) elaborating the design and (iii) potential applications of the results in practice.

The main challenge in this project is involved with the unemployment of petroleum workers and related people caused by the great deal of transition from carbon-based economy to green-based. In 2016, there are 185 300 people were employed by the petroleum sector and related industries, , either directly or indirectly, accounting for almost 7 percent of the total number of employment in Norway (MPEMPD, 2018). The increased share of renewable energy and a lower level of vitality in the oil and gas industry recently has already caused 47 000 people in Norway unemployed compared with 2013, a decrease of about 20%. For decades, Norway is known as a prosperous country in the world relying on the offshore exploitation of petroleum and the petroleum workers, engineerings are quite popular. But now, they are unwanted. They are facing an uncertain future. In other words, the employment needed by other economic industries are due to the demands of the oil and gas industry. Furthermore,

considering the aging effect, there is a tendency of raising proletariat in the job market. And, as largest contribution in terms of appended value, government revenues, export revenues and capital inflows, the oil and gas sector in Norway is also facing the uncertainty, and even influence the global market. This encourages us to think about the future lifestyle, the social-economy structure, daily demand of energy, living and working environment according to the climate change and the way of development of the city.

However, in general, my research provides a possibility of utilizing energy transition as a tool to mitigate climate change and even general more energy through this change, and finally reach the evolutionary resilience of the city. Especially, as a major energy nation in Europe, Norway has the unique set of resources of 20% hydropower, 40% gas, 60 % oil and new renewable energy sources such as wind power and biomass, and has already devoted himself to low-carbon energy and new technology system. In addition, 90% of exported energy in Norway is exported to European country, if Norway can play his strength in clean energy and be the pioneer in the energy transition process under climate change situation, the road towards climate neutral will be much easier. This approach can not only be applicable in the North Sea region where the countries has similar situation, but also relevant to the global society in a broader context.

This graduation project can be seen as the exploratory research by design. There are three key steps during the process. The first is to make it clear what is the climate change and what is the relation between climate change and energy transition. In my case, the water from sky and sea is the crux, which brings the water risks but also the opportunity for renewable energy. The second key step is the systematic process of utilizing the transitional energy system as the tool to mitigate climate change and increase opportunity. It is essential to clarify how the process of transformation should be executed and what needs to be done more urgent. The last is to illustrate this idea both on regional structure and local design. The regional structure shows the reconstruction of task distribution and the detailed urban design is to test and evaluate the aim on the regional scale. The research and design consistently correlate to contribute to a convincing and practical project. Meanwhile, the logic of unfolding this project's idea is also important. A clear and persuasive narrative will make the communication more efficient and the audience will be easier to understand. This is appropriate to both written report and oral presentation.

Reference

1. MPEMPD (Ministry of Petroleum and Energy, the Norwegian Petroleum Directorate) (2018) , Employment in the Petroleum Industry. Norway. See https://www.norskpetroleum.no/en/economy/employment (accessed 22/05/2018).

5.4
SOCIETAL AND SCIENTIFIC RELEVENCE

This graduation project contributes to the Delta Intervention Studio by exploring the resilience pathway of energy system under the uncertainties of climate change impact according to the energy transition policy.

Societal relevance

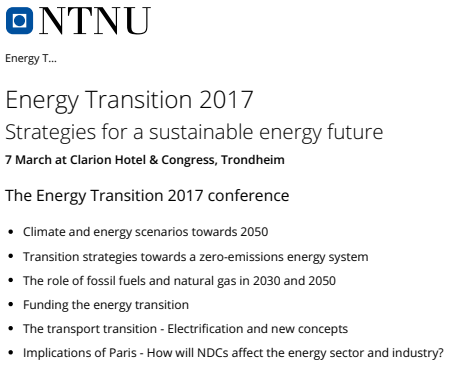
Nowadays, climate change mitigation is a global topic. In 2015, 195 countries adopted the first and universal binding climate agreement at 2015 Paris Climate Conference (COP21), with the ambition to keep the increased temperature below 2 degree centigrade.

The energy transition was regarded as an opportunity for the countries to great extents to reduce greenhouse gas and contribute to climate change mitigation. However, the dependence of renewable energy on weather and environment makes the green energy more vulnerable. Given the increasingly serious climate change and incremental energy demand due to population growth, how to keep the continuous of the energy system especially in the transition is essential and urgent to the society.

In Norway, the public finances are greatly boosted by petroleum sector, and nearly 30% employment is provided by energy system and related service system (Statistics Norway, 2017), which will be greatly influence by the change of coastal energy system. Meanwhile, it will also challenge the other water related or coast based economy for example fish breeding sectors. This also encourages us to think about the future lifestyle, will our daily demand of energy be satisfied, how will the delta environment be according to the climate change and what is the impact on the way of development of delta urbanism.

On the other hand, as a main production and export country for energy, Norway has already devoted himself to low-carbon energy. New tech-knowledge and new now are applied to energy generation for example using electricity exclusive hydropower to generate energy and access to new energy like wind power and flexible hydropower. Norway has a good beginning in the production and usage of energy in the new field, comparing with average consumption in the world which has a relatively low rate. Furthermore, 90% of energy in Norway is

exported to European country. If Norway can play his strength in clean energy as the only provider in European, the supply is promised and CO2 emission of energy system will be lower, also shorter distance to transport and lower the carbon tax. In this aspect, Norway can serves as a paragon that other countries can copy the success on resilience energy system under climate change.



Scientific relevance

The graduation project tries to find out some adaption and mitigation strategies for coastal areas under climate change, especially in the progressively transition from carbon-based energy to green energy, which is rarely studied till now. Although there is a lot of academic paper discuss about the meaning of resilience in terms of the whole urban system, and the vulnerability of energy system in the engineering domain, few has studied on the combination of both two. The knowledge transferred in the research of case study could be applied to other relevant question. Furthermore, this kind of interdisciplinary methodology can be applied to other fields.

Although the one-year master thesis is quite plain, it can still contribute to existing state of knowledge on pathways to develop coastal adaptive design on energy system. Also, more relevant questions are aroused, how to deal with coastal energy infrastructure after redundancy, how to keep prosperous and achieve sustainable economic transitions of cities that lost their economy

Fig. 145. Keynote of The Energy Transition 2017 conference
Source: Norwegian University of Science and Technology, https://www.ntnu.edu/energytransition2017

pillar like petroleum sector. The challenge that urban designers are facing is not only to find a solution to protect specific infrastructure or system in order to make our city safe, but also to make it better, more resilient, more sustainable. This graduation project may serves as motivator to assemble designers and researches to thinking for a better future for our regeneration.

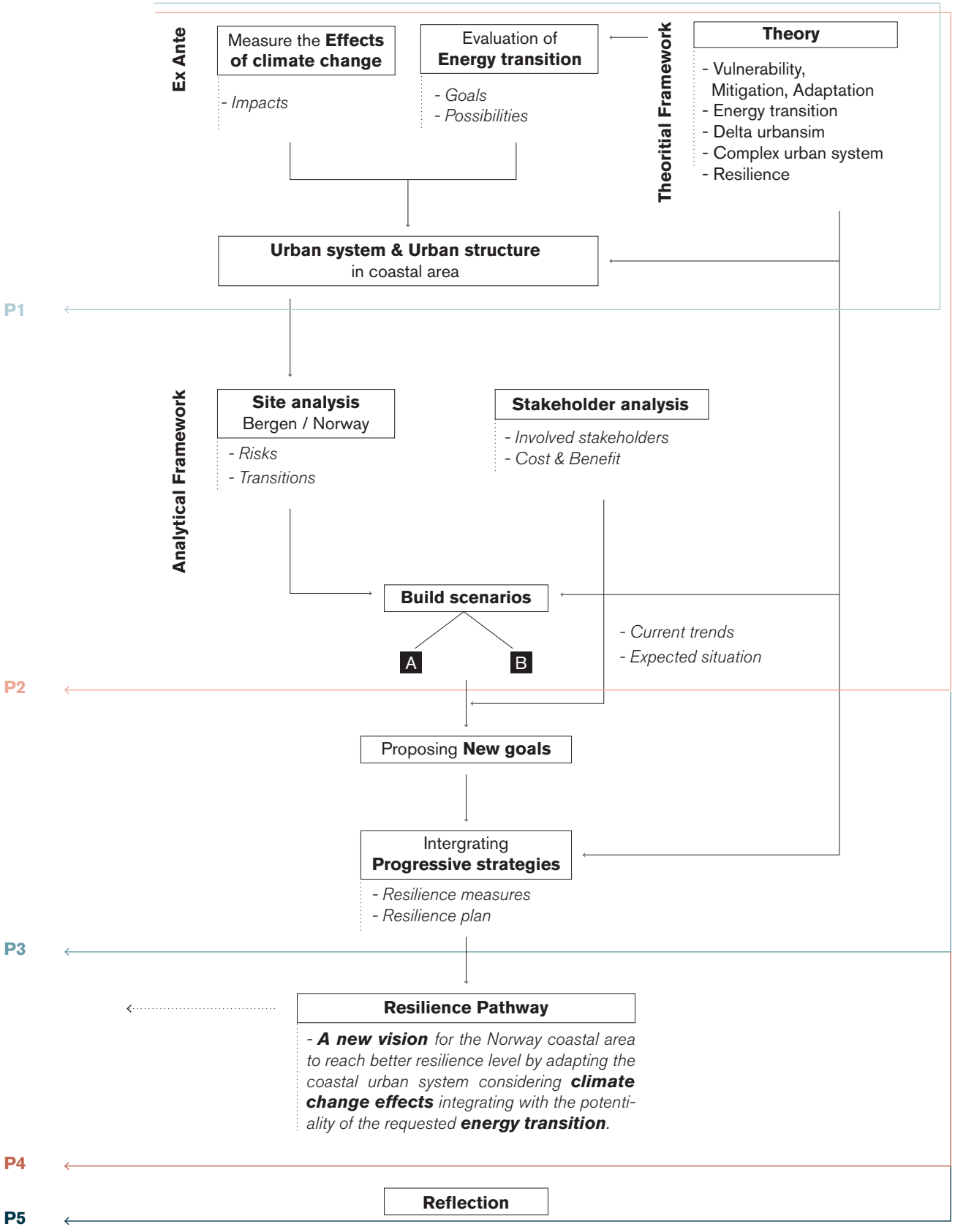
Specific to the Delta Intervention Research group

This research studio concentrates on evaluate the impact of spatial interventions to the dynamic delta environment according to the global climate change. The North Sea as the chosen site for this year in the studio is greatly influenced by changing climate, with much uncertainty, where delta urban design is not only a mean of spatial improvement but also a way of research to explore the future potentials and reframe the current approaches. My graduation project was designed to find an adaptive pathway to balance dynamic natural system and manual activities corresponds well to the focus of Delta Intervention Research Group.

Meanwhile, exploring adaptive design for the energy system in the coastal region of Norway can contribution to this studio as well. Based on the same emphasis on the dynamic relation between nature and human with Delta Intervention Studio, the graduation project can furthermore provide a potential paths for delta urbanism.

ANNEX

TIMEFRAME


Ex Ante
Measure the Effects of climate change
- Impacts
Evaluation of Energy transition
- Goals
- Possibilities
Theoritial Framework
Theory
- Vulnerability, Mitigation, Adaptation
- Energy transition
- Delta urbansim
- Complex urban system
- Resilience
Urban system & Urban structure in coastal area
P1
Analytical Framework
Site analysis Bergen / Norway
- Risks
- Transitions
Stakeholder analysis
- Involved stakeholders
- Cost & Benefit
Build scenarios
A
B
- Current trends
- Expected situation
P2
Proposing New goals
Intergrating Progressive strategies
- Resilience measures
- Resilience plan
P3
Resilience Pathway
- A new vision for the Norway coastal area to reach better resilience level by adapting the coastal urban system considering climate change effects integrating with the potentiality of the requested energy transition.
P4
Reflection
P5

REFERENCE

- Motivation

Anthony, E. J. (2015). Wave influence in the construction, shaping and destruction of river deltas: A review. Marine Geology, 361(Supplement C), 53–78. https://doi.org/10.1016/j.margeo.2014.12.004

- Context of project

Holt, S. J., & Raicevich, S. (2017). Evolution of the theory of rational fishing. The case study of the North Sea. Regional Studies in Marine Science. https://doi.org/10.1016/j.rsma.2017.09.001

Glennie, K. W. (1998). Petroleum Geology of the North Sea: Basic Concepts and Recent Advances. Blackwell Publishing. pp. 11–12. ISBN 978-0-632-03845-9.

Noreng, Ø. (1980). The oil industry and government strategy in the North Sea. Croom Helm ; Boulder, Colo. : International Research Center for Energy and Economic Development, London

Barry, M., Elema, I., & van der Molen, Paul (2006). Governing the North Sea in the Netherlands: Administering marine spaces: international issues. Frederiksberg, Denmark: International Federation of Surveyors (FIG). pp. 5–17, Ch. 5. ISBN 87-90907-55-8.

OSPAR, 2000. Quality Status Report 2000, Region II - Greater North Sea. OSPAR Commission, London, 136 pages.

Safecoast (2008), Coastal flood risk and trends for the future in the North Sea region, synthesis report. Safecoast project team. The Hague.

Bjørnland, H. (1998). The Economic Effects of North Sea Oil on the Manufacturing Sector. Scottish Journal of Political Economy, 45(5), 553–585.

Strtistics Norway. (2017). This is Norway 2017. What the figures say. the Department of communications, Statistics Norway. http://www.ssb.no/en/befolkning/artikler-og-publikasjoner/this-is-norway/

Ferrier, R.W. & Bamberg, J.H. (1982). The History of the British Petroleum Company. Cambridge, United Kingdom: Cambridge University Press

Kemp, A. (2013). The Official History of North Sea Oil and Gas. Vol. I: The Growing Dominance of the State. London, United Kingdom: Routledge

Stauble, A.J. & Milius, G. (1970). Geology of Groningen Gas Field, Netherlands. The Hague, The Netherlands: Bataafse Petroleum Maatschappij

Central Intelligence Agency, 2017. The World Factbook, Country Comparison, Crude Oil, Proved Reserves. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/rankorder/2244rank.html on 02-10-2017

- Problem field & theoretical framework

Meyer, H. & Nijhuis, S.(2014), Urbanized deltas in transiton, Techne Press, Amsterdam, The Netherlands

Zevenbergen, C., Veerbeek, W., Gersonius, B. & Van Herk, S. (2008), Challenges in urban flood management: travelling across spatial and temporal scales. Journal of Flood Risk Management, 1, 81-88.

Overeem, I. & Brakenridge, R. G. (2009). Dynamics and vulnerability of delta systems, GKSS Research Centre, LOICZ Internat. Project Office, Inst. for Coastal Research.

Meyer, H. & Nijhuis, S. (2013) 'Delta urbanism: planning and design in urbanized deltas – comparing the Dutch delta with the Mississippi River delta', Journal of Urbanism 6 (2); 160-191 DOI: 10.1080/17549175.2013.820210

Gleeson, B. 2008. 'Waking from the Dream: An Australian Perspective on Urban Resilience,' in Urban Studies, 45, pp. 2653-2668.

Birkmann, J., Cardona, O., Tibaduiza, M., Barbat, A., Pelling, M. & etc. (2013). Framing vulnerability, risk and societal responses: The MOVE framework. Natural Hazards, 67, 193–211. https://doi.org/10.1007/s11069-013-0558-5

Lonescu, C., Klein, R. J. T., Hinkel, J., Kumar, K. S. K., & Klein, R. (2009). Towards a Formal Framework of Vulnerability to Climate Change. Environmental Modeling & Assessment, 14(1), 1–16. https://doi.org/10.1007/s10666-008-9179-x

Brooks, N., (2003). Vulnerability, risk and adaptation: A conceptual framework. Tyndall Centre for Climate Change Research Working Paper, 38, 1-16.

Sharifi, A., & Yamagata, Y., (2014) Major principles and criteria for development of an urban resilience assessment index. In: Proceedings of the 2014 international conference and utility exhibition on green energy for sustainable development (ICUE): IEEE; 2014. p. 1–5.

Barata-Salgueiro,T., & Erkip, F., (2013) Retail planning and urban resilience – an introduction to the special issue. Cities. 2014;36:107–11.

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, 4(1), 1–23.

Adger, N., (2000), Social and ecological resilience: Are they related?. Progress in Human Geography, 24(3) (2000), pp.347-364

Proag, V. (2014). The Concept of Vulnerability and Resilience. Procedia Economics and Finance, 18(Supplement C), 369–376.

Conference of the Parties (COP). Adoption of the Paris Agreement. Available online: https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (accessed on 31 October 2017).

Mitchell, M., (2009), Complexity: a guided tour, Oxford University Press, Inc., New York, ISBN 978-0-19-512441-5.

- Research

The Norwegian Centre for Climate Services (NCCS), (2017), *Cliamte in Norway 2100*, NCCS report no. 1/2017, M-741.

Bergen Kommune, (2014), Bergen ROS (overordnet risiko- og sårbarhetsanalyse for Bergen) 2014

BaltCICA, http://www.baltcica.org/casestudies/bergen.html

Statistics Norway, (2014), http://www.ssb.no/energibalanse

Ministry of Petroleum and Energy, (2013), National Renewable Energy Action Plan under Directive 2009/28/EC Norway, Inofficial translation of September 2012, based on NRAP in Norwegian of June 2012

GRIND, https://grind.no/industri-energi-naturressursar/vannkraft-i-hordaland

SSB, (2017), https://www.ssb.no/kommunefakta/bergen

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and society,* 15(4).

Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Downing, TE, Butterfield, R, Cohen, S, Huq, S, Moss, R, Rahman, A, Sokona, Y and Stephen, L (2001). Vulnerability Indices: Climate Change Impacts and Adaptation, UNEP Policy Series, UNEP, Nairobi.

Polsky, C., Neff, R., Yarnal, B.(2007), Building comparable global change vulnerability assessments: The vulnerability scoping diagram, Global Environmental Change, 17 (3–4) (2007), pp. 472-485.

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, 4(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Bergen commune (2016) Grønn strategi, Klima - og energihandlingsplan for Bergen 2016

Barata-Salgueiro, T., & Erkip, F. (2014). Retail planning and urban resilience. Cities, 36, 107-111.

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., ... & Van Vuuren, D. P. (2016). Biophysical and economic limits to negative CO 2 emissions. Nature Climate Change, 6(1), 42.

Davoudi, S.,Zaucha, J., and Brooks, E. (2016), Evolutionary Resilience and Complex Lagoon Systems, Integrated Environmental Assessment and Management, 12(4), pp. 711–718.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). IPCC

Hanssen-Bauer, I., Drange, H., Førland, E. J., Roald, L. A., Børsheim, K. Y., Hisdal, H., ... & Sundby, S. (2009). Klima i Norge 2100. Bakgrunnsmateriale til NOU Klimatilplassing.

de Koning, R., & Nes, A. (2017). "Mind the Mindemyren". A new spatial analysis tool for linking building densification strategies to public transport and street network accessibility in Bergen city in Norway.

Bergen Kommune, Siemens & Bellona, (2011).

Bergen SmartCity: Energy Efficiency. https://www.bergen.kommune.no/bk/multimedia/archive/00105/Bergen_SmartCIty_105941a.pdf (accessed on 27 June 2018).

Sirin Engen (ed.), Tore Amundsen, Andreas Bratland, Line Barkved, Hege Brende, etc. (2015). Norway 2050: a vision for a low-carbon society. Oslo, Norway. The Bellona Foundation, R&Dialogue.