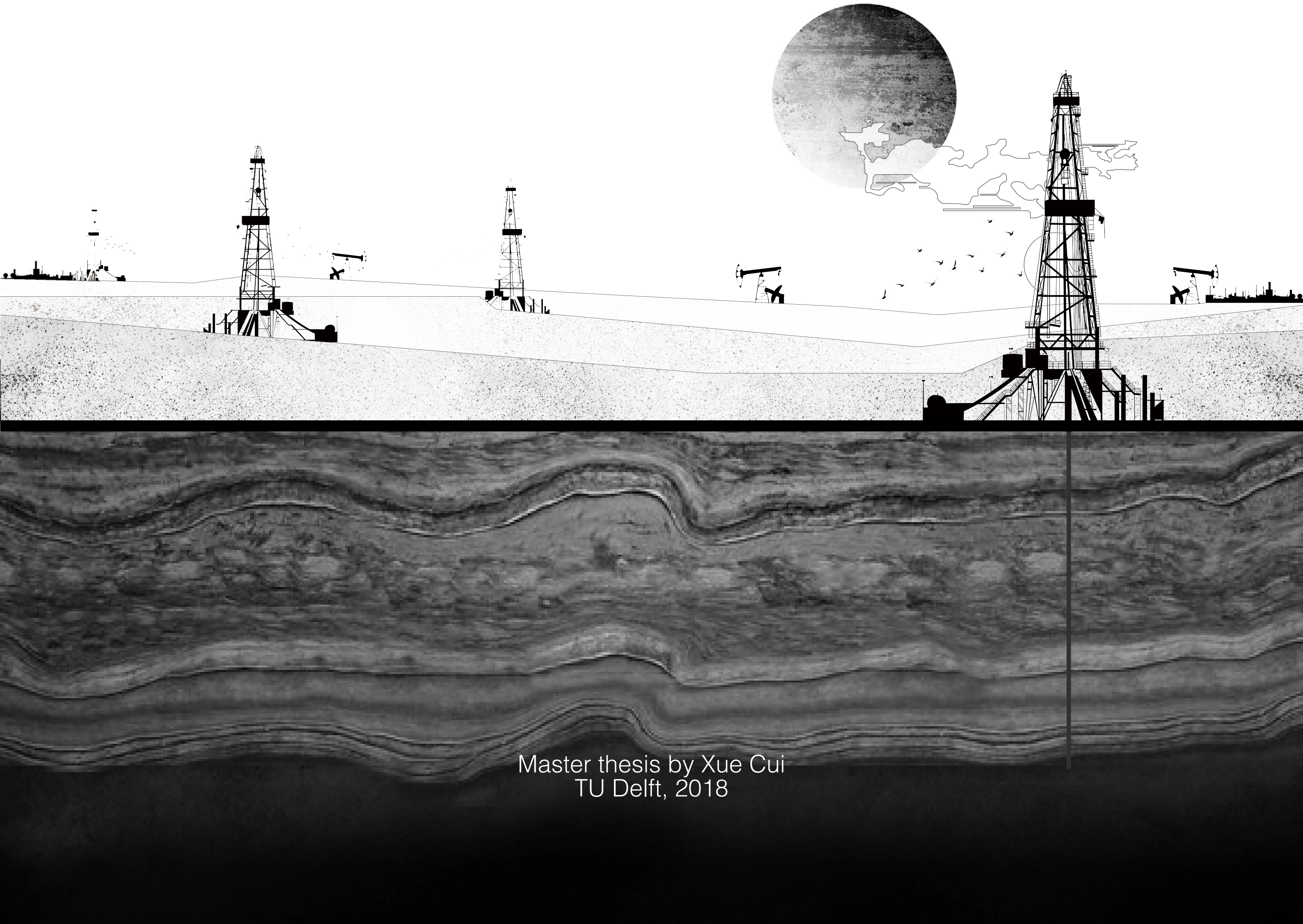
REPOWER THE PETROLEUMSCAPE OF DAQING



Master thesis by Xue Cui
TU Delft, 2018

Master thesis
Repower the petroleumscape of Daqing

Combining Drosscape and Energy Landscape Theory
in a Post-petroleum Planning of Daqing

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REPOWER THE PETROLEUMSCAPE OF DAQING

Combining Energy Landscape Theory and Scenario
Planning in a Post-petroleum Planning of Daqing

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Contents

Abstract

As petroleum depletion and climate change becoming evident, it is relevant for urban designers and planners to think within a new energy paradigm contextualized by post-petroleum era. This report combines drosscape and energy landscape theory with post-petroleum planning, and tests this proposed method in Daqing, an oil city located in the northeast fringe of China. The present conditions of Daqing are analysed to provide a comprehensive understanding of the situation. Scenario building is then applied as a scholarly research method to deal with the future uncertainties in the hypothetical post-petroleum context, and picture spatial consequences of Daqing powered by renewable energy. Among the possible futures, two scenarios concerning renewable energy supply a base, upon which series of spatial strategies are delineated. This report is a research-based design – an experiment of using landscape (especially the abandoned petroleumscape) to facilitate renewable energy production and pursue urban economic and energy resilience, while improving the spatial quality of Daqing.

Keyword: Petroleumscape, post-petroleum planning, energy landscape, drosscape

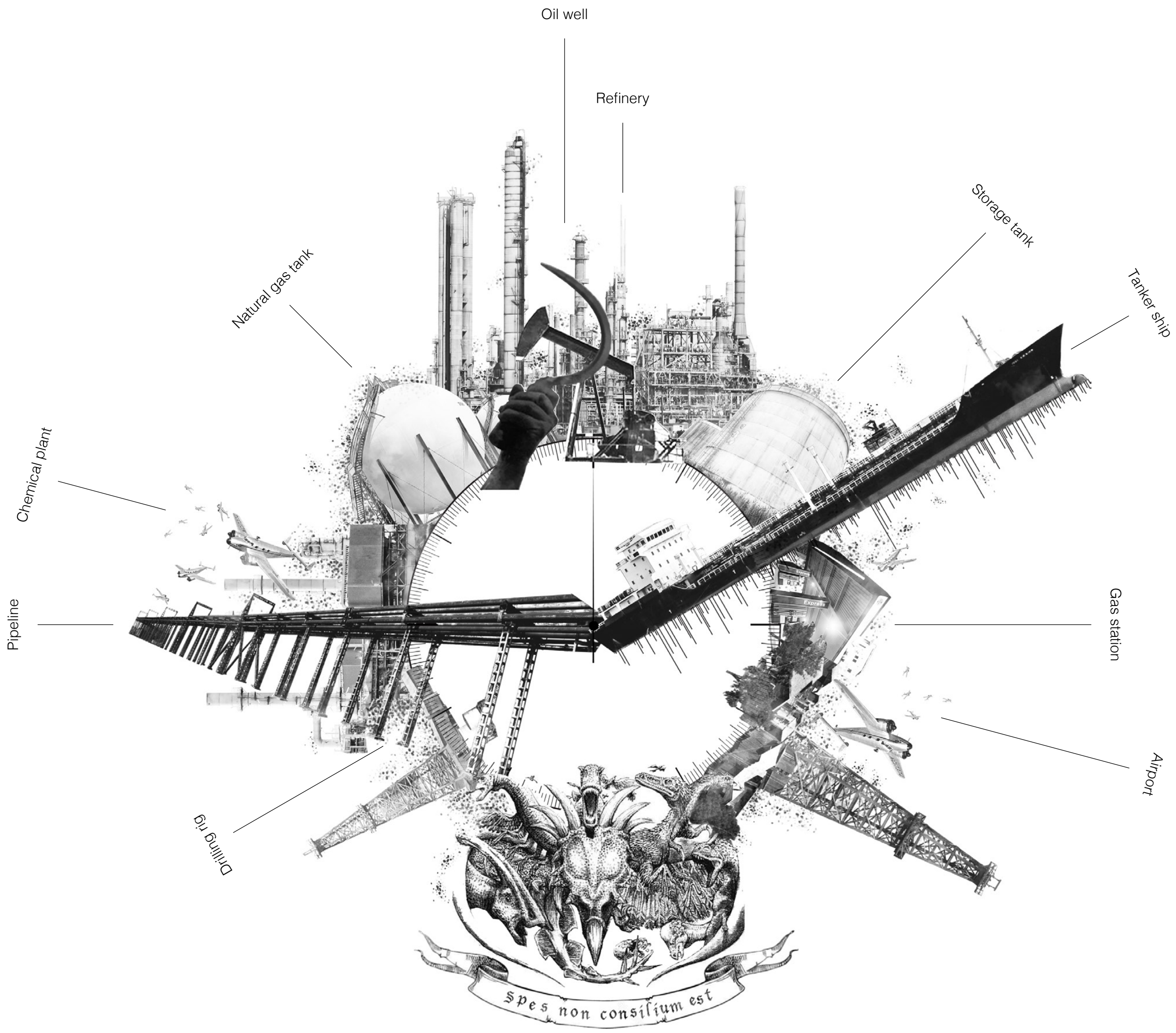


Figure 1 A collage illustrating 'petroleumscape', a term borrowed from Carola Hein (2015)'s work.

Image made by the author.
Source of images used in the collage: https://www.flickr.com/; http://www.dinozaury.com;

Introduction

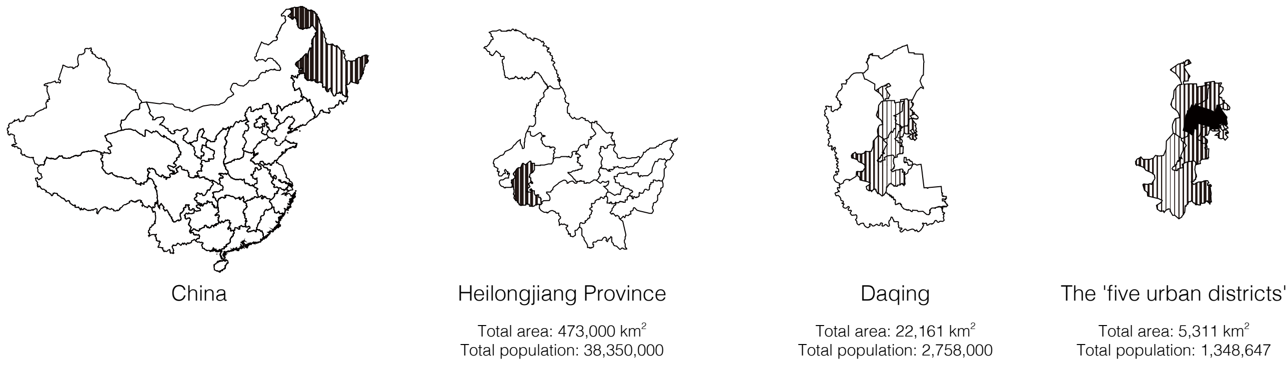


Figure 2 The location of Daqing

Petroleum and its derivatives have so deeply rooted in our economic, social and cultural patterns that it is even impossible to picture modern human society without vehicles, plastic products, chemical fibres and modern agriculture. However, as stated in a report of the Industry Taskforce on Peak Oil and Energy Security (ITPOES, 2010), we have past peak oil: 'as we reach maximum oil extraction rates, the era of cheap oil is behind us'. Despite the 'oil crunch' we are faced with, the exponential growth of the population and the great shift in lifestyle make it unrealistic for the society to operate in a pre-industrial level and without the modern energy-intensive cities. It is relevant for urban designers and planners to think within a new energy paradigm contextualized by the post-petroleum era, and to prepare existing cities with economic and energetic resilience for the upcoming transition.

The term 'petroleumscape' in the title is borrowed from Carola Hein's work 'Exploring architectural history through the Petroleumscapes of the Randstad to imagine new fossil-free futures' (2015). The concept is employed to describe the interaction between the 'architectural emanations of petroleum' and the built environment. It is pointed out in this article that the contemporary built environment has been shaped by petroleum and its derivatives 'in visible and invisible interconnected ways'. The evidence lies in every corner of the urban scene, from the most obvious ones such as gas stations and oil headquarters to the grid blocks of modernist cities resulted from automobile-oriented urban planning.

Compared to cities which are oil consumers or recipients, where the visibility of the petroleum industry is relatively low and more or less hidden from the daily life, Daqing, the site of this project is a more extreme case: it is a city completely resulted from the petroleum industry. Its name, literately means 'great celebration', is to memorize the finding of the biggest oil field in China. The only reason for the emergence of this city on the northeast fringe of China is the demand for serving the oil production and processing industries in this area. The petroleumscape of this city is a witness of political power and oil-dominated economy colliding with the landscape, and thus implies the void left behind when these drivers leave.

The meaning of petroleumscape is not limited to the extraction facilities, storage tanks, refineries, petrochemical industries, research institutions spread across Daqing's landscape (Figure 1), but also refers to the economic and social patterns reflected by this urban scene. Built on this insight, the project aims to use the case of Daqing to interpret the term 'petroleumscape' in a new context: explore the possibility of combining existing petroleumscape with a new energy paradigm (i.e renewable energy production) to re-power the city's economic and energy system in a hypothetical post-petroleum era.

The structure of this report is as follows: Chapter 1 discusses the problem statement of this project and the relevance to larger topics; Chapter 2 is an explanation of the theoretical background and research questions; Chapter 3 illustrates the methodology to be followed; Chapter 4 and 5 explain the process of scenario building, analysing how the present situation will change under the hypothetical context of a post-petroleum era, where the city is powered by renewables. Chapter 6 is the design reflection of the research — spatial changes at the city scale and urban codes on the local scale; Ultimately, conclusions and reflections of this report are illustrated in Chapter 7 and 8.

I

Problem Statement

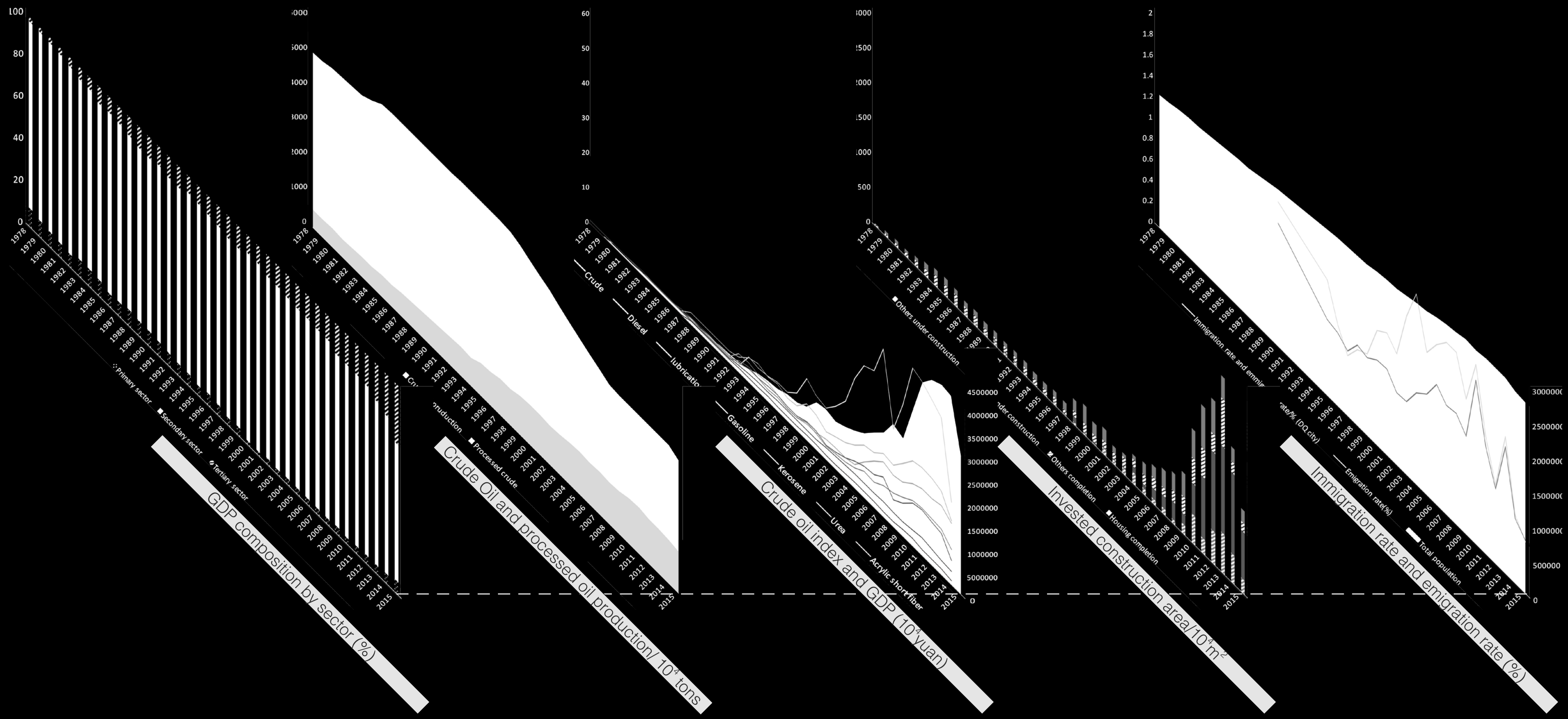


Figure 3 Present status of Daqing's social-economy

Image made by the author.
Data source: Daqing Bureau of Statistics, 2016

I Problem Statement

1.1 Problem statement

In the next decade, Daqing, one of the most famous petroleum cities in China, will be faced with the depletion of exploitable petroleum resources. The industrial sectors, especially oil extraction and processing industries (which belong to two state-owned enterprises, China National Petroleum Corporation and SINOPEC, respectively), are the main revenue sources of the municipality. The reducing annual oil production, together with the falling international oil price has seriously affected the city's economy. This recent decline in GDP has further led to a slowdown in Daqing's urbanization process (Figure 3).

Meanwhile, it should also be noted that the energy supply of the city and the concerned region is largely fossil fuel based. Figure 4 shows the energy flow in Heilongjiang Province: different from the provincial government, the municipality of Daqing is not capable of collecting and publishing energy data. This report then assumes that Daqing's energy production and consumption pattern is basically the same as the provincial average.

As shown in Figure 4, despite the considerable production, Daqing exports more than half of its crude oil to southeast coastal cities (through ports in Qinhuangdao and Dalian). Coal (imported from other parts of Heilongjiang Province) power provide most electricity and heat, while only a small amount of energy comes from renewable sources. The increasing number of depleted coal mines in the province and rising mining costs imply a possible energy crisis in the future.

Regarding energy consumption, the industrial sector consumes most energy of all the urban functions; the transportation sector consumes most fuel and will thus suffer the greatest impact from the oil depletion; automated agriculture is also highly dependent on fuels.

This dual reliance on fossil fuels indicates the vulnerability of the city's economy and energy system, and thus reveals the urgency of transformation. The solution to Daqing as an oil city in the post-petroleum era

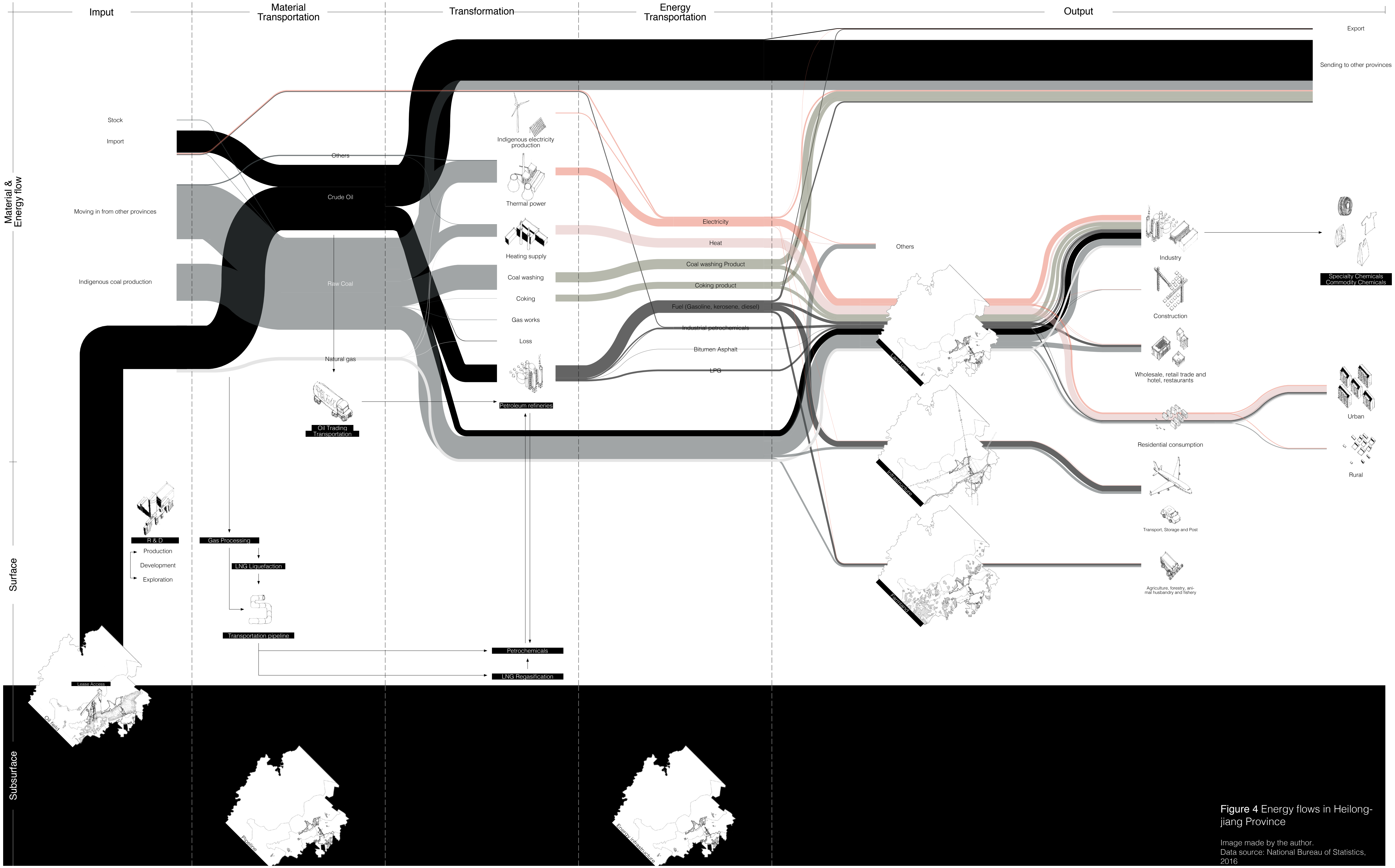


Figure 4 Energy flows in Heilongjiang Province

Image made by the author.
Data source: National Bureau of Statistics, 2016

‘Spring of the North Realm, A Dream City’: A Jurassic theme park, the construction expected to be completed in 2016, the developer turned out to be a dummy company

‘China Zhongwang’: An Aluminum processing industry projected by the municipality, project terminated due to protesting

Figure 5 Sites of the two failed transformation attempts have turned into wasted landscapes

Source: https://www.google.nl/

is far more complex than designing a petroleum-free urban energy system. Referring to the famous cases such as Detroit in the United States and Ordos in China, it should be noted that Daqing is faced with not only an energy crisis but also socio-economic problems if losing its pillar industry – petroleum industry – such as unemployment, tax revenue loss, even generation of ghost towns caused by the following recession.

Over the last decade, there were two attempts to create new economic opportunities in the city but both of them failed. A developer claimed to build a Jurassic theme park in the city, which will trigger Daqing’s transformation into a tourism city. However, despite years of publicity, the construction of the theme park has never started. The municipality has projected an aluminium processing factory – which is expected to provide thousands of jobs and considerable revenues – in the high-tech development zone of the city. But public protests (against possible pollution) forced termination of the project (Figure 5).

Most of the Chinese researchers, practices, and policies tend to investigate solutions to this certain type of ‘resource-exhausted city’ from the economic sector, especially focus on the economic transformation into tourism cities. Regarding the energy supply, the current official suggestion is transporting resources from other regions to support Daqing (works through the centralized political system), which is neither sustainable nor economical in the long term.

This project aims to explore other possibilities and smarter economic and energy solutions for Daqing as a ‘future post-petroleum city’. It is assumed in the project that the city is faced with petroleum depletion, or an even more extreme situation where the universal fossil fuel depletion of the earth and for human race comes true. In the post-petroleum era, it can be speculated that the demographic structure, urban land use and transportation of Daqing will inevitably change due to the shift in the economy, leading to a new energy demand. Meanwhile, landscape, as the spatial embeddedness of the energy system, will be reshaped by this new context. The most significant change happens in the large area of the oil field, which will be abandoned and become ‘wasted landscapes’ (Berger, 2006), another possible impact is the urban shrinkage in the post-petroleum era. Evidence such as current energy policies of Chinese government indicates that the city will probably adjust to this new context by meeting the energy demand with renewables (See Figure 6).

The project explores the possible futures, and measurements for Daqing of transforming into an economic and energetic resilient city before the safe nuclear energy/artificial sun (controlled nuclear fusion) era comes. Specifically, the starting point is discussing the possible spatial changes, and making use of the unique landscape in Daqing, including farmland, (both natural and artificial) lakes, agricultural lands, saline lands, brown lands (e.g. refineries and thermal power plants abandoned in the future; land with underground geological damage caused by petroleum exploitation) for renewable energy production (e.g. solar energy, wind energy, biomass energy, geothermal energy).

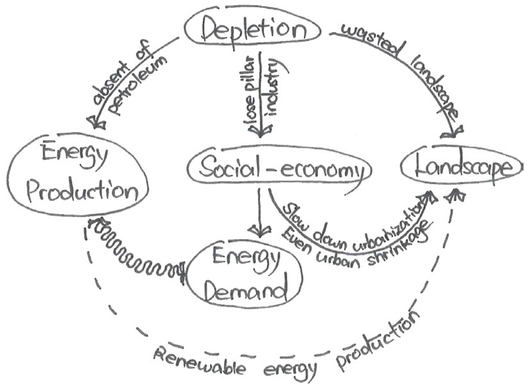


Figure 6 An understanding of Interaction between social-economic issues, energy demand & production, and landscape of Daqing when entering the post-petroleum era

Renewable energy is an opportunity to the city’s energy regime but a threat to the landscape. Compared to fossil fuels, a crucial feature of renewable energy production is the latter ‘appropriates disproportional amounts of space’ (Sijmons et al., 2014), and will consequently squeeze the landscape and the built environment. Renewable energy solutions cannot be taken without considering the impact on landscape value and spatial quality of the built environment.

Besides, the challenge for the energy transformation lies in the extremely cold climate of the area: The annual average temperature is 4.2 ℃; the average temperature is -18.5℃ during the coldest month; the extreme temperature even goes as low as -39.2 ℃. In the hypothetical situation where the coal depletes, the current heating system powered by thermal power stations (that cause heavy air pollution) will collapse. Obviously, the seasonal uncertainty of renewable energy and urgent heating demand in the winter is a serious problem.

1.2 Relevance

Social relevance

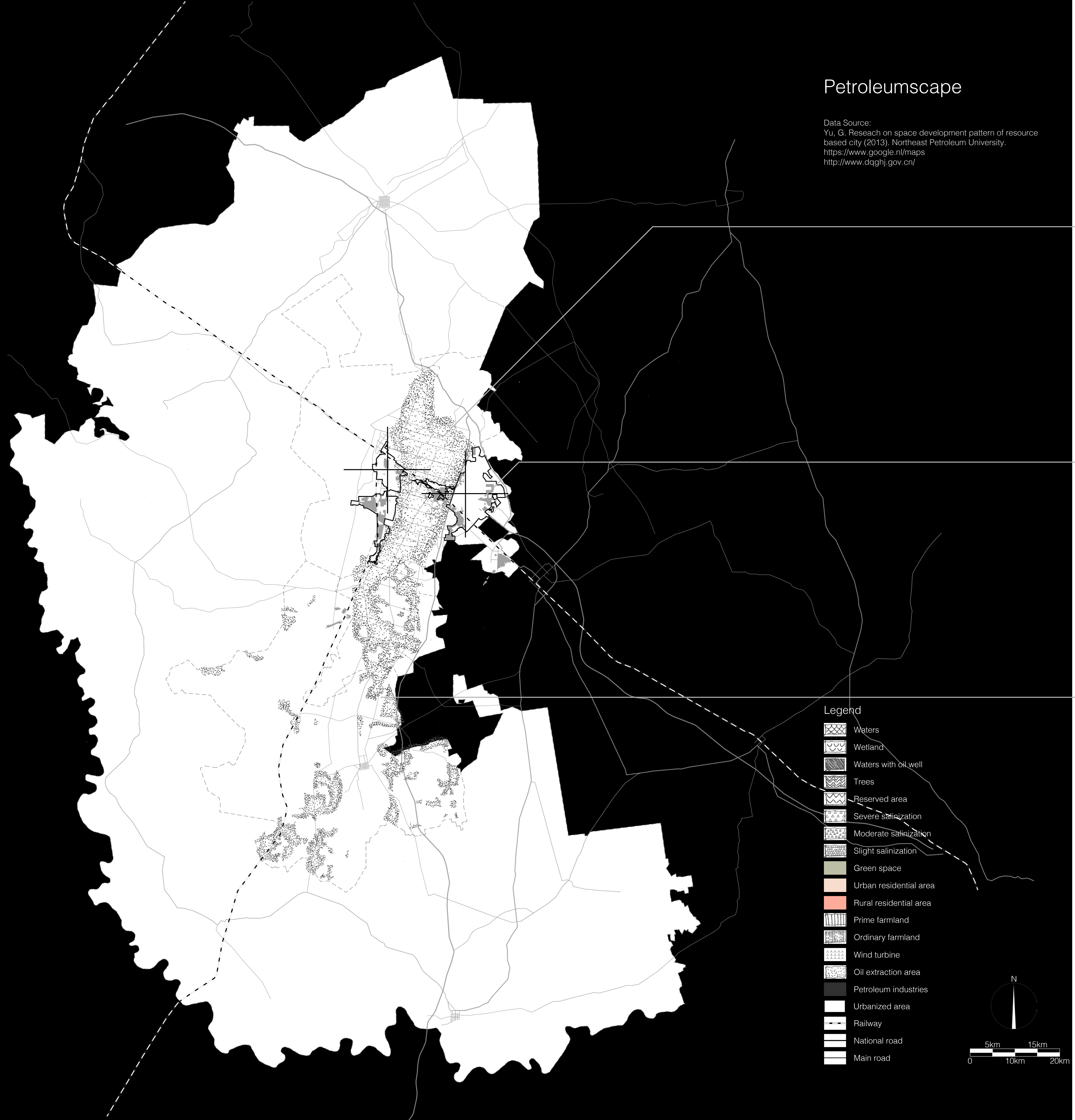
The upcoming petroleum depletion and the economic recession it implies is causing depression in the city across different social classes. This project discusses the possible futures and the strategies of moving towards a desirable future, envisioning a sustainable situation where the city is powered by clean energy, providing enough decent job opportunities and has high spatial quality. This optimistic picture will contribute to social harmony and help to convince different stakeholders to work together towards the desirable future.

Scientific relevance

The current Chinese Government’s energy transformation policies target energy saving, domestic self-sufficiency, diversity, environment-friendly, innovation, economic reforming, international cooperation, and livelihood improvement, but do not reflect on the spatial aspects, while the spatial planning regimes often miss energy considerations. This project is an experiment of filling the gap by applying the energy landscape theory on a Chinese resource-based city, taking the energy transition and its spatial embeddedness into consideration simultaneously. This report discusses the energy and economic transformation of a ‘resource-exhausted city’ considering spatial impacts, spatial strategies and interventions for applying renewables; it is an exploration of involving energy and landscape considerations in a spatial planning. In addition, in this project, the energy landscape theory is combined with scenario planning method, which is a tool to deal with the uncertainties of a post-petroleum era.

Petroleumscape

Data Source:
Yu, G. Reseach on space development pattern of resource based city (2013). Northeast Petroleum University.
https://www.google.nl/maps
http://www.dqghj.gov.cn/



Oil extraction land

Source: http://dp.pconline.com.cn

Petroleum industries

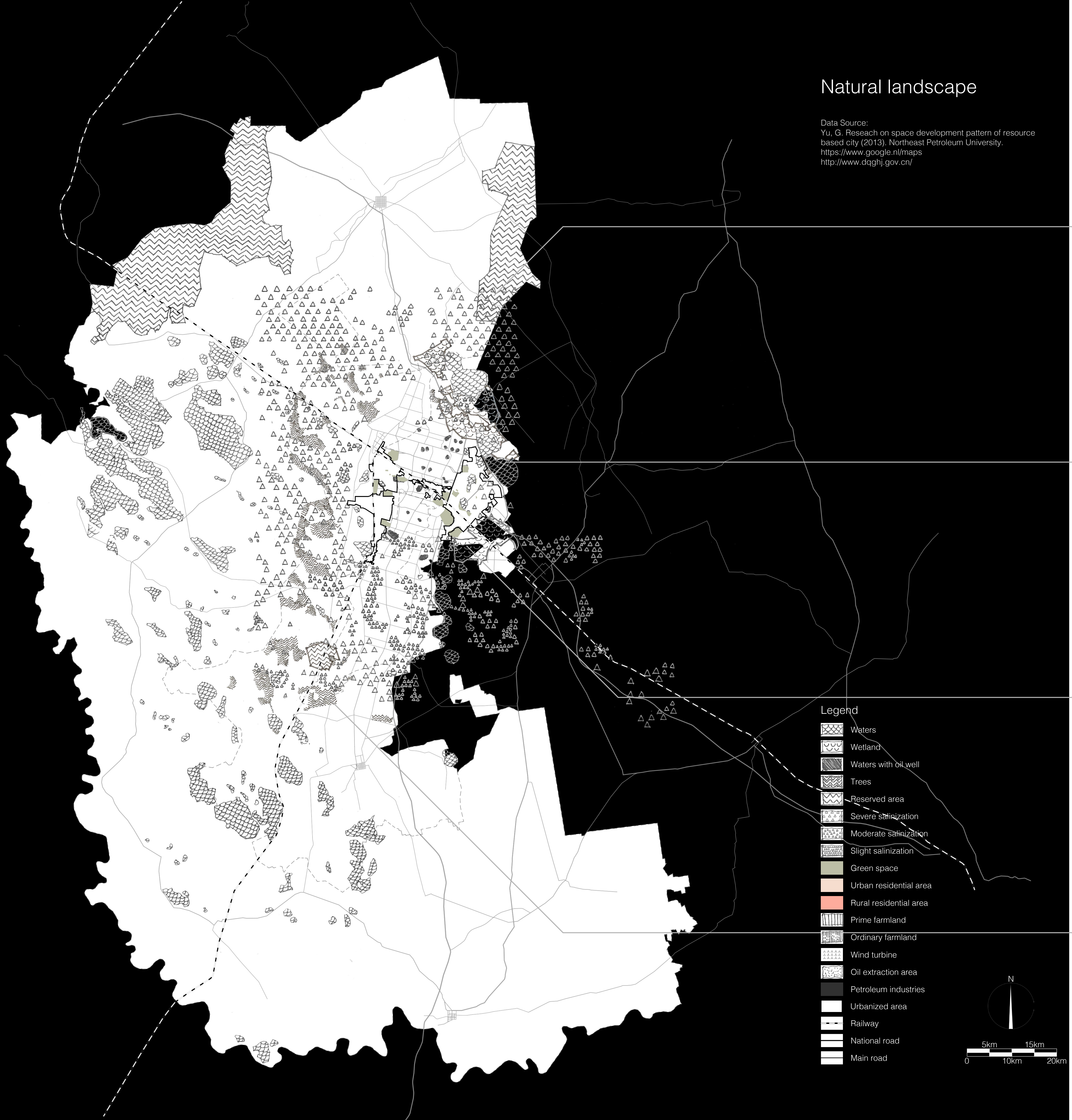
Source:http://www.bf150.com/keyanjishu/wsdpjishu/424.html

Oil transfering station

Source: http://www.huitu.com

Natural landscape

Data Source:
Yu, G. Reseach on space development pattern of resource based city (2013). Northeast Petroleum University.
https://www.google.nl/maps
http://www.dqghj.gov.cn/



Soil salinization

Photograph by the author

Green & blue structure

Source: http://dp.pconline.com.cn

Reserved areas: Longfeng wetland

Photograph by the author

Trees

Source: http://dp.pconline.com.cn

II

Theoretical Framework

II

Theoretical Framework

2.1 Theoretical framework

Petroleumscape of oil cities and post-petroleum planning

Carola Hein (2015)'s work coined the term 'petroleumscape' which this paper borrowed for its title. Compared to normal cities where the visibility of oil processing and production facilities is relatively low, the urban landscape of oil cities are more influenced by petroleum industries. There are a variety of studies investigating the formation process of 'petroleumscape' (in other words, the process of petroleum industries impacting the landscape) based on historical data (Monte, 1978; Cooke, 2017) and remote sensing (Smirnova & Rusanova, 2008; Tang, Wang, & Yao, 2008). Examples of petroleum industries' impact on landscape include the degradation of natural landscapes such as wetland and grassland, as well as the expansion of human settlements (Tang, 2009).

Post-petroleum era implies two unfavourable conditions for a petroleum-oriented city: the city loses its pillar industry, and in the mean time faced with universal fuel depletion. The vulnerability of this certain type of resource dominant cities has already generated some awareness among scholars and policymakers. On the one hand, 'Resource-exhausted city', a concept proposed by Chinese central government, has been highly debated in recent years. Most authors discuss the (economic) transformation and sustainable development of such cities from policy and legislation aspects (Li, Long & Chen, 2013; Wang & Guo, 2012); and refer to cases of successful transition like Ruhr (Li, 2002) and Huston (We, Wang & Li, 2011). However, scholars seldom especially relate the transition of 'resource-exhausted cities' with their spatial context.

On the other hand, although not particularly focus on oil cities, there are a variety of discussions on urban development and spatial planning in the post-petroleum era. While there are no models for predicting how cities will manage in a post-petroleum era, scenarios (which will be further illustrated later) are often used as a scholarly research method in this field. Newman (2007) suggested four post-petroleum scenarios in his article: collapse, ruralized city, divided city and resilient sustainable solar city, respectively; among the scenarios he believe the latter two are the probable futures, where social segregation becomes extreme due to the difference in affordability of dwellings powered by solar technologies. Beatley (2007) envisions an urban future based on renewables, and pointed out that renewable energy production has 'an important economic multiplier effect'. Some other authors (Aftabuzzaman & Mazloumi, 2011; Geels, 2012) also focus on the transportation system, as it will suffer the greatest impact of oil depletion. Among them, Thayer (2008) analyses by scenarios the landscape impact when the new difficulties of travel and shipping caused by oil depletion become evident.

Discussions on the spatial planning of post-oil cities in this report can be seen as a combination of the concerns of 'petroleumscape', 'resource-exhausted cities', and post-petroleum planning. On the one hand, the petroleum industry has reshaped oil cities' landscape and turned it into 'petroleumscape', leaving behind damages to the natural landscape such as soil contamination, biodiversity loss, and the irreversible expansion of human settlements; on the other hand, the inevitable disappearance of the petroleum-dominated economy will lead to a new round of radical or drastic changes to the socio-economy and urban landscape of oil cites. Exploring solutions to post-oil cities within their spatial context, while neutralizing the impact left over in the petroleumscape is therefore relevant in the post-petroleum era.

Landscape planning of renewable energy production: energy=space

As climate change and global fossil fuel depletion becoming evident, renewable energy is currently undergoing a 'renaissance' (Nadaï & Van Der Horst, 2010). As the concept of energy emerging as one of the central focuses of urbanism, the discussions on energy as part of urban planning vocabulary moved from 'energy conservation' (which is often mentioned in the 1970s) to renewable sources (Droege, 2006). Pasqualetti (2000) pointed out that compared with fossil fuels, renewable energy (especially wind power) is more local and visible. Van den Dobbelsteen, Keeffe & Tillie (2013) further put forward the statement 'energy = space', explaining the future necessity of solving the energy demand at the earth's surface, with underground supplies of fossil fuels depleted. Similar ideas are mentioned in 'Landscape and energy: designing transition' (Sijmons et al., 2014), emphasizing the importance of considering renewable energy production and its spatial embeddedness — landscape — in a whole system.

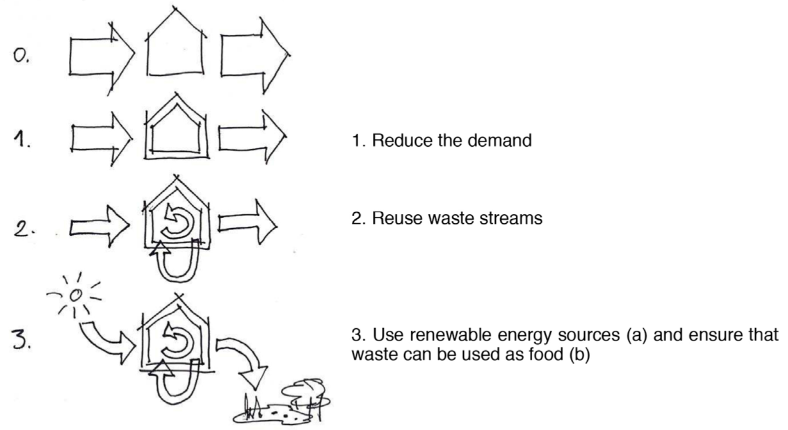


Figure 9 A diagram explaining the 'New Stepped Strategy'

Source: Van den Dobbelsteen, 2008

Although 'Energy landscape', or 'energetic urbanism' (Dobbelsteen & Tillie, 2011) has not yet developed into a new subdiscipline, the interaction between (renewable) energy and landscape is attracting increasing academic attention (for example, Schöbel & Dittrich, 2010; Selman, 2010; Bridge et al., 2013). Some authors (Stremke & Koh, 2011) further argued for an 'energy-conscious planning and design', and emphasis the 'second (thermodynamic) law[1] thinking', providing a new insight of minimizing exergy destruction and entropy production in the landscape[2]. Other ideas include combining life cycle analysis and exergy[3] studies with the design of sustainable energy landscapes (Vandevyvere & Stremke, 2012).

In terms of spatial planning for the new energy paradigm, Van den Dobbelsteen (2008) put forward 'The New Stepped Strategy' for sustainable planning, defining three steps 'reduce, reuse and produce'[4] (Figure 9). This model was extended in Rotterdam Energy Approach & Planning (REAP) (Tillie et al., 2009), which is 'one of the first worldwide methods to approach energetic urban planning in a structured way' (Van den Dobbelsteen, Keeffe & Tillie, 2013, p. 5). Following REAP, the method was further tested in Amsterdam Guide to Energetic Urbanism (LES) (Hakvoort et al., 2011) and extended in the REAP2 study (Van den Dobbelsteen et al., 2011).

New initiatives towards energy resilience, energy-neutral or carbon-neutral have emerged in western countries, focusing on saving energy and powering the city with renewables. Among them there are well-known Beddington Zero Energy Development (BedZED)[5], 'Freiburg Solar Region'[6], and other practices in Adelaide[7], Austin[8], Chicago[9], and Santa Monica[10] (Beatley, 2007).

Renewable energy production is an opportunity to the energy and economic

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[1] First Law of Thermodynamics states the conservation of energy, the Second Law states that the sum of the entropies increases in a natural thermodynamic process, the Third Law states the entropy of a system approaches a constant value as the temperature approaches absolute zero.

[2] Known as entropy generation minimization (EGM), as mentioned in Bejan (1996)'s earlier work.

[3] Exergy stands for the ability of a given quantity of energy to produce work.

[4] Referring to reduce energy consumption, reuse waste energy streams, and renewable energy production, respectively.

[5] A zero carbon emission housing development in the UK.

[6] Located in Freiburg, Germany, where is known as the 'ecological capital of Europe'.

[7] Adelaide, Australia: 'North Terrace Solar Precinct', installation of photovoltaics on public buildings.

[8] Austin, the US: building solar energy economy.

[9] Chicago, the US: low-energy homes; installation of photovoltaics on public buildings and facilities; solar schools; grid-connected PV street lamps.

[10] Santa Monica: power municipal lights and buildings with regionally-produced renewable energy.

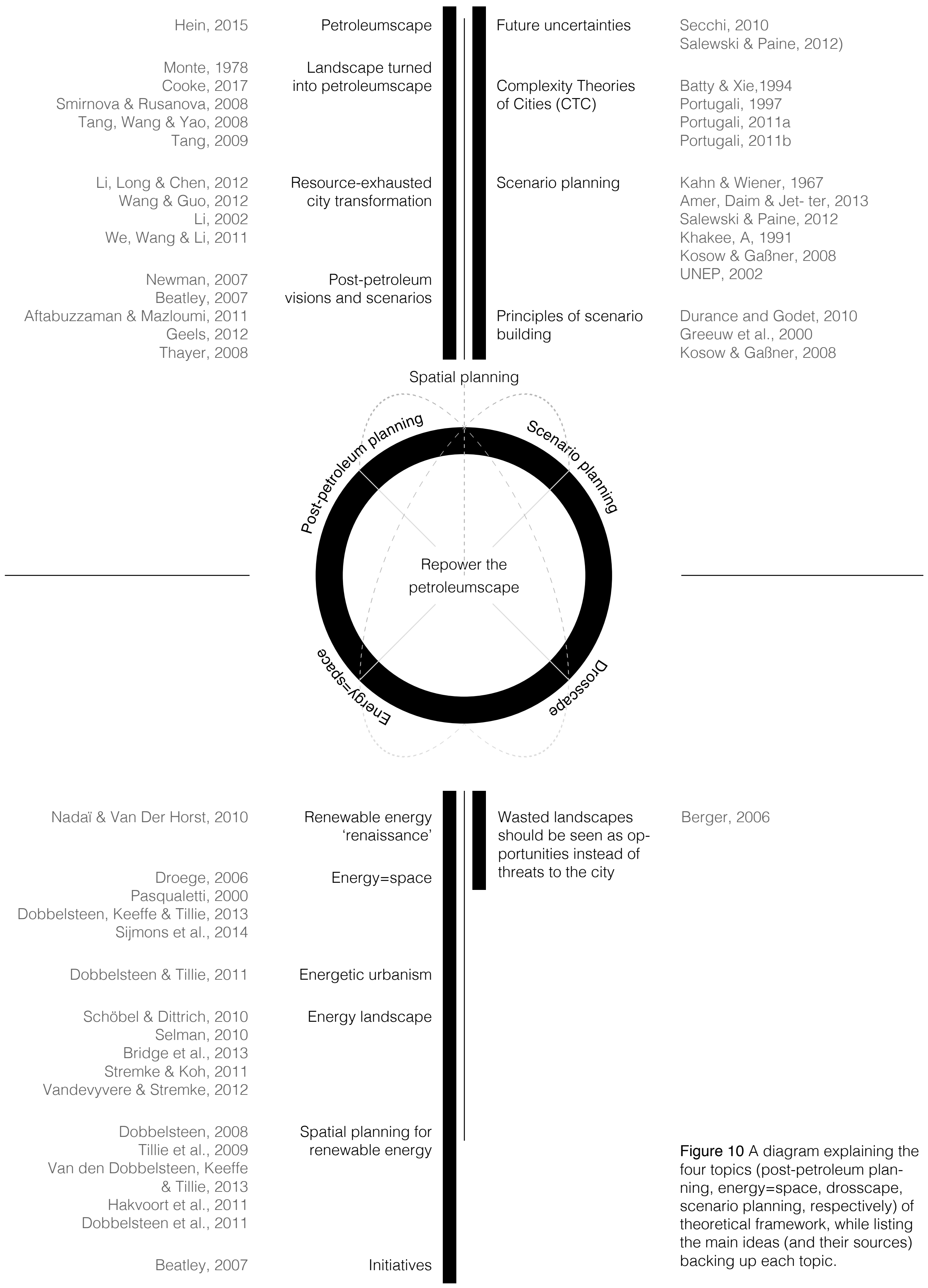


Figure 10 A diagram explaining the four topics (post-petroleum planning, energy=space, drosscape, scenario planning, respectively) of theoretical framework, while listing the main ideas (and their sources) backing up each topic.

regimes of post-oil cities: renewable sources such as biodiesel (fatty acid alkyl esters), despite its limitations, can be considered as alternative fuels for the (currently fossil powered) motorized transportation (Janaun & Ellis, 2010); introducing renewables brings local job opportunities and economic revenues, which will help the city avoid recession. Although unlikely to achieve the massive economic advancement running parallel with the petroleum industry, the green jobs and revenue generated by renewable energy industries will still be substantial for post-oil cities. However, as mentioned above, large-scale renewable energy production facilities are threats to the value of (settled or unsettled) landscapes. In order to minimize the external effect, it is necessary to consider renewable energy solutions within the frame of spatial planning.

Drosscape: petroleumscape as a potential

The term 'drosscape', coined by Alan Berger (2006, p. 237), refers to a condition where 'vast, wasted, or wasteful land surfaces are modelled in accordance with new programs or new sets of values that remove or replace real or perceived wasteful aspects of geographical space (i.e., redevelopment, toxic waste removal, tax revenues, etc.)' It implies that wasted landscapes generated by economic or industrial production collapse (such as what will happen in a post-petroleum era) have the potential to be used for new functions or revenue generation. Such landscapes (e.g. the land used for oil production and processing industries) however should not be oversimplified treated as 'voids' and filled with new urban functions.

The wasted landscapes, in other words, abandoned petroleumscapes generated in a post-petroleum era are seen as ideal locations of renewable energy generation. There are multiple advantages: it can provide large renewable energy production facilities like wind turbines with remote locations away from densified areas, minimizing possible conflicts with residents and the degradation of more valuable landscapes; Meanwhile, the introduction of renewable energy production facilities leaves lands unprogrammed for some time before recovering from the contamination of petroleum industries.

Scenario planning as a tool for dealing with complexity and future uncertainties

As far this chapter has argued for re-powering the petroleumscape of oil cities with renewable energy. However, uncertainties might be quite pervasive in this process: the temporal span of the post-petroleum era is unknown; the impact on landscapes also remains opaque; some studies (Lesser, 2010) are conservative about the market penetration of renewable sources due to the present high costs of production. As mentioned before, scenario planning is widely applied in post-petroleum studies as a tool for dealing with future uncertainties. In order to provide a comprehensive understanding of this methodology, the following paragraphs illustrate a brief review of scenario planning techniques.

In the 1960s, as the unprecedented urban growth in western Europe reaches an end, the urban projects could no longer 'rely upon consistent urban expansion as much as upon a set of precise and limited interventions' (Secchi, 2010, p. 1). Urbanism in post-industrial worlds has embraced an epistemological revolution: the awareness of the ineffectiveness of past blueprint planning (often rely on linear forecasting and prediction methods); followed by a transformation towards series of strategies that emergent within a long-term vision. A vision, as described by Secchi (ibid.), 'delineates a vanishing point' for a set of coherent strategies, interventions, and actions that move towards a shared future.

Any view into the future, however, as stated by Salewski & Paine (2012), 'reveals major uncertainty and complexity.' Over the past decades, the future uncertainties of urban development have been systematically discussed within self-organization theories, or more commonly referred to as complexity theories. The origin of complexity dates back to a physics experiment in early 1900s[11]; the 1990s then witnessed a trend towards the application of complexity theories to cities (Batty & Xie,1994; Portugali, 1997). The core idea of complexity is that there exists no technical way to establish causal relations among the parts composing a complex system, due to their numerous numbers and non-linear interconnections of feedback and feed-forward loops (Portugali, 2011a). The recent work by Portugali (ibid.) has pointed out the paradox in complexity theories of cities (CTC) and their applications: On the one hand, CTC suggests some modelling tools for cities such as CA (cellular automata), AB (agent base), and graph-theoretic physical field models; on the other hand, it also exposes the limitations of these quantitative tools (Portugali, 2011b).

Scenario planning techniques, as another means of treating complexity and future uncertainties, have been attracting increasing scholar attention in the urban regime. During the 1960s, military analyst Herman Kahn invented scenario as a tool for future studies; and defined it as 'hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points' (Kahn & Wiener, 1967, p. 6). Scenario methodology has since then been extensively used for social forecasting, public policy analysis and decision making (Amer, Daim & Jetter, 2013). Especially, urban planning practices, vary from the National Physical Planning of the Netherlands (Salewski & Paine, 2012) to the urban planning of cities like Västerås, Sweden (Khakee, A, 1991), employ scenarios to support decision-making processes in a spatial context.

Different from conventional forecasting or prediction methods, scenario planning is based on a fundamental assumption that 'numerous different alternative futures are always possible and that scenarios have the purpose of spanning the space to be filled by possible futures' (Kosow; Gaßner, 2008, p. 17). Instead of comprehensive descriptions of the 'truth', scenarios are narratives of hypothetical future, constructed of carefully selected key drivers, factors, and events:

'Scenarios are descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play.' *(UNEP 2002, p. 320)*

An article by Durance and Godet (2010) has defined five principles for credible and useful scenarios, namely pertinence, coherency, likelihood, importance, and transparency; as well as a necessary distinction between the two major types of scenarios: normative and exploratory. Normative scenarios (asking questions of 'how') focus on values, interests and seek for desirable futures, while exploratory scenarios (asking questions of 'what if') often explore possible futures regardless of their desirability (Greeuw et al., 2000).

2.2 Research Questions

The main research question of this project is defined as follows:

How can Daqing's urban landscape facilitate renewable energy production and contribute to neutralise the energy and economic crisis of the post-petroleum era, while extending its own sustainability?

This question can be further discussed in 6 sub-research questions:

1 How is the present landscape, economy, and energy demand & production of Daqing shaped by petroleum industries?
2 How will the current landscape, economy and energy demand & production of Daqing change in the near future, when the depletion becomes evident?
3 How will post-petroleum era (and the possible introduction of renewable energy) reshape the socio-economy and energy demand & production of Daqing in the far future?
4 What will be the spatial consequences on the landscape of powering Daqing with renewable energy in the post-petroleum era?
5 How will the spatial changes affect the sustainability of the landscape?

Design goals:
Spatial strategies of making use of Daqing's urban landscape for renewable energy production while extending its own environmental sustainability

11 Referring to Rayleigh–Bénard convection, an experimentally observed macro pattern in the molecular movement of a plane horizontal layer of liquid heated from below.

III

Methodology Framework

III

Methodology Framework

The project is organized in a research-based design methodology, which largely agrees with the 'five-steped approach' developed by Stremke & Van Den Dobbelsteen (2012). The five steps are defined as follows (see Figure 11):

(1) Analysing present conditions
(2) Mapping near-future development
(3) Illustrating possible far-futures
~~*(4) Composing integrated visions*~~
(5) Identifying energy-conscious spatial interventions

This report further metaphors the 'five-steped approach' as a light cone, an abstract physics model describing the form of all the results in time and space caused by one single event (See Figure 13). In the model, the (spatial) results are chronologically and continuously distributed along the time's arrow and as such form a cone; our observations can then be understood as sections of the cone at certain points in time. The observation of post-petroleum era starts at the 'present' point; the next development in the near future (2025) is an extrapolation of current trends; the introduction of scenarios then pictures four possible far futures that scattered into four different directions, as a result of different levels of economic and technological development. As far these futures are conceived to be mostly mutually exclusive while still share some commonalities with each other. As the light cones become more divergent, the future goes infinitely unpredictable and can only be delineated by the unrestrained imaginations of fiction novels. The following paragraphs explain in detail how the methodology unfolds as described in the 'five-steped approach'. However, it should be noted that step 4 is excluded in this report, due to the mutual exclusion between a vision and an exploratory scenario (which will be explained later).

3.1 Analysing present conditions (answering sub-research question 1)

The theoretical framework argues for introducing renewable energy production industries to meet the energy demand and trigger economy development of post-oil cities. Spatial planning is then addressed as the central issue of this process. At the initial stage of spatial planning, the present spatial conditions of the landscape are discussed in four aspects, namely petroleumscape, natural landscape, renewable energy landscape and human settlements, respectively (Figure 12). Moreover, energy production, energy demand and socio-economy prosperity reflected by these spatial elements are also here identified as crucial factors. In order to provide a comprehensive understanding of the present status, secondary data of Daqing is collected through literature review (National Bureau of Statistics, 2016; Daqing Bureau of Statistics, 2016) and organized by mapping.

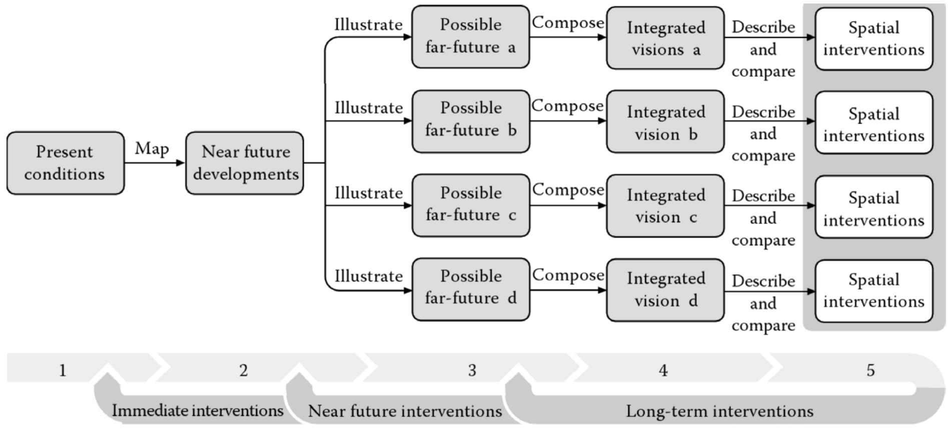
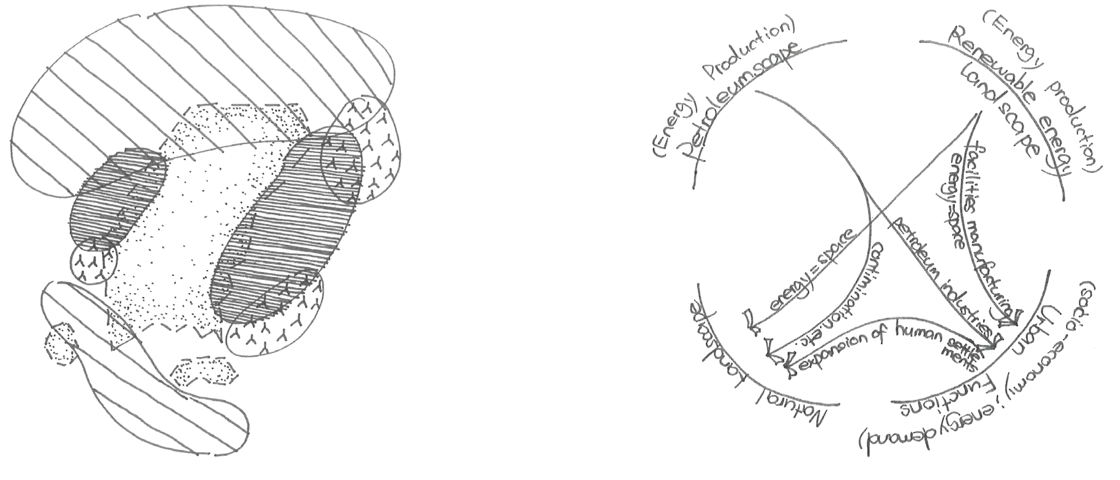


Figure 11 The 'five-steped approach'

Source: Stremke & Van Den Dobbelsteen, 2012



Legend
▨ Petroleumscape
▨ Renewable Energy landscape
▤ Human settlements
▧ Natural landscape

Figure 12 A diagram demonstrating the interactions among the four spatial elements (namely petroleumscape, renewable energy landscape, human settlements, and natural landscape) and their present interactions.

3.2 Mapping near-future development (answering sub-research question 2)

'The energy transition will not happen overnight', as stated by Dirk Sijmons (2014), instead of directly jumping into 2050, it is more realistic to firstly delineate an image of the near future, or in other words, a 'known future' (ibid.). Current energy goals and urban plans are synthesized by literature study (China Energy Research Society, 2016; National Energy Administration, 2014), based on which the near future is generated through trend extrapolation. It is assumed that by the year of 2025 part of these goals will have been achieved, a near-future mapping is then made to demonstrate their spatial consequences on the above-mentioned four elements.

3.3 Illustrating possible far-futures: scenario building

In the theoretical framework, scenario planning is suggested as a tool for dealing with the future uncertainties lying in the post-petroleum era, such as the time span of the post-petroleum era, landscape impacts, the market penetration of renewable energy, etc. Among all the methods developed for building scenarios (such as Schwartz, 1996; Von Reibnitz, 1988; Godet, 2000), this report follows an 'ideal-typical fashion' scenario process summarized by Kosow & Gaßner (2008, p. 25), which works through five phases: 1) identification of the scenario field; 2) identification of key factors (or 'descriptors'/ variables); 3) analysis of key factors; 4) scenario generation; 5) scenario transfer.

(1) Identification of the scenario field
Tow key drivers are identified and quantified based on the analysis of trends and drivers: the prosperity of the petrochemical industry, and the market penetration of renewable energy, respectively. Daqing is the destination of imported Russian oil (which is transported through China-Russia oil pipeline, see Figure 14). However, it does not necessarily mean that after running out of its own production in 2050, the city will process Russian oil as the main revenue source. Because different from crude oil that can be transported cheaply and easily (through pipelines and by ship), petrochemical products (usually transported by tank truck, train, and ship) cost more to transport. The fringe location of Daqing will then be a restriction to the petrochemical industry: the evidence is that the seven new petrochemical bases addressed by Chinese Central Government in 2015 are all coastal or delta cities (National Development and Reform Commission, 2015).

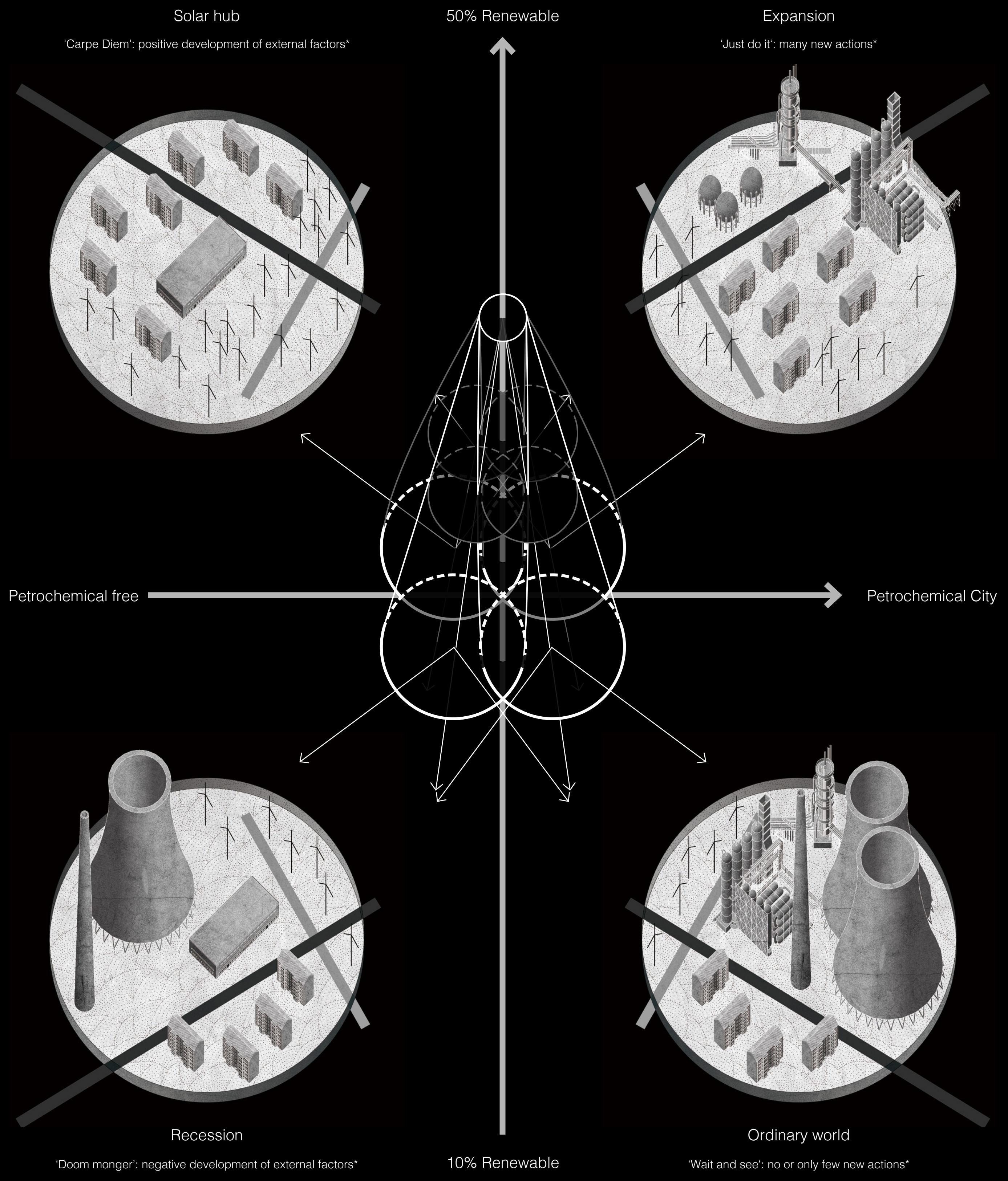


Figure 13 A diagram illustrating the four scenarios in this report, which agrees to the four typologies summarized by Kosow & Gaßner (2008)

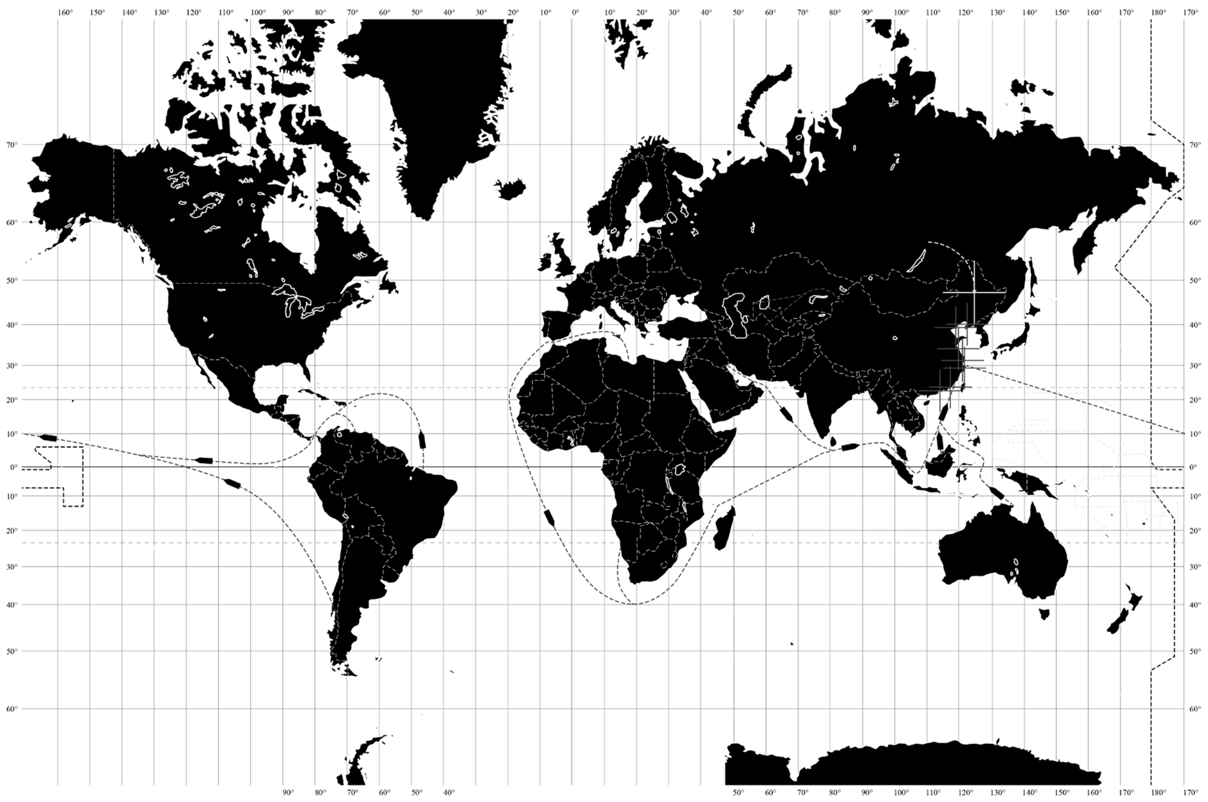


Figure 14 China's crude oil imports routes, most destinations of which are coastal/ delta cities.

Source of the base map: https://english.freemap.jp/

It should be claimed that due to the centralized political system of China, the two key drivers are largely decided by external forces, the scenarios discussed in this report thus belong to the school of exploratory scenario instead of normative scenario.

This report defines in the horizontal axis two extreme conditions of the prosperity of the petrochemical industry: petrochemical city, and petrochemical free, respectively. According to Durance and Godet (2010), one of the principles for credible scenario building is 'likelihood' (as mentioned in the theoretical framework), referring to the necessity of justifying the existence of the conceived scenario fields. 'Petrochemical city' assumes that Daqing becomes a petrochemical city processing Russian oil & gas, in order to meet the energy demand of Heilongjiang province. It can be speculated that there will be a resource movement effect in this condition: other industries (in this case especially renewable energy production industries) are faced with higher labour costs resulting from the prosperity of petrochemical industries. 'Petrochemical free' supposes that the transformation to the petrochemical city is not as successful as suspected: one possible reason is the energy demand of Heilongjiang Province goes lower due to a massive economic recession; other reasons include the universal oil depletion has become evident, as well as the 'geopolitical instability' (Sijmons, 2014), which in this case refers to Russia cutting off the oil & gas supply.

According to Wilson (1998), the ideal number of scenarios is believed to between two and four. Based on the second key factor, this report further defines a vertical axis and other two extreme conditions: 50% Renewable and 10% Renewable. In '50% Renewable', the economic availability of renewable energy has increased because of technological innovation; Heilongjiang province is projected as a wind energy base by the central government (an extrapolation based on China Energy Research Society, 2016); Harbin (the capital city) and Daqing are equipped with the best facilities as well as accessibility to skilled workers, and consequently facilitate the manufacturing of renewable energy facilities. In '10% Renewable', the renewable energy penetration in Daqing is not as fast as suspected, which may result from the central government's extra emphasis on offshore wind energy; or the introduction of a nuclear power plant in Heilongjiang Province.

(2) & (3) Identification and analysis of key factors (answering sub-research questions 3&4)
The employment impact, potential of renewable energy production, and assumptions on post-petroleum energy production & consumption in Daqing is discussed in order to answer sub-research question 3. The four spatial elements mentioned in the analysis of present status (section 2.3.1), namely petroleumscape, renewable energy landscape, human settlements, and natural landscape remain as key factors in scenarios. An important product of this part is the land demand of powering Daqing with renewables.

The discussions are backed-up by literature study and quantitative analysis of data. Applying qualitative narrative techniques like scenarios does not necessarily exclude quantitative analysis. Instead, scenario planning bridges evidence-based and imagination-driven designs. In the practice, scenarios are 'often based on a hybrid approach in which both qualitative and quantitative data are gathered and translated from quantitative to quantitative knowledge (quantification) or from quantitative to quantitative narrative knowledge' (Kosow & Gaßner, 2008, p. 33).

Especially, the calculation of future energy demand and production, as well as discussions of efficiency improvement of future sustainable energy technology innovations refer to David MacKay's (2008) free tool book 'Sustainable Energy-without the hot air', as well as 'Landscape and energy: designing transition' by Dirk Sijmons (2014).

(4) Scenario generation
Four scenarios, namely solar hub, expansion, recession, and ordinary world are generated based on permutations of the extreme conditions explained in phase 1. The logic behind can be traced back to the four typologies of scenarios summarized by Kosow & Gaßner (2008): 'Carpe Diem', 'Just do it', 'Doom monger', and 'Wait and see' (Figure 13). Ultimately, two selected scenarios, solar hub (conservative renewable energy scenario) and expansion (liberal renewable energy scenario) demonstrate two hypothetical maps picturing different impacts on the spatial elements in the post-petroleum era, based on synthesis maps (of spatial restrictions and potentials) and a selection of existing and probable spatial trends and drivers. The two scenarios, despite mutually exclusive, share some commonalities with each other: petroleum job (such as prospecting and drilling) cuts, the prosperity of renewable energy industries, etc.

(5) scenario transfer
After an evaluation of sustainability, the two selected scenarios are combined and transferred into a base, upon which a series of spatial strategies are designed. Among the four factors of sustainable development in Duijvestein (2002)'s tetrahedron (Figure 15), the social and economic sustainability are decided by external forces (i.e. the prosperity of renewable energy industries). It is assumed that the two 2050 scenarios have attained environmental sustainability by applying a series of remediation programmes.

3.4 Identifying energy-conscious spatial interventions (answering sub-research question 5)

Ultimately, a series of design principles for the renewable energy production landscape is discussed. This report also designs a set of urban codes for two pilot urban projects, exploring ways for the four aspects of landscape, namely petroleumscape, natural landscape, renewable energy landscape and human settlements to coexist harmoniously in the post-petroleum era. The design aims to make use of the urban landscape to facilitate renewable energy production while extending its own spatial quality.

The 'five-steped approach', as a flexible framework for sustainable energy landscape design and planning, has been tested through series of (Dutch) studios and workshops. It is interesting to revisit it through the lens of a social-political context which operates in a completely different way from western European societies. Besides, this project tries to involve post-petroleum planning and 'drosscape' topics in the energy landscape discussion, which to some degree can be seen as an extension to the original focus of the 'five-steped approach'.

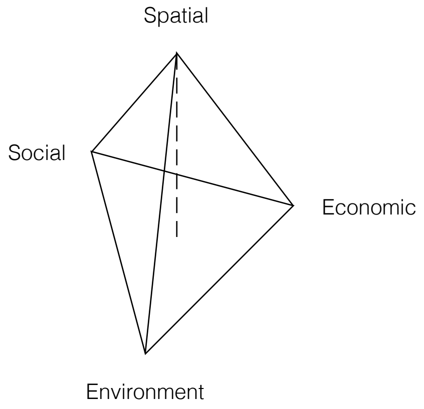


Figure 15 A simplified diagram based on Duijvestein (2002)'s sustainable construction tetrahedron

IV

Scenario Building: Employment Impact of The Post-petroleum Era

4.1 Employment loss in the oil industry
4.2 Green jobs created by renewable industries

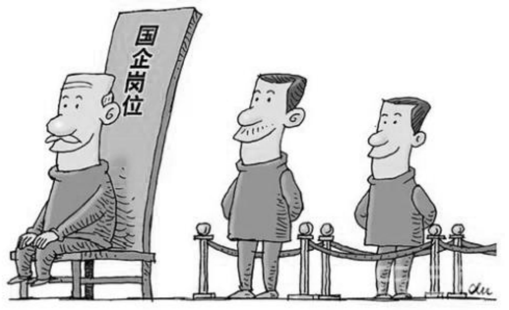


Figure 16 A comic that implicitly satirizes the job guarantee system enjoyed immensely by 'oilfield children'. In the picture, the Chinese characters written on the chair says: 'jobs in state-owned enterprises'.

Data source: www.zhgshhw.com`

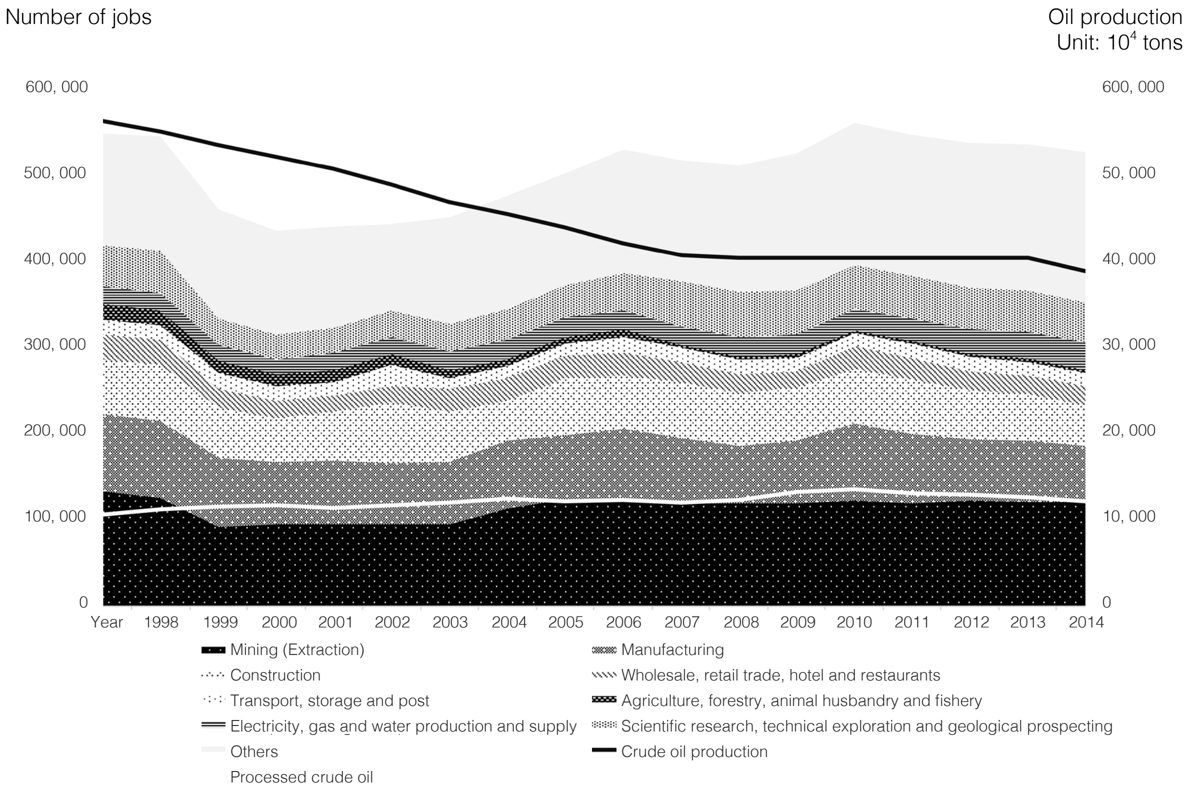


Figure 17 Occupational structure in relation to crude oil and processed oil production in 2015 (Daqing Region).

Image made by the author.
Data source: Daqing Bureau of Statistics (2016)

IV Scenario Building: Employment Impact of The Post-petroleum Era

4.1 Employment loss in the oil industry

Petroleum is key to Daqing's economy: more than half of its working population (in most cases living together with their families) is engaged in petroleum-related industries. The population agglomeration in this region, as a result of decades of oil extraction, has greatly promoted the development of local real estates. During the planned economy era (1949-1979), oil workers gathered in gated communities around petroleum industries; while today's employees are distributed throughout the entire built-up area. Young staff of the oil company tend to commute between their homes in the city and remote workplaces (by special commuting buses) every day. New construction homes located adjacent to city centres (or in the High-tech Development Zone) are especially popular among the citizens, thanks to their high accessibility to shopping malls, public hospitals, and schools.

Even after the national-wide reform of state-owned enterprises (dates back to 1998[12]), oil company employees are still well-paid and have good social welfare such as social insurance and national housing fund. Their children had even enjoyed the privilege of inheriting their parents' jobs until 2014 (Figure 16).

However, it should be noted that the prosperity is supported by only one fact: during its short history, Daqing has always been an energy-exporting city. In 2015, 59% of its crude oil production is exported to prosperous coastal regions. Figure 17 compares the crude oil & processed oil production from 1998 to 2015 and the changes in the occupational structure in the city's labour force. As shown in the graph, there seems no obvious correlation between the working population engaged in mining (in this case refers to crude oil and natural gas extraction) industries as well as manufacturing (refers to petroleum, petrochemical processing) industries[13] and the petroleum production. This is probably because that unlike in a free market system, where the employment is determined by the law of supply and demand, jobs in state-owned enterprises are relatively stable and largely affected by top-down administrative measures. However, whether the driving force is the market economy, macroeconomic regulation, or a collection of both, the oil depletion will eventually lead to a reduction or relocation of employees in the petroleum industries.

The working population engaged in scientific research, technical exploration and geological prospecting experienced an increase in 2003, resulting from the campus relocation of the Northeast Petroleum University. Similar to the oil company, this university is relatively less affected by Daqing's petroleum production, due to its special administrative attribution (to the Education Department of Heilongjiang Province instead of the Daqing city government). In the post-petroleum era, the university may yet be faced with a reorganization, due to the reduction in the number of students and employees or changes in its specialities.

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[12] After realizing the redundancy and low efficiency of the socialist production relations, the central government adopted a series of reforms to state-owned enterprises. On the one hand, this event directly led to the mass unemployment at the end of the 20th century; but on the other hand, it has subsequently become a prerequisite for private investment to flourish.

[13] As defined by the Chinese Bureau of Statistics, the mining (extraction) industry refers to industries which involve in coal mining and washing, ferrous metal mining and dressing, non ferrous metal mining and dressing, crude oil and natural gas extraction; the manufacturing industry contains 30 categories, which includes petroleum processing industry, coking and nuclear fuel processing industry, chemical raw materials and chemical products manufacturing industry, chemical fibre manufacturing industry, and plastic products manufacturing industry.

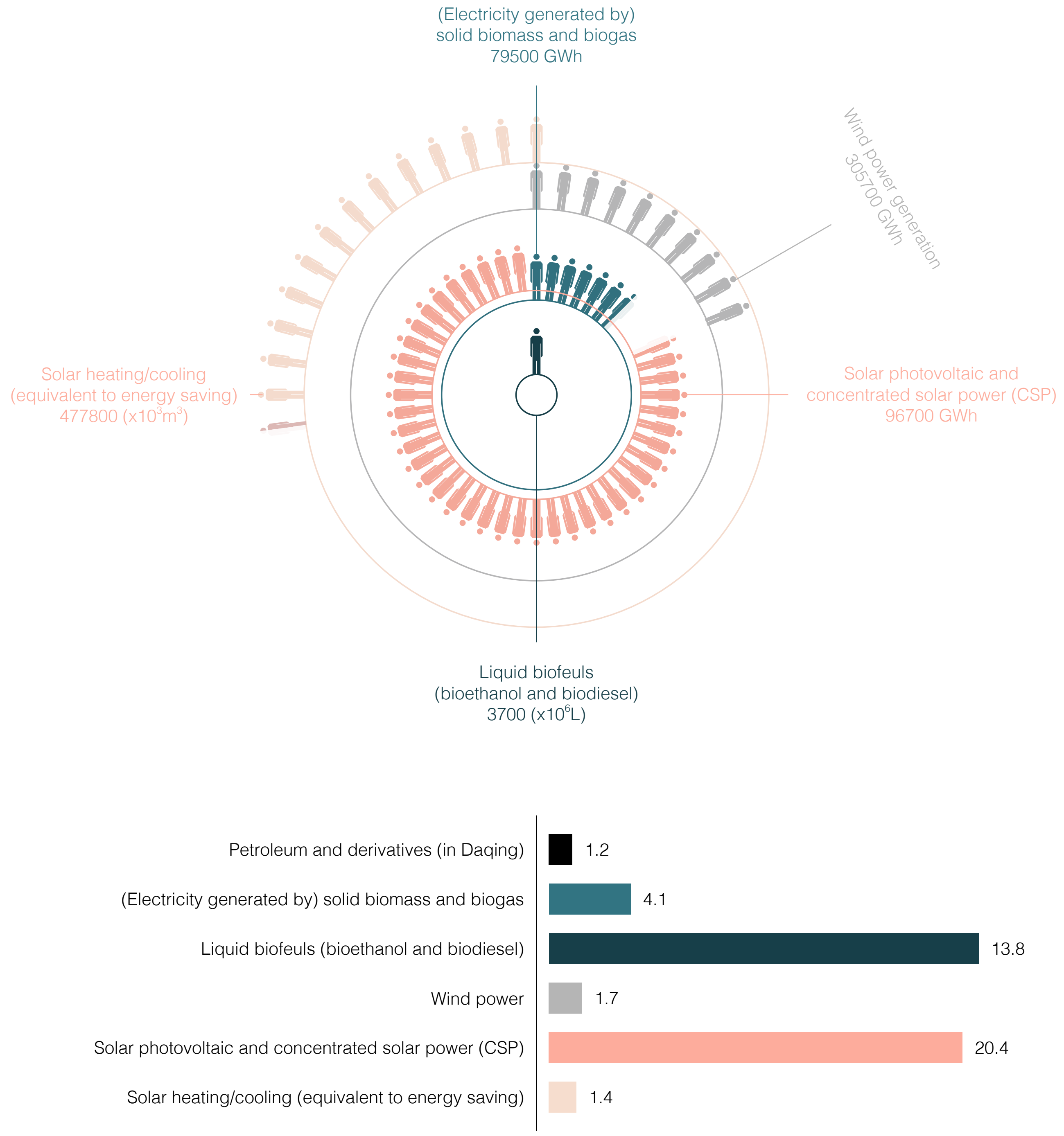

Figure 18 The above figure illustrates the national employment in each renewable energy branch; the size of circles represents the amount of the total energy production; the below graph shows the calculated ‘employment multipliers’ of each branch, which is assumed to basically stay the same in 2050.

Image made by the author.
Data source: IRENA, 2017; National Bureau of Statistics; National Energy Administration; USDA, 2017

4.2 Green jobs created by renewable industries

The discussions in this report are base on the premise that renewable energy will thrive in the post-petroleum era, as an economic and energy chance to Daqing as an energy-exporting city. In the context of a renewable future, the development of renewable energy industries is expected to promote Daqing’s economy and provide green jobs that can to some extent fill the voids left by the declined petroleum industries. Although seems to be expensive in today’s fossil fuels dominated energy market, the production costs of renewable energies will decline exponentially with its mass production (and installation) process, followed by job creation in renewable energy sectors. Just as stated by Lehr et al. (2008): ‘high investment levels and large capacities installed directly exert a positive effect on the employment in the respective industries’.

The international renewable energy agency (IRENA, 2011) classifies green jobs into three categories: direct, indirect and induced jobs. Direct jobs refer to those related to a sector’s ‘core activities’, such as manufacturing, operation, and maintenance; indirect jobs are those involved in supplying the renewable energy industries, such as steel industries, consultancy companies, and research institutions. Induced jobs are created by the redistribution of income: for instance, the professionals educating the children of renewable energy industry employees. The following discussion pays more attention on direct jobs involved in extraction, manufacturing and energy supplying, indirect jobs such as researchers and geological practitioners, as well as induced jobs that belong to the service industries in Daqing, while indirect jobs in steel industries or silicon chemical industries are considered to exist in other parts of China.

In order to comprehensively understand the interrelationship between the penetration of renewable energies and associated green jobs, this report conducted a brief literature review on existing analysis of the impact of renewable energy industries on employment. Moreno & Lopez (2008) mentioned a concept - ‘employment multipliers’ - that is ratio used to describe the (possible exists) linear relationship between the employment in each renewable energy branch (L_i) and its energy output (X_i). The expression is: $I_i = (L_i / X_i)$

According to the reviewed academic articles (Lehr et al., 2008; Lin, 2014; Moreno & Lopez, 2008; Wei et al, 2010), this ratio often changes dramatically with factors such as location, investors, or even the units of measurement. Technically there is no universal ratio that can be applied to every case; in order to find the accurate ratio, specific renewable energy projects that are directly linked to Daqing should be studied. However, this precondition obviously has to be relaxed due to a lack of referenceable renewable energy projects in the region. Thus, when anticipating the employment derived from renewable energy industries in the 2050 scenarios, this report applies the national average of China, which is calculated based on data from the National Bureau of Statistics, International Renewable Energy Agency (IRENA) and other open data sources (Figure 18).

V

Scenario Building: Energy Production & Demand

V Scenario Building: Energy Production & Demand

5.1 Speculations on energy production & demand in 2050

As a promising alternative to fossil fuels, renewable energies has been highly debated among Chinese policymakers. There is a set of documents looking into the future of sustainable energy, such as China Energy Outlook 2030 (China Energy Research Society, 2016) and Energy Development Strategic Action Plan 2014-2020 (National Energy Administration, 2014). A recently released official report, World and China Energy Outlook 2050 (ETRI, 2017) conducted a series of speculations on China's energy consumption (and production) by the year 2050, which are summarized as follows:

(1) Fossil fuel: China's demand for fossil fuel (referring to petroleum and coal) will peak by 2030. The share of coal in 2050 (2.58 billion tons) will be 67.5% of that in 2015. ↓

(2) Oil & gas: China's annual crude oil production will remain at 200 million tons before 2030, and subsequently experience a gradual decline; meanwhile, the annual natural gas demand (and production) will grow rapidly before 2040 (especially in sectors such as electricity supply, residential, and industry), reaching 380 billion cubic meters by the year 2050. ↓ ↑

(3) Electricity: the electricity demand will rise steadily and reach 11.8 trillion kWh per year in 2050; after 2030, the power generated by coal will account for less than 50% of the total electricity generation. ↑

(4) Final consumption: by 2050, the economic transformation China is advancing will reduce its industrial energy demand to 54.6%; at the same time, construction energy demand (especially the demand for electricity and natural gas) will increase to 26.2% as a result of the urbanization process; the increase in car ownership and rapid development of civil aviation will lead to an increase in traffic energy (fuel) consumption, reaching 19.2% in 2050. ↑ ↓ ↑

(5) Clean energy: the market share of clean energy (such as natural gas and non-fossil fuels) will experience a significant increase before 2030; after gradually replacing the coal, its market share will eventually exceed 50% around 2045. ↑

Source of icons: Arthur Shlain; Ana María Lora Macias; Stock Image Folio; Bakunetsu Kaito; Marco Livolsi; Olivier Guin; Mahmure Alp from the Noun Project. Modified by the author

In order to estimate the energy production and demand of Daqing region in 2050, this report firstly assumes the aforementioned trends to be basically accurate on the national scale; it is also surmised that Daqing's energy consumption pattern in 2050 follows or sometimes leads the national trends. The following paragraphs then describe two possible post-petroleum futures: Daqing as a petrochemical city (conservative scenario), and Daqing as a solar energy hub (liberal scenario).

After its annual crude oil production peaked at 55.74 million tons in 1998 (Daqing Bureau of Statistics, 2016), the municipality and the oil company for the first time decided to steadily cut down Daqing's crude oil production. From 2008 to 2014, the production remained at 40 million tons and subsequently started to decline again in 2015.

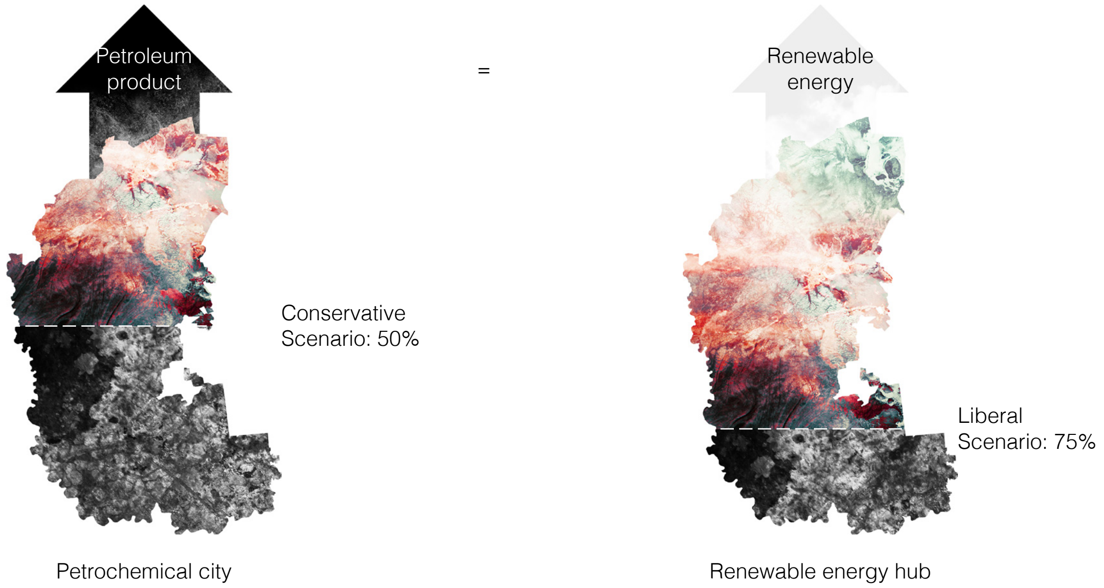

Figure 19 A diagram illustrating the settings of two scenarios

The 2050 scenarios assume a high penetration of renewable sources to the energy markets: renewable energy facilities are applied in the built environment and landscape of Daqing, help meet the energy demands of the optimal operation of the city. In 2050, with the implementation of a 50% 'renewable portfolio standard (RPS)[14]*', more than 50% of energy is generated by renewable sources. Due to the presence of oil and gas resources, the petrochemical city scenario tends to be relatively conservative in renewable energy production - fossil fuels still meet a large share (but less than 50%) of Daqing's energy demand. While the solar hub scenario delineates a maximum penetration (75%) of renewables within the physical limitations (Figure 19).*

Daqing is assumed to maintain its current position as an energy-exporting city in both two 2050 scenarios. in the conservative scenario, Daqing exports petroleum products to other parts of the Heilongjiang Province: part of the oil & gas imported from Russia is processed in Daqing, in order to meet the demand of Heilongjiang Province for petroleum products. The imported oil & gas maintains the production capacity of Daqing's petrochemical industries at the original level (the same as that of today).

In the liberal scenario, renewable energy replaces petroleum and its derivatives as the predominant source of energy exports: without exogenous oil supply, the production of processed crude oil declines rapidly with the oil depletion, while most of the crude oil is still exported to coastal areas; eventually, almost all of the petrochemical industries are shut down by the year 2045. In 2050, instead of crude oil, Daqing exports renewable energy to other parts of Heilongjiang Province as a solar energy hub.

Compared to the crude oil reserves (6.75 billion tons, Daqing Bureau of Statistics, 2016), Daqing's proved reserves of natural gas (282.33 billion cubic meters, which is equivalent to 0.23 billion tons of crude oil[15]*, Daqing Bureau of Statistics, 2016) is less sufficient. The natural gas has always been treated as a by-product of oil extraction and has never been exported in large-scale. The scenarios thus assume that in 2050, Daqing will still have enough natural gas reserve for meeting its own demand.*

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[14] Renewable portfolio standard is a regulation proposed by the federal government of the United States, which requires the production of energy (especially electricity) increase to a certain proportion.

[15] Natural gas equivalent: 1225m^3 of natural gas = 1t of crude oil

5.2 Renewable energy production solutions for Daqing in 2050

The 2050 scenarios assume that a 50% renewable portfolio standard (RPS) is implemented in Daqing: it will become mandatory for the energy companies to ensure that renewable energy accounts for more than 50% of their energy production. The following paragraphs further discuss the possible renewable energy solutions for Daqing as a city with the temperate continental monsoon climate.

5.2.1 Solar energy

Theoretically, the solar irradiance at midday on a cloudless day is approximately 1000 W/m^2 (if the measured area faces directly towards the sun) (MacKay, 2008). In practice, the amount of available solar energy is always affected by environmental factors such as solar elevation angle (which changes with local latitude) (Figure 20), the number of cloudless days during a year, the sunshine duration, and the atmospheric condition. The average intensity of solar energy in Daqing, per unit land area, is about 156 W/m^2 (Ma, Li & Zhang, 2016).

Solar energy is usually collected in two forms: thermal energy (low-grade energy[17]), which is collected by solar thermal panels, usually used to heat water for showering; and electrical energy (high-grade energy), which is converted through photovoltaic cells (or solar cells, in other words) for powering buildings; excess power generated could be sold to the grid.

(1) Solar thermal collectors

Roof-mounted solar water heaters have been commercialized for decades in China. When competing with a natural gas or electricity powered water heater, the advantage of a solar heating system is obvious: it cuts the energy bill. Its limitations, at the same time, cannot be ignored - solar panels and water tanks take much more space than the tank-less water heaters. Solar heating systems are thence more popular in rural residences than in urban dwellings. In Daqing, a 60 L solar water heater with a heating power of 3000 W (including auxiliary electric heating) is sufficient to meet the daily hot water demand of a single household.

(2) Photovoltaic cells

Nowadays, the photoelectric conversion efficiency of commercial photovoltaic (PV) systems is usually around 24%. Fundamental physical laws limit the maximum efficiency of photovoltaic systems with hypothetical perfect concentrating mirrors or lenses to 60%, and 45% without any concentration (MacKay, 2008). According to information provided by George Washington University on July 12th, 2017, an ambitious research group has designed a GaSb-based photovoltaic cell that captures most of the solar energy, with a photoelectric conversion efficiency of 44.5%. *In the 2050 scenarios, the average efficiency of commercial PV systems (during their effective working hours) is postulated to reach 30%.*

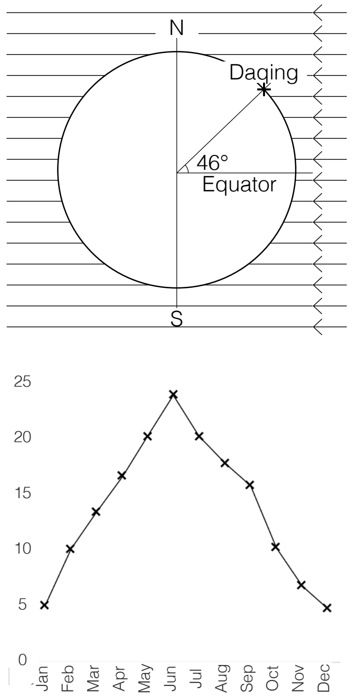

Figure 20 In Daqing, the solar irradiance on a 50-degree slope during the vernal/ autumnal equinox, is about 20.6 MJ/m^2.

Image made by the author.
Data source: Ma, Li & Zhang, 2016

Based on open data, in December, the average solar irradiance in Daqing falls to a minimum of 4.73 MJ/m^2 per day; in June, the average solar irradiance reaches a maximum of 23.49 MJ/m^2 per day, the amount of captured solar energy on 1 m^2 of properly installed photovoltaic with an assumed 30% photoelectric conversion efficiency is:

$4.73 \times 10^6 / (3.6 \times 10^6) \times 30\% =$ **0.4 kWh/d in December**
$23.49 \times 10^6 / (3.6 \times 10^6) \times 30\% =$ **2 kWh/d in June,**
and **411.9 kWh** annually.

(3) Photovoltaic thermal hybrid solar collectors

Solar arrays, whether used for distributed energy generation or placed intensively in large-scale solar farms (Figure 21), require considerable surface area. For space-saving considerations, photovoltaic thermal hybrid solar collectors (also known as PVT systems[18], which have not yet been commercialized on a large scale) have been introduced as an alternative for separate solar thermal collectors or photovoltaic cells. However, the high cost of PVT systems limits the possibility of its mass-production: it is currently 1.5-2 times more expensive than a PV system of equivalent capacity. But if taking the extra generated thermal energy into consideration, a PVT system can be more economical than a conventional solar thermal collector or PV system.

It is assumed that in 2050, the current technical barriers (for instance, the complicated design and installation processes, the low long-term reliability, the high costs of raw materials) to the mass-market adoption of PVT systems have already been overcome by researchers. The solar industries no longer rely on government grants or other assistance. There are officially certified technical standards supporting PVT installers, as well as helping customers (including real estate developers and individual buyers) understand the benefits of PVT systems. Usually combined with ground coupled heat pumps (which will be described in detail later), PVT systems have become especially popular among the owners of residential townhouses: both new construction homes and renewal projects are equipped with wall-mounted and roof-mounted PVT systems. In the 2050 scenarios, the average photoelectric conversion efficiency of commercial PVT systems (during their effective working hours) is postulated to be 15%, while the thermal efficiency reaches 80%.

In December, the average solar irradiance in Daqing falls to a minimum of 4.73 MJ/m^2 per day; in June, the average solar irradiance reach a maximum of 23.49 MJ/m^2 per day, the amount of captured thermal energy on 1 m^2 of properly installed PVT system with an assumed 80% efficiency of thermal energy conversion is:

$4.73 \times 10^6 / (3.6 \times 10^6) \times 80\% =$ **1.1 kWh/d in December**
$23.49 \times 10^6 / (3.6 \times 10^6) \times 80\% =$ **5.2 kWh/d in June,**
and **1098.3 kWh** annually.

The amount of captured electrical energy on 1 m^2 of properly installed PVT system with an assumed 15% photoelectric conversion efficiency is:

$4.73 \times 10^6 J / (3.6 \times 10^6) \times 15\% =$ **0.2 kWh/d in December**
$23.49 \times 10^6 J / (3.6 \times 10^6) \times 15\% =$ **1 kWh/d in June**
and **205.9 kWh** annually.

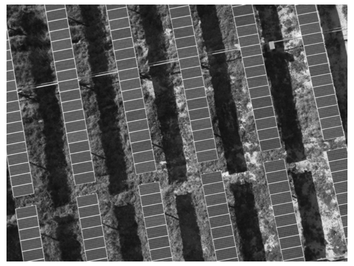

Figure 21 A solar farm in Williamsdale, New South Wales, Australia.

Source: Darrell Burkey, derived on August 20th, 2018 from https://www.flickr.com/photos/dburkey/40699963155/in/photostream/. Modified by the author.

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[17] Low/ high-grade energy (low-enthalpy energy): energy sources with a higher percentage of utilizable ingredients (and thus require fewer conversion processes) are higher rated, and vice versa.

[18] PVT are solar systems that convert sunlight into both thermal and electrical energy simultaneously and as such generate more energy per unit surface area. Because heat is carried away continuously from the PV cells, the photoelectric conversion efficiency will be reduced to some extent. For instance, of the nine PVT designs analysed by Zondag et al. (2003), the most efficient system has a photoelectric conversion efficiency of 9%, and a thermal efficiency of 63%.

5.2.2 Wind energy

According to MacKay (2008), the power of kinetic energy passing through the swept area of wind turbine blades can be calculated as:

$1/2\ \rho\ v^3 = 1/2 \times 1.3 \times 6.5^3 = 178.5\ \mathrm{W/m^3}$,
where ρ represents the density of air, which is about 1.3 $\mathrm{kg/m^3}$; v is the wind speed - the average wind speed in Daqing at 80 m is about 6.5 m/s.

Figure 22 An existing wind farm in Daqing, combined with a pasture.

Photograph by the author's mother, Shuzhi Liu. Modified by the author.

Apparently, not all kinetic energy is converted into electrical energy. According to Betz's law[19], under an ideal condition, the wind energy utilization coefficient (C_p) of a turbine can reach up to 59.3%. In order to reduce the disturbance of the downstream wind current, wind turbines are generally spaced at three to five times the blade diameter (which is usually expressed as 3d-5d). In this report, it is assumed that the average distance between wind turbines is 5d. For example, the blade diameter of turbines in Huaneng Daqing wind farm is 113.3 m; while the distance between the shaft and the ground is 90 m (Figure 22). *In the 2050 scenarios, if the same type of wind turbines (C_p = 50%), arranged in grid patterns, were applied in all wind farms, the average power generated by 1 m^2 of a wind farm will be:*

$$\frac{1/2\ \rho\ v^3 \times 1/4\ \pi\ d^2 \times 50\% \times 60 \times 60 \times 24}{3.6 \times 10^6 \times (5d)^2} = \frac{1/2\ \rho\ v^3 \times\ \pi\ \times 24}{25 \times 8 \times 10^3}$$
$$= 0.067\ \mathrm{kWh/d}$$

According to the above formula, this number is not affected by the blade diameter or height of the shaft. The number could be even less: for machine protection considerations, turbines will stop working when the wind speed exceeds or falls below their rated value. In Heilongjiang Province, effective wind speed only lasts for 4342 hours (49.6%) throughout the year (Li, Zhao, Du, 2011), which reduces the average power generated by 1 m^2 of a wind farm to

0.067 × 49.6% = **0.033 kWh/d**

However, Betz's law does not limit the efficiency of other innovative wind energy conversion systems: bladeless wind turbines[20], for instance, can capture the wind energy by the resonance phenomenon produced by an aerodynamic effect named vortex shedding (also known as Vortex Induced Vibration, VIV) and convert it into other utilizable forms of energy (Villarreal, 2018). Although the current wind energy utilization coefficient of the bladeless wind turbine is relatively low (approximately 30%) compared to that of conventional wind turbines (around 50%), there is still room for improvement. Furthermore, different from conventional turbines, bladeless wind turbines are not affected by the downstream wind current, and as such can be installed at a higher density (Figure 23); by fitting in the compact urban environment, bladeless wind turbines have the potential to compensate the energy utilization efficiency with space efficiency.

Figure 23 An imaginary picture of bladeless wind turbines installed In the wilderness.

Source: https://vortexbladeless.com/

The estimated rated power output of a 2.75 m high bladeless wind turbine is approximately 100 W. There is currently no data on larger models or the exact efficiency of bladeless turbines. *In both two scenarios, large-scale wind turbines are assumed to be concentrated in wind farms; while for aesthetics and noise considerations, bladeless wind turbines in small sizes are adopted by end consumers in the urbanized area, as means of distributed power generation. In 2050, if each household owned a 100 W roof-mounted or ground-mounted bladeless wind turbine (the C_p of which is around 50%), the daily energy generated by the bladeless turbine will be:*

$(100 \times 60 \times 60 \times 24)\ /\ (3.6 \times 10^6 \times 2.6) =$ **0.9 kWh/d per capita**

5.2.3 Geothermal

Geothermal energy is the immense thermal energy obtained from the creation of the Earth and the radioactive decay of minerals. It is normally used in two ways: direct utilization (of medium and low-temperature geothermal energy) and geothermal power generation (by high-temperature geothermal energy). The former method uses shallow groundwater or soil as a heat source for air heating and hot springs; several relevant pilot projects already exist in Daqing. The latter method mines higher temperature heat sources existing in hot dry rock (HDR) for electricity generation, and yet has not been industrialized in China. Although seems to be a stable and virtually limitless source of energy (compared to the inconsistent wind energy and solar energy), geothermal energy is only renewable when the extracted heat is less than the thermal energy replenishment in groundwater, soil, or HDR. Otherwise, the underground thermal imbalance will make geothermal a finite energy source just like nuclear energy and fossil fuels.

The average terrestrial heat-flow density[21] of Songliao Basin (where Daqing is located) is about 69 mW/m2, with an average geothermal gradient[22] of 3.1 C /100m (Ren, Xiao & Chi, 2001). If the density of mantle heat flow is 10 mW/m2 (MacKay, 2008), the radioactive decay in the Earth's crust then adds 59 mW/m2 to the heat flow from the Earth's core (Figure 24). In order to utilize geothermal energy sustainably, 69 mW/m2 is the theoretical maximum energy that can be extracted from the Earth. In an extreme scenario where all exploitable geothermal energy is utilized by perfect heat pumps and power stations, the available energy per square meter will be

$(69 \times 10^{-3} \times 60 \times 60 \times 24)\ /\ (3.6 \times 10^6) = 1.656 \times 10^{-3}\ \mathrm{kWh/d}$;

(1) Direct utilization: geothermal heat pumps
Geothermal heat pumps (or ground source heat pump, GSHP) are central air heating/ cooling systems that carry underground heat to houses through heat exchangers, or on the contrary. Some GSHP systems also supply hot water. In recent years, there has been an increasing number of relevant pilot projects in North China, where the annual heating time is almost equal to cooling time. However, in Daqing, the heating demand during long winters is generally much greater than the cooling demand in summers, which means that the amount of heat taken away from the soil or groundwater far exceeds the heat input of the system. Furthermore, Daqing's population is not evenly distributed throughout the region - the population density in a typical gated community can reach approximately 0.04 person per square meter, which reduces the local available geothermal energy to

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[19] Proposed by Albert Betz in 1919, Betz's law is the fundamental theory of wind energy utilization studies. The law assumes a hypothetical 'ideal wind wheel' that can capture all the kinetic energy of the fluid (which is continuous, incompressible, and has no resistance) passing through. Fundamental physical laws limit the maximum efficiency of a wind turbine to 16/27, which is approximately 59.3%.

[20] Developed by a Spanish company named Vortex Bladeless. Vortex wind generators are 'more similar in features and cost-effectiveness over time to solar panels than to regular wind turbines', according to Vortex Bladeless.

[21] Terrestrial heat-flow density (or heat flux density) is the heat flow rate of per unit area and unit time, that transfers from the interior to the surface of Earth and then released into space. The common unit of heat flux density is $\mathrm{mW/m^2}$.

[22] Geothermal gradient refers to the rate of temperature rise associated with per unit depth in the Earth's interior.

1.656×10^{-3} / 0.04 = **0.0414 kWh/d per capita**

In order to heat multi-storey residential or commercial buildings in such communities, the existing GSHP systems in some pilot projects adopt densely installed vertical single U or even double U type soil heat exchangers, which in the long term will almost certainly lead to underground thermal imbalance. In the 2050 scenarios, *in order to compensate for the heat loss, GSHPs are combined with the aforementioned PVT systems: the excess heat collected by solar panels in summer can be stored for winter use.*

(2) Geothermal power generation: geothermal power plants

Both medium-low temperature geothermal (< 200°C, shallow geothermal) and high temperature geothermal (> 200°C, deep geothermal) sources can be used for power generation. Presently, almost all of the commercial geothermal power projects are based on the former technology, while the latter remains in an experimental phase. *In 2050, it is assumed that limited by the level and cost of drilling technologies, geothermal power plants that may appear use medium-low temperature hydrothermal resources (geothermal reservoirs) to power generators, with a drilling depth around 3 km.* Fundamental physical laws limit the conversion efficiency of low-enthalpy geothermal resources to a lower level, compared to that of high-grade energy sources (which are used by conventional thermal power plants): according to Zarrouk (2014), the highest reported conversion efficiency of geothermal power plants is approximately 21%. *In 2050, if the average efficiency of geothermal power plants reaches 25%, the average available geothermal energy per square meter will be*

$1.656 \times 10^{-3} \times 25\% = 4.14 \times 10^{-4}$ kWh/d

In spite of its invisibility, the extraction area of a 10 MW geothermal power plant will be immense:
$(10 \times 10^{6}) / (69 \times 10^{-3}) = 144927536$ m^2,
which accounts for approximately 1/153 of Daqing's total area.

5.2.4 Biomass

According to Sijmons (2014), there are normally two generations of biomass: the first generation biomass (such as corn) compete directly with food production; while the second generations are non-food energy crops like switchgrass (Panicum virgatum). Agricultural by-products and waste such as straw and chicken poo also can be sources of biomass, though they represent 'relatively small amounts and the collection of the material uses a lot of energy' (ibid.). After collected from farmlands, biomass can be converted into other forms of energy in two ways: compressed and sent to thermal power stations for combustion ('coal substitution', using the expression of MacKay, 2008), or fermented in biorefineries to produce bioethanol or biodiesel ('petroleum substitution', ibid.).

(1) Non-food energy crops

Although both plant leaves and photovoltaics work as solar collectors, the efficiency of photosynthesis and biomass boilers is extremely low compared to the photoelectric conversion efficiency of mono-crystalline silicon. In other words, a low-grade energy source such as biomass loses a huge amount of energy when converted into a high-grade energy source like electricity. In the 2050 scenarios, where the cost of PV cells is assumed to be low enough to eliminate the price advantage of biomass electric generation, energy crops are preferentially considered as raw materials for bioethanol and biodiesel production instead of fuels for power generation. If the solar energy utilization rate of these energy crops is around 0.5%, during the time period when the climate allows crops to grow (generally from May 1st to October 31st), the average chemical energy stored in biomass will be 4.5 kWh/m², which is calculated based on the solar irradiance data mentioned in section 4.2.1. If the conversion efficiency is around 70% in 2050, the available energy stored in bioethanol or biodiesel that made from energy crops will be:

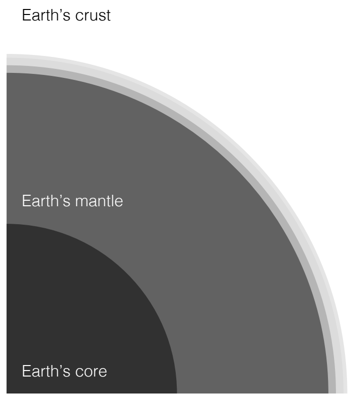


Figure 24 The underground temperature change of Songliao Basin, with respect to the increasing depth in the Earth's interior.

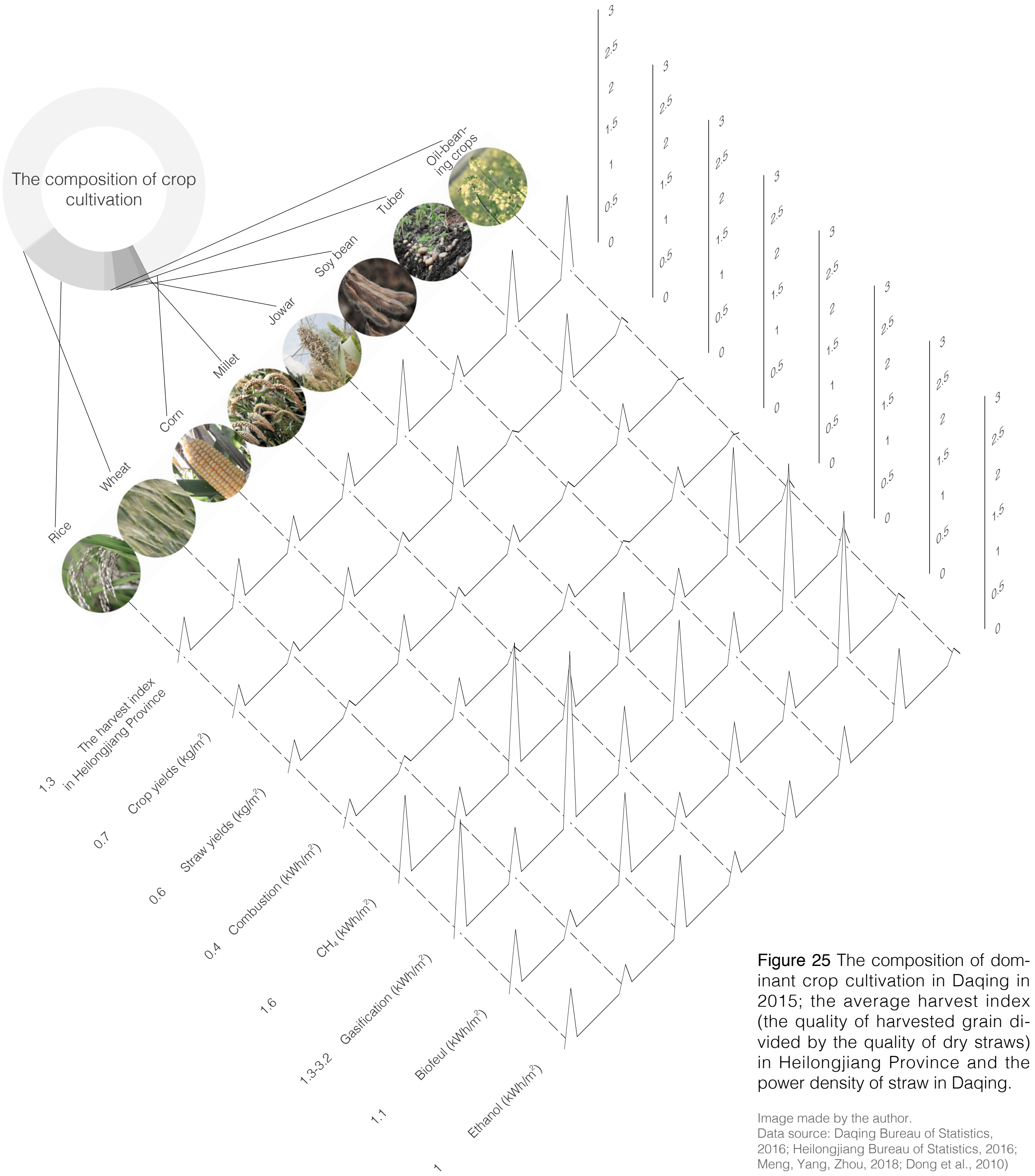


Figure 25 The composition of dominant crop cultivation in Daqing in 2015; the average harvest index (the quality of harvested grain divided by the quality of dry straws) in Heilongjiang Province and the power density of straw in Daqing.

Image made by the author.
Data source: Daqing Bureau of Statistics, 2016; Heilongjiang Bureau of Statistics, 2016; Meng, Yang, Zhou, 2018; Dong et al., 2010)

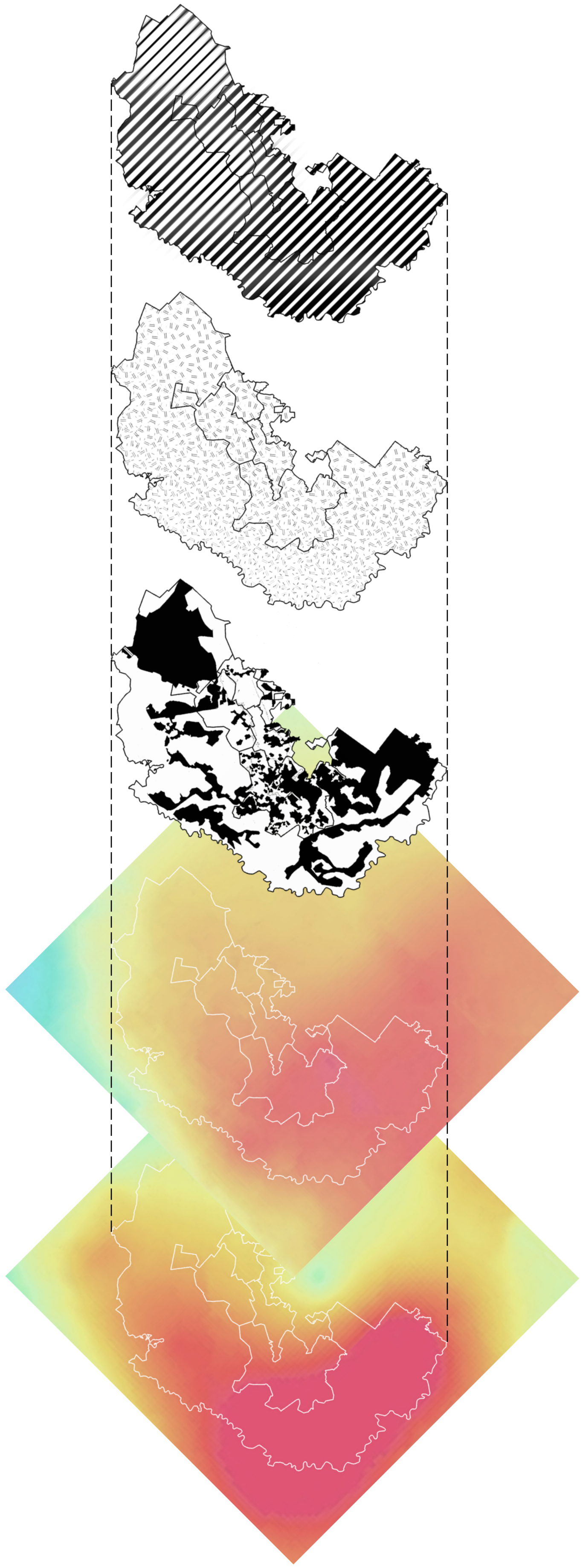


Image made by the author.
Data source: http://fd.bjx.com.cn/

Image made by the author.
Data source: https://news.solarbe.com/201603/24/97015_1.html

Image made by the author.
Data Source: Yu, 2013.

Image modified by the author.
Data source: Li, 2017.

Image modified by the author.
Data source: Li, 2017.

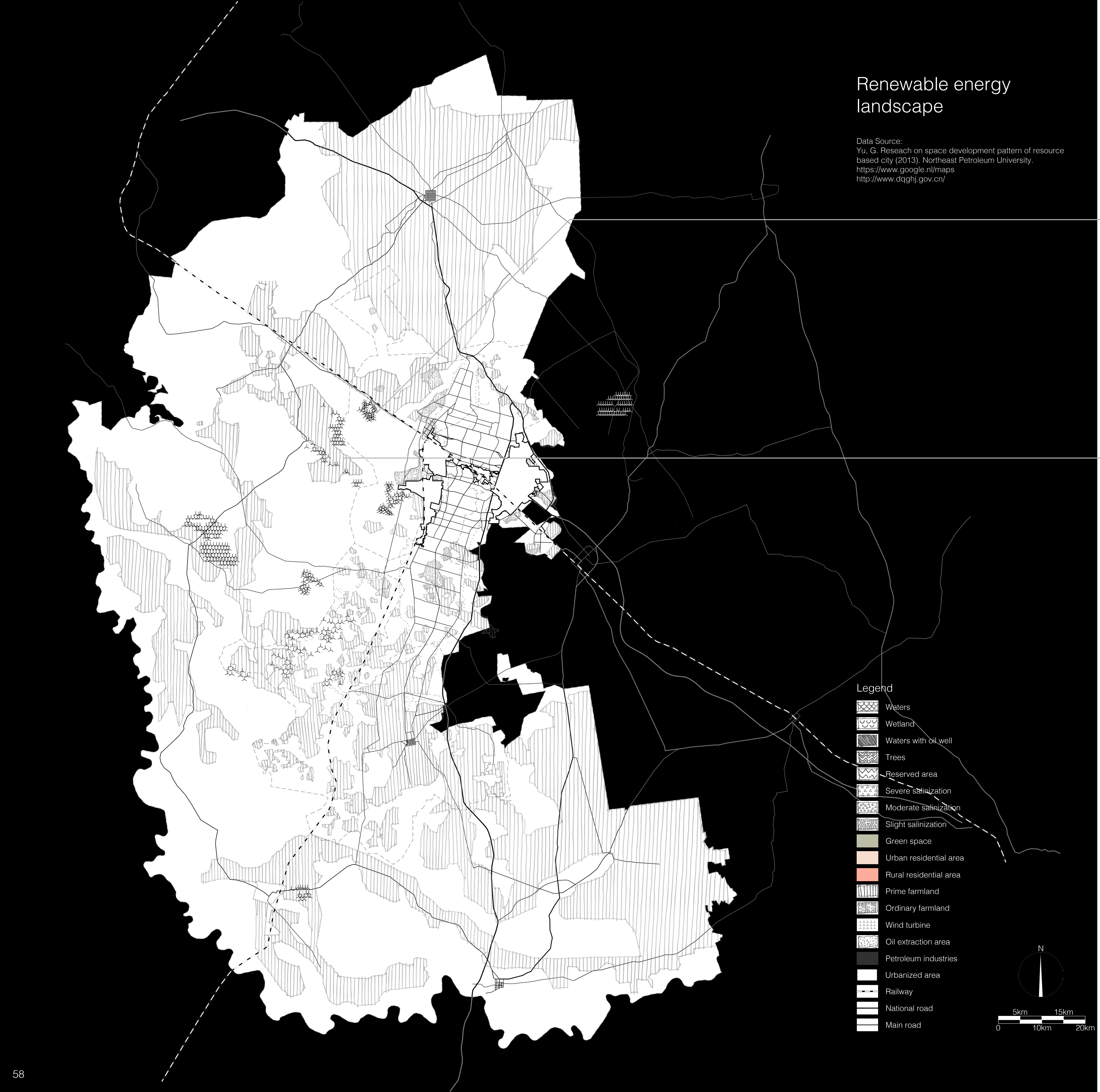
4.5 × 70% = **3.2 kWh/m^2**

(2) Waste straw

In 2015, 34% (7478.6 km^2) of the land surface in Daqing is used for crop cultivation (Daqing Bureau of Statistics, 2016). Presently, 30% of the collected straws go to open-burning, which is not only a waste of energy but also a major source of air pollutants (Meng, Yang, Zhou, 2018); others are used as livestock feeds, industrial raw materials, growth medium for edible mushroom, burnt in furnaces for winter heating in rural residences, and returned to the field as fertilizers. *In 2050, It is speculated that due to food safety regulations, the cultivation of energy crops (that may appear) will not encroach on the land of original crops. 50% of the waste straw collected from farmland is converted into petroleum substitution or sometimes used as coal substitution for dealing with the intermittency problem of solar energy and wind power. The power density of straw is shown in Figure 25, which is assumed to remain basically unchanged in 2050. Apparently, the utilization rate of straw gasification or fermentation is much higher than that of direct combustion.*

Renewable energy landscape

Data Source:
Yu, G. Reseach on space development pattern of resource based city (2013). Northeast Petroleum University.
https://www.google.nl/maps
http://www.dqghj.gov.cn/



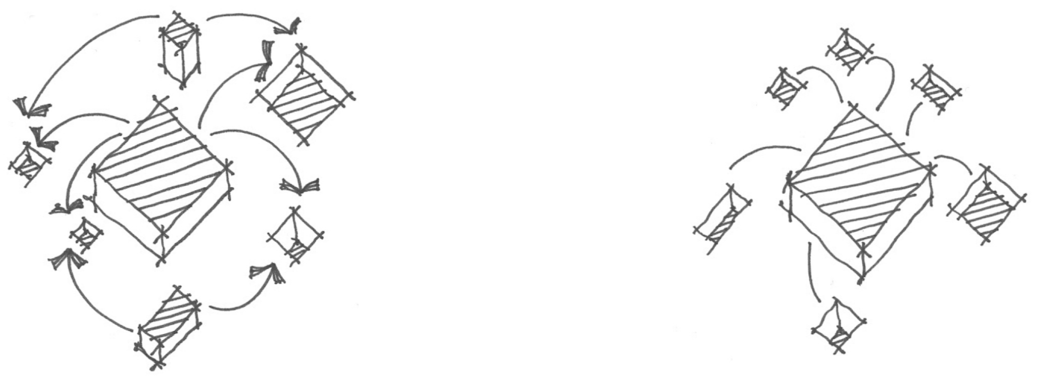
Wind farm

Photograph by the author

Biomass

Photograph by the author

5.3 Renewable energy consumption in Daqing's built environment



Build physical connections between source and sink areas that 'lie in close proximity to one another'

Locate new energy sinks in the proximity of existing source areas

Figure 28 Two approaches derived from the source-sink thinking

The following paragraphs discuss Daqing's energy consumption in 2015 (which is calculated base on the energy balance sheets of Heilongjiang Province), followed by assumptions on the energy production & demand in 2050. In agreement with the official statistical methods, the energy consumption is discussed by six sectors: (1) (rural and urban) residential sector; (2) wholesale, retail trade, hotel and restaurants; (3) construction sector; (4) transportation, storage and post; (5) industrial sector; (6) agriculture, forestry, animal husbandry and fishery, respectively.

The current energy demand per capita of Daqing is assumed to be the same as the provincial average; the total energy consumption is then calculated by multiplying the energy consumption per capita and Daqing's population. Limited to the availability of data, this report uses the 2015 statistics as its basis for calculations and inferences. Considering the urban-rural dualization phenomenon, the energy consumption of urban and rural residents must be calculated separately. However, the urbanization rate of Heilongjiang Province (58%) is higher than that of Daqing (51%) - technically, their rural-urban distribution of the population is different from each other. However, this difference has to be ignored in this report due to data restrictions.

In the following sections, the units of energy are all converted into kilowatt hours per day instead of joules: whether derived from renewables or fossil fuels, the energy supply must not only meet the annual energy demand but also satisfy the daily energy needs. The mass or volume of coal, natural gas, crude oil and petroleum products is converted into equivalent chemical energy.

Due to historical reasons, the economy developments taking place in Europe (especially in western European countries) in the modern times has always been decades ahead of China. This fact to some extent makes today's energy consumption (especially that of the residential sector) in EU 28 countries a reference for the 2050 scenarios of Daqing. Most of the energy assumptions on the residential sector are as such based on the current average energy consumption of the 28 EU member countries. However, it should be noted that this does not necessarily mean that the future is linear and predictable; on the contrary, we must always consider the possibility of the occurrence of 'black swan events'[23], or 'wild cards', as mentioned by Kosow & Gaßner (2008). For instance, the large-scale adoption of new technologies in the energy production processes; the massive upgrades to energy infrastructure in both urban renewal and new construction projects, the implementation of supporting policy measures, etc.

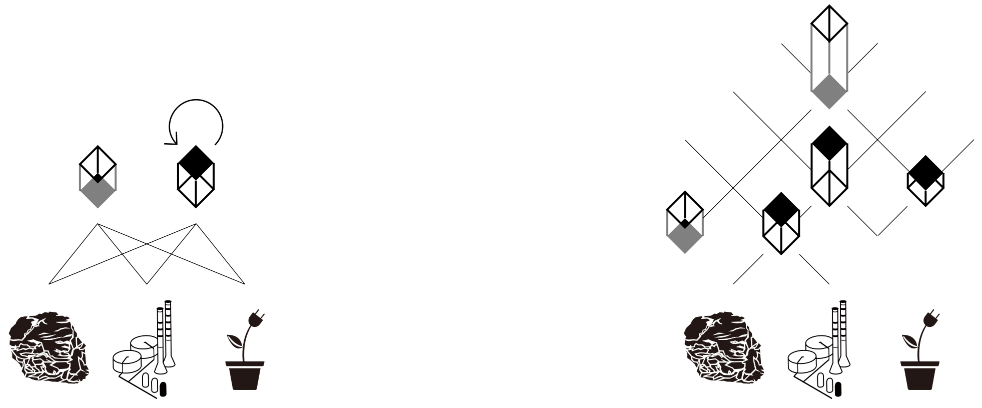


Figure 29 Two diagrams illustrating the conservative scenario and liberal scenario

Source of icons: Arthur Shlain; Ana María Lora Macias; Stock Image Folio; Bakunetsu Kaito; Marco Livolsi; Olivier Guin; Mahmure Alp from the Noun Project. Modified by the author

While analysing the renewable energy approaches that could be developed to meet the demands in the post-petroleum era, this section also focuses on spatializing the renewable energy production process: linking the abstract energy flow to specific urban space.

Stremke & Koh (2011) has promoted the source-sink thinking in the energetic perspective: a source-sink relationship exists when source areas export surplus energy to sink areas. There are two strategies derived from the source-sink concept: the first is to build physical connections between source and sink areas that 'lie in close proximity to one another'; the second strategy is then 'to locate new energy sinks in the proximity of existing source areas' (ibid.) (Figure 28).

Three of the aforementioned six sectors - residential, service, and agriculture - are energy consumers while also have the capability of becoming renewable energy suppliers in the post-petroleum era, and as such can be seen as both source and sink areas. The construction, transportation and industrial sector in another aspect, are seen as sink areas which depend on exogenous energy input. Transportation of energy causes energy loss. The energy demand is firstly met locally and is connected to exogenous sources only when it cannot be satisfied by neighbouring energy sources.

Based on hypothetical breakthroughs of renewable energy technologies, the conservative scenario assumes that a source in the built environment (e.g. a building) only produce renewable energy for its own needs; while the liberal scenario illustrates the maximum conceivable renewable energy production within spatial limitations. It is postulated that through a physical smart grid, sources and sinks can exchange excess energy generated by renewable sources such as solar collectors and wind turbines, which greatly reduces external energy input (Figure 29).

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[23] A black swan metaphorizes a sudden event that is far beyond expectations, and as such extremely difficult to predict. For instance, the global financial crisis of 2007-2008, the rapid economic growth of China during recent years, etc.

5.3.1 Urban and rural residential sector

(1) Consumption

The differences in energy consumption pattern between rural and urban residential sectors reflect the urban-rural dualization in this region. *The scenarios yet assume that in 2050, the urban-rural differences in Daqing have become almost negligible, thanks to a series of (probably both top-down and bottom-up) measures to promote rural (agricultural) economic growth. At this time, people can enjoy a comfortable modern life as well as decent transport and energy infrastructure whether living in the city or out in the countryside.*

① Electricity

As shown in Figure 30, the average electricity demands of rural and urban residents are both around 1.2 kWh/d per capita (National Bureau of Statistics, 2016). *It is postulated that in 2050, the increase in people's requirements for living comfort has lead to a sharp growth in average domestic electricity consumption, reaching the average level of the 28 EU member countries in 2016 (which is 1584 kWh/y per capita =* **4.3 kWh/d per capita***, Eurostat, 2016). The average electricity generation of PVT systems in three typical housings is shown in Figure 33.*

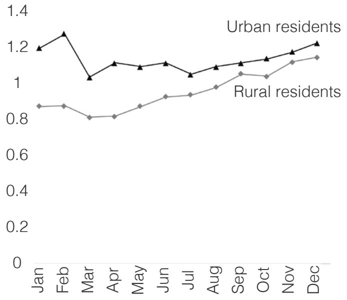


Figure 30 The seasonal fluctuation of domestic electricity consumption is not obvious in Heilongjiang Province.

Data source: Heilongjiang Bureau of Statistics. (2011). Retrieved August 11, 2018, from http://www.hlj.stats.gov.cn/tjsj/ydsj/

② Water & air heating

The scenarios assume that the hot water demand in the residential sector reach the standard of today's European household - 100L per day per household (MacKay, 2008). The temperature of tap water (comes from groundwater in most parts of Daqing) remains around 17 °C throughout the year; the suitable water temperature for washing, cleaning, and comfortable showing is generally believed to be around 40 degrees.

The density of water at 17 °C is 998.774 kg/m^3; the specific heat capacity of water at 17 °C is 4.1937 kJ/kg ·K, and 4.1766 kJ/kg ·K of water at 40 °C.
Quality of 100L of water at 17 °C = 100 / 1000 × 998.8 = 99.9 kg
The average specific heat capacity of water between 17 °C and 40 °C is: (4.1937 + 4.1766) / 2 = 4.18515 kJ/kg ·K
The heat required to heat 100L of water from 17°C to 40°C = 99.9 × 4.18515 × (40-17) = 5434 kJ = 1.5 kWh
The average energy demand for heating water is: 1.5 / 2.6 = 0.6 kWh/d per capita

Most urban dwellings in Daqing are centrally-heated, with a heating season from October 15th to April 15th. The current average energy demand for maintaining a comfortable indoor thermal environment during heating season is approximately 16.2 kWh/d per capita (National Bureau of Statistics, 2016). The air heating in rural residences, in another aspect, often relies on small coal-fired boilers or direct combustion of loose coal and biomass. However, in recent years, small boilers are officially banned by the municipality due to their low combustion efficiency and high air pollution levels. *In 2050, if rural residences and urban housings shared a same thermal comfort level, and are both equipped with combined PVT and ground coupled heat pump systems, the thermal energy demand for water and air heating will be:*

16.2 + 0.6 = **16.8 kWh/d** per capita from October 15th to April 15th

0.6 kWh/d per capita from April 15th to October 15th

③ Cooking

Open flame cookware that consumes LPG or natural gas is essential to Chinese cuisine. Compared to LPG that has to be transported and stored by compressed gas cylinders, natural gas is much safer: CH_4 does not liquefy at room temperature thanks to its smaller molecular mass, and as such is suitable for pipeline transportation. In 2015, the average domestic LPG consumption in urban area is 1.4 kWh/d per capita, while the natural gas consumption is about 1.1 kWh/d per capita (National Bureau of Statistics, 2016). *The 2050 scenarios assume that the gas pipeline renovation project has led to a comprehensive replacement of LPG by natural gas in urban and rural homes. If LPG and natural gas cookers shared a same combustion efficiency, the average natural gas consumption in 2050 will be:*

1.4 + 1.1 = **2.5 kWh/d per capita**, which equals to **0.25 m^3/d per capita**

(2) Production

There is a difference in the renewable energy potential between urban and rural areas: the roof area per capita differs greatly. The solar power solutions mentioned in the previous section might be feasible in rural areas where bungalows expand horizontally across the landscape. However, 51% of Daqing's population lives in residential town houses or high-rise apartments that have less roof area per capita for installing photovoltaics (Figure 31). Moreover, the rate of urbanization keeps rising: official forecasts (The State Council of the People's Republic of China, 2017) have pointed out that the national average urbanization rate will be 70% by 2030; *in the 2050 scenarios, we boldly assume this number reaches 85%.*

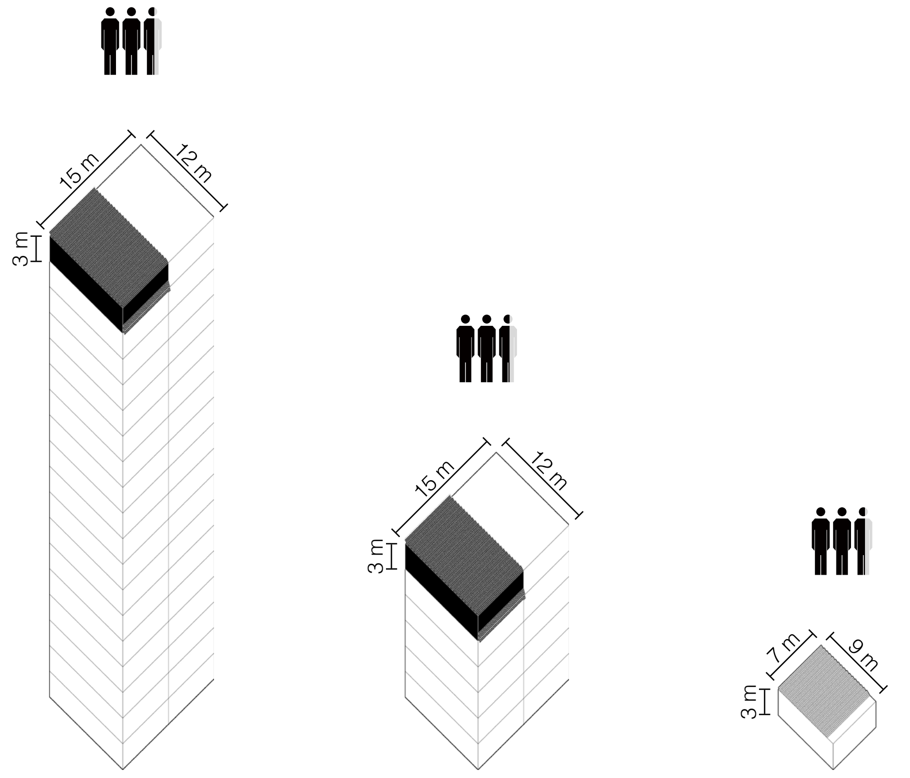
Figure 31 The popularization of wall-mounted solar energy collectors is currently limited by economic costs, the bearing capacity of the supporting wall, and aesthetic considerations.

Photograph by Gav Scott, retrieved August 21, 2018, from www.flickr.com/

Rural residents can take full advantage of the roof space to place solar collectors; while wall-mounted solar energy collectors can serve as an alternative and supplement to the more popular roof-mounted ones in urban housings (Figure 32). Based on this precondition, the following paragraphs illustrate a simple calculation investigating the possibility of meeting the electricity and heat demands with solar power solutions:

Figure 32 A photograph of Daqing's residential town houses, which are equipped with solar panels; compared with high-rise buildings where solar collectors are officially forbidden due to safety concerns. However, the top left corner of this photo shows a secretly installed solar water heater, which belongs to an anonymous resident living in a high-rise apartment.

Photograph by the author



A typical
18-storey high rise apartment

A typical
6-storey residential townhouse

A typical
rural residence

Figure 33 Two hypothetical typical urban dwellings and one typical rural dwelling.

Urban population in Daqing = 1413300
Total gross floor area (GFA) of urban residences in Daqing = 48880000 m^2
Average GFA of urban residences = 48880000 / 1413300 = 34.6 m^2 per capita

Average population per household = total population / total household = 2754800 / 1067000 = 2.6
Average GFA per urban household = 34.6 × 2.6 = 90 m^2

If the size of a typical residential unit was 12 m × 7.5 m × 3 m, in an extreme scenario all roof space and 1/3 of the south facade (the dwellings in Daqing are usually south-facing due to lighting considerations) is covered by wall-mounted solar cells. The average area of solar collectors will be:

(90 / 18 + 3 × 1/3 × 7.5) / 2.6 = 4.8 m^2 per capita in a typical 18-storey high rise apartment
(90 / 6 + 3 × 1/3 × 7.5) / 2.6 = 8.7 m^2 per capita in a typical 6-storey residential town house
Taking aesthetic needs into consideration, if 2 m^2 of south facade per household was covered by wall-mounted solar cells. The available area for placing solar collectors will be even less:

(90 / 18 + 2) / 2.6 = **2.7 m^2 per capita** in a 18-storey high rise apartment
(90 / 6 + 2) / 2.6 = **6.5 m^2 per capita** in a 6-storey residential town house
Average GFA of rural residences = 23.7 m^2 per capita
Average GFA per rural household = 23.7 × 2.6 = 61.6 m^2

If the size of a typical rural residence was 9 m × 7 m × 3 m, corresponding to the energy demand in the scenarios, part of the roof (about 21.5 m^2 per capita) of a typical single-storey rural dwelling is covered by roof-mounted solar collectors.

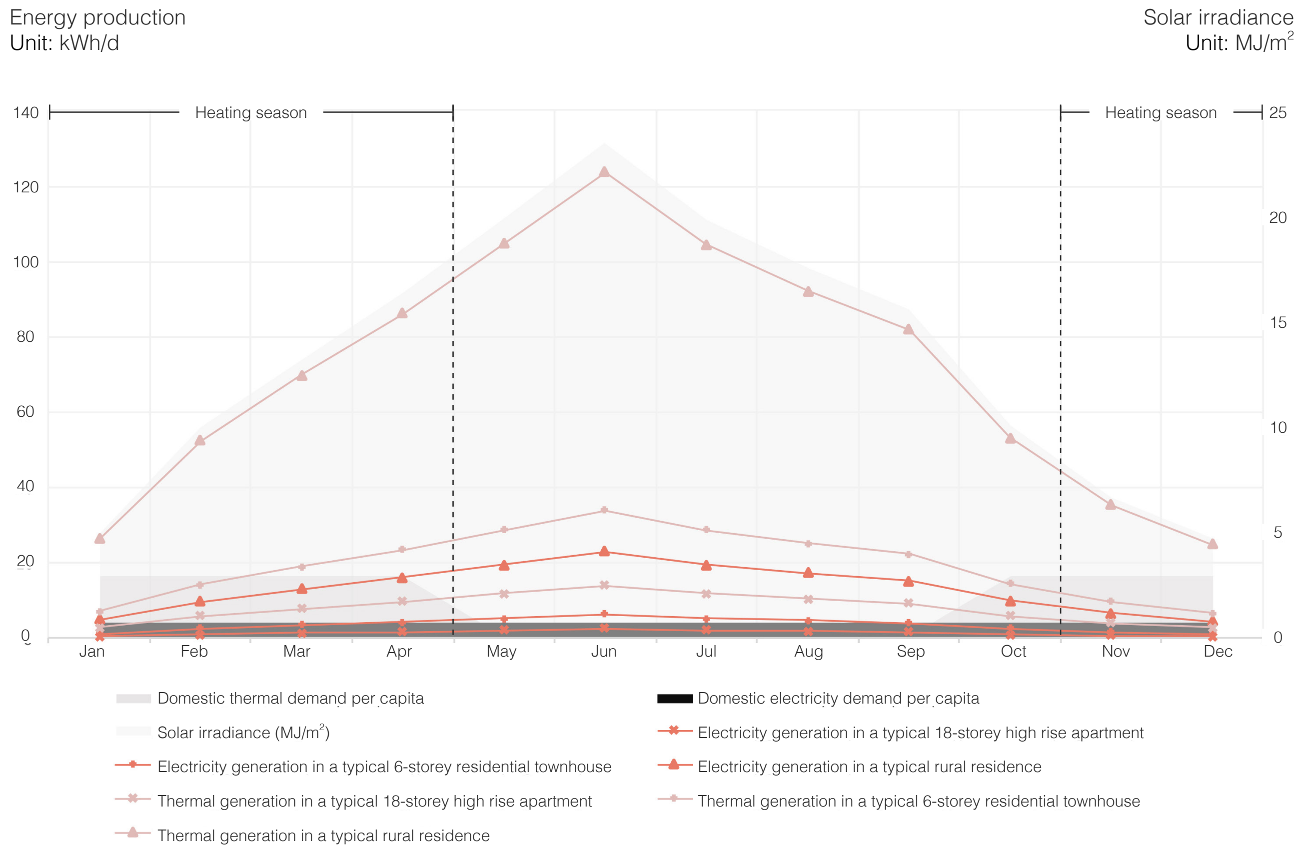


Figure 34 Estimated daily average electrical and thermal energy generation of PVT systems in three typical housings during a year.

Data source: Daqing Bureau of Statistics (2016) and other open data sources

(3) Conclusion

As shown in Figure 34, although it will be possible for rural residences to be self-sufficient by adopting PVT systems, the available installation area in typical urban residences is far from enough to meet its own energy demand during the winter. Therefore, the energy gap in residential sector must be filled by an exogenous energy source. In December, when the solar irradiance falls to the lowest level, the gap between electricity supply and demand will be:

4.3 - 0.5 = 3.8 kWh/d per capita in a typical 18-storey high rise apartment
4.3 - 1.3 = 3 kWh/d per capita in a typical 6-storey residential town house

the value of a whole year will then be:

4.3 × 365 - 556 = 1013.5 kWh per capita in a 18-storey high rise apartment
4.3 × 365 - 1338.5 = 231 kWh per capita in a 6-storey residential town house
(Calculated based on the solar irradiance data mentioned in section 4.2.1)

the gap between thermal supply and demand is:

16.8 - 2.8 = 14 kWh/d per capita in a typical 18-storey high rise apartment
16.8 - 6.8 = 10 kWh/d per capita in a typical 6-storey residential town house

As a supplement to PVT systems, ground source heat pumps work as seasonal thermal energy storage (STES) systems that bridge the extra thermal energy demand in heating season and the excess thermal energy stored in summer. The amount of excess heat stored from April 15th to October 15th is:

2005.2 - 0.6 × 183 = 1895.4 kWh per capita in a typi-

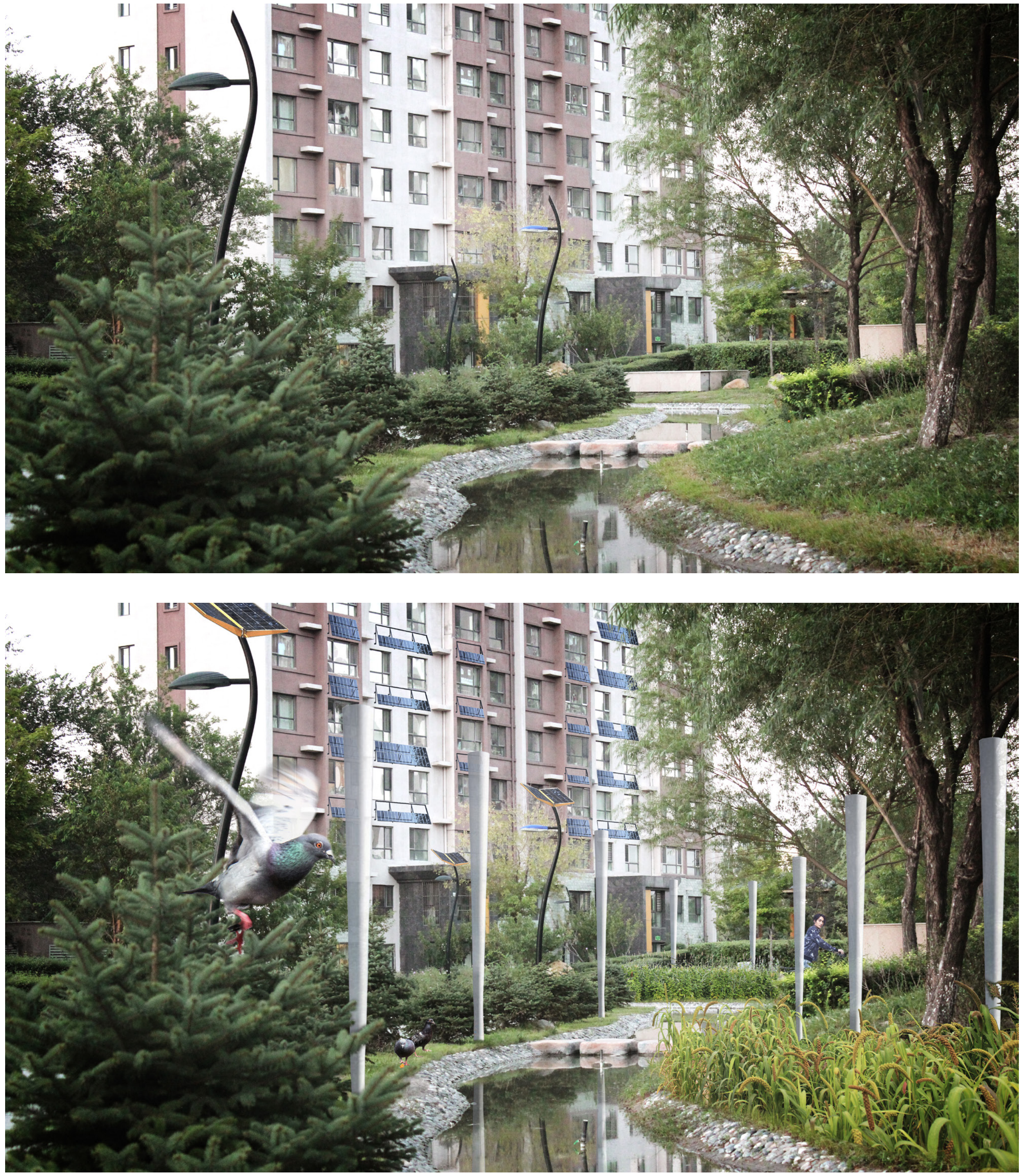


Figure 35 An imaginary picture of the energy landscape in urban residential area in 2050.

Photograph and modified by the author

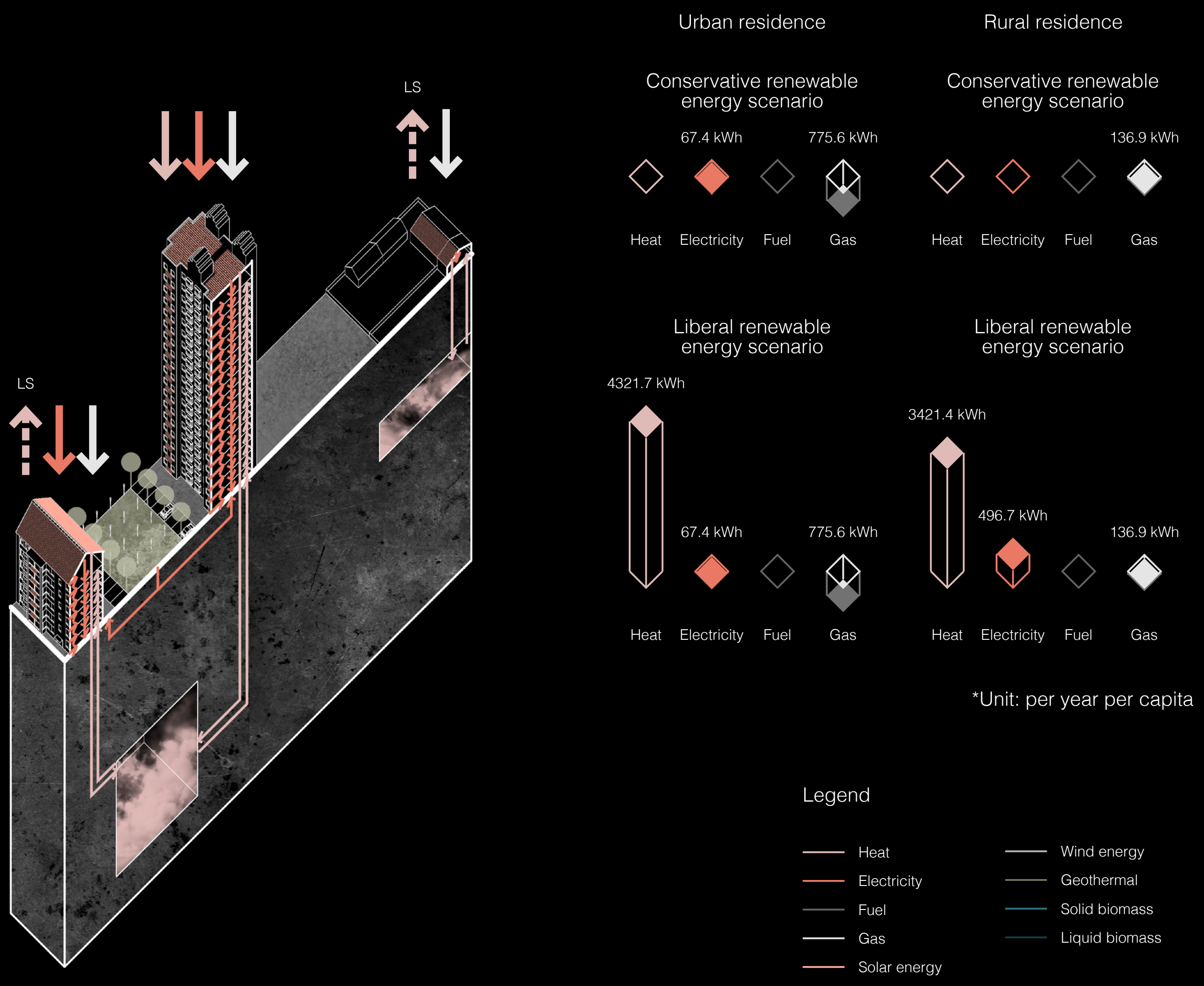


Figure 36 A section showing the energy flow in the residential sector.

cal 18-storey high rise apartment
8220.2 - 0.6 × 183 = 8110.4 kWh per capita in a typical 6-storey residential town house
(Calculated based on the solar irradiance data mentioned in section 4.2.1)

From October 15th to April 15th, the amount of thermal energy demand that can not be satisfied by PVT systems is:
16.8 × 182 - 960.2 = 2097.4 kWh per capita in a typical 18-storey high rise apartment, which slightly exceeds the amount of storage,
16.8 × 182 - 2297.1 = 760.5 per capita in a typical 6-storey residential town house, which can be met by the stored heat (ibid.)

Early urban residential projects in Daqing are predominantly composed of 6-storey residential town houses, a wave of high-rise building construction then emerged around 2008. Although high-rise housing projects are located near the edge of the urbanized areas, high-rise apartments are still surrounded by 6-storey dwellings; some recently built communities include both two types. Therefore, it will be possible for different types of dwellings to share their stored heat through centralized underground thermal energy sinks and achieve self-sufficiency for heat. *In 2050, if the majority (70%) of Daqing's urban population live in 6-storey apartments, while the rest 30% living in high-rise apartments, the annual energy balance per capita will be as shown in Figure 36.*

5.3.2 Service sector: wholesale, retail trade, hotel and restaurants

(1) Consumption

The energy consumption in the service sector is closely tied to the area of commercial properties as well as the volume and distance of freight. It is as such largely affected by the citizen's demand for commercial services (Figure 37). *The 2050 scenarios assume the development of e-commerce has resulted in a sluggish retail market and a recession in the hospitality industry, leading to a 15% decrease in the per capita area of commercial properties and energy demand (for heating and powering commercial buildings); while the energy consumption of freight has seen a 20% rise.*

Presently, an abundant amount of commercial buildings use private coal-fired boilers for heating. The heat consumption is approximately 4.6 kWh/d per capita (3.2 kWh/d supplied by coal-fired boilers[24] and 1.4 kWh/d by centralized-heating systems, National Bureau of Statistics, 2016). In 2050, this number will fall to:

4.6 × 85% = 3.9 kWh/d per capita
the electricity consumption will reduce to: 0.4 × 85% = 0.3 kWh/d per capita
the traffic fuel consumption, in another aspect, will increase to: 2.9 × 120% = 3.5 kWh/d per capita

(2) Production

It is much more difficult to estimate the renewable energy production pattern of commercial buildings than that of residential communities: the vast majority of residential projects in Daqing are developed and managed collectively by state-owned enterprises or private developers, it is therefore possible to promote renewable energy through integral urban renewal projects[25]; the regeneration of commercial buildings yet involves multiple stakeholders, making much of the future opaque. *Thus, in the 2050 scenarios, the renewable transformation in the commercial sector is postulated to remain at an intermediate stage that involves minimal building renovation work: only the idle roof space of commercial buildings is used for renewable energy production. Further developments may occur in the more distant future. The conservative scenario supposes commercial buildings meet their own electricity needs by deploying roof-mounted PV cells. The liberal scenario boldly assumes that all of the rooftops of non-residential buildings such as shopping malls, office buildings, museums, chain restaurants, and hotels are covered by photovoltaics: the roof layer of the city forms a tremendous urban solar farm. The following paragraphs then illustrate a simple calculation investigating the capacity of this solar farm:*

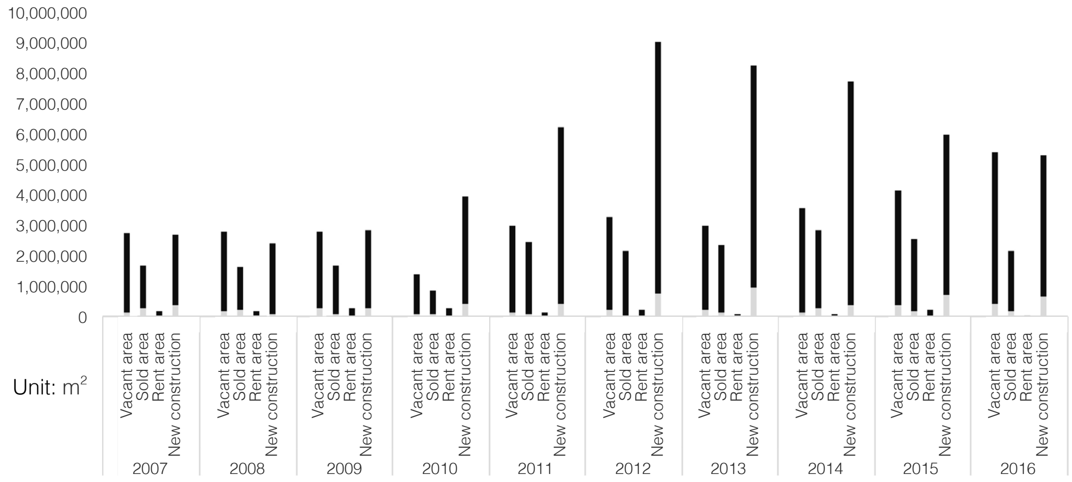


Figure 37 Vacant, sold, rent and new construction area in Heilongjiang Province, 2015

Data source: Fixed Assets Investment Statistics Division of National Bureau of Statistics, 2016

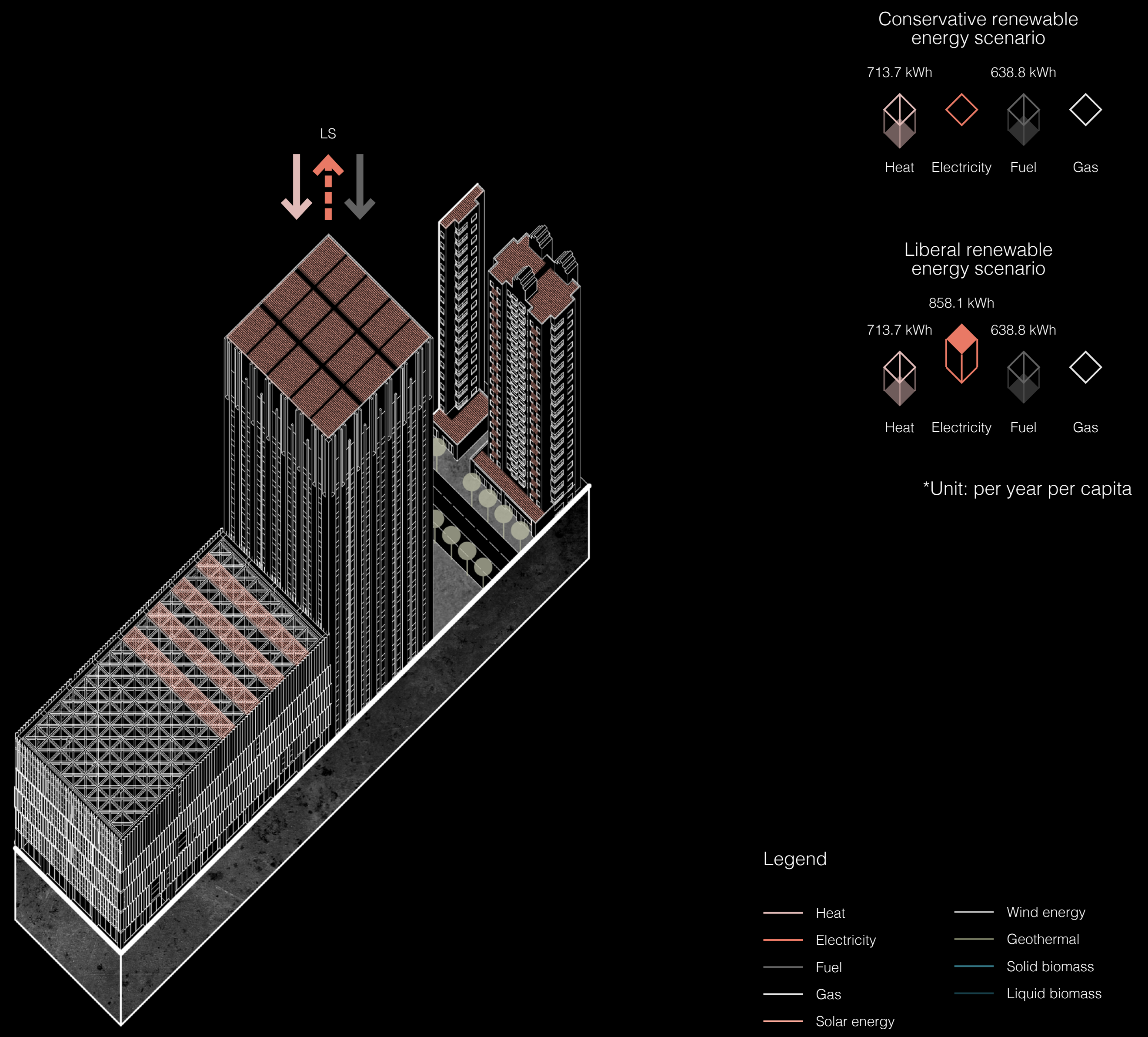


Figure 38 A section showing the energy flow in the service sector.

Urban population in Daqing = 1413300
Total GFA of non-residential urban buildings in Daqing = 38940000 m^2
In 2050, the per capita rooftop area of commercial buildings (that are assumed to be 6 stories high on average) will be:
38940000 / 6 / 1413300 × 85% = 4.6 × 85% = 3.9 m^2
Based on the calculation and solar irradiance data in section 4.2.1, the power generated by the rooftop urban solar farm will be:

0.4 × 3.9 = 1.6 kWh/d in December, and 1606.3 kWh per capita for a year, which is enough to satisfy the electricity demand of commercial buildings;

In addition, a considerable area of commercial activities is combined with the ground floors of residential buildings - a typical spatial configuration of Chinese city named 'ground floor commerce'. The renewable energy potential of this type of commercial space is already covered in the residential sector.

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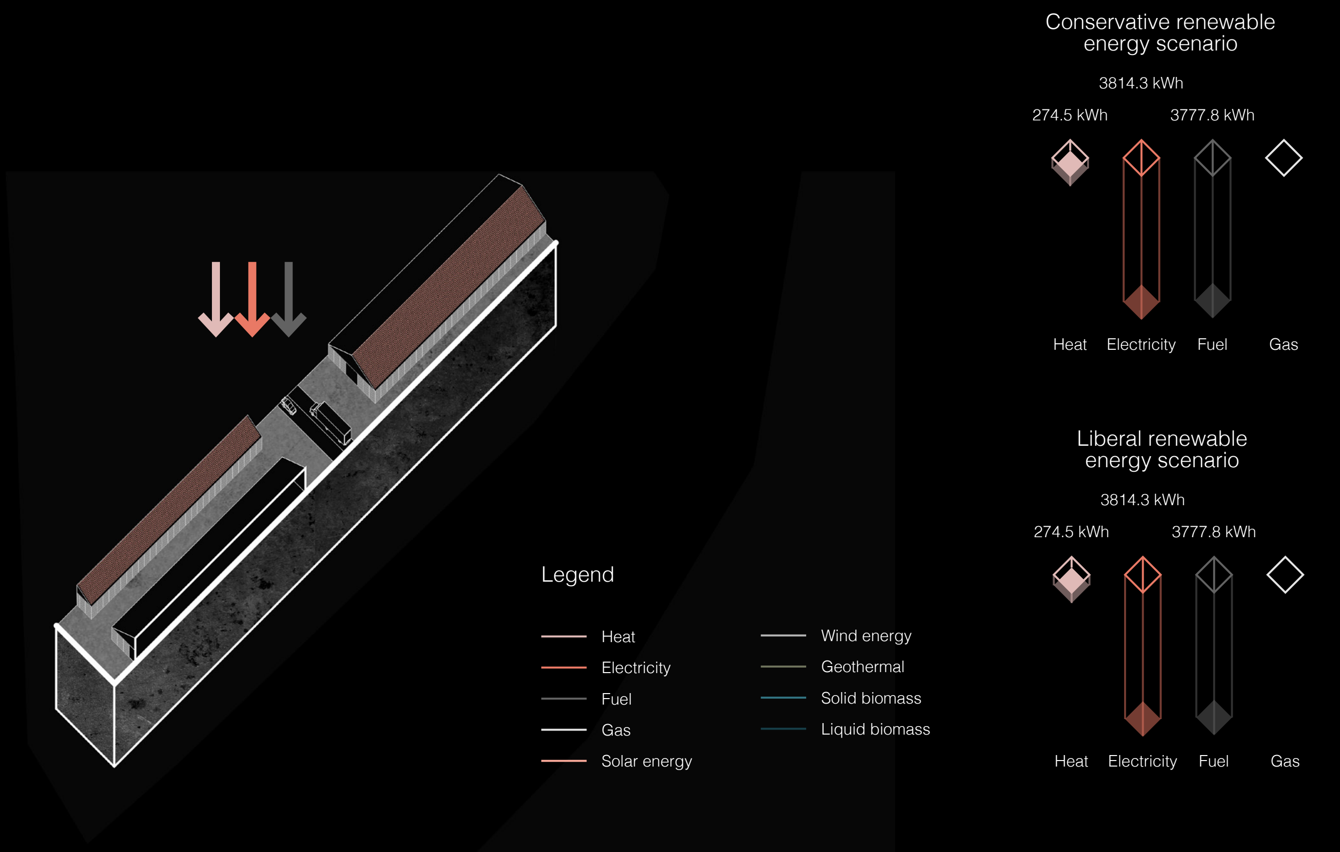
[24] The combustion efficiency of coal is assumed to be 25%.

[25] Integral urban renewal projects financed fully, or primarily by the municipality is quite common in Chinese cities.



5.3.3 Transportation sector

In 2015, the transportation sector consumed 0.08 kWh/d per capita (National Bureau of Statistics, 2016) of electricity and 1.24 kWh/d per capita (0.3 kWh/d supplied by coal-fired boilers and 0.94 kWh/d by centralized-heating systems, ibid.) of heat. *The 2050 scenarios assume that the development of e-commerce has led to a 20% increase in the energy demand of warehousing. The electricity consumption will increase to:*

0.08 × 120% = 0.1 kWh/d per capita

the heat consumption will be:
1.24 × 120% = 1.5 kWh/d per capita

In 2015, the fuel demand in the transportation sector was 3.7 kWh/d per capita. *It is postulated that in 2050, the increased vehicles per capita and the growth of logistics have resulted in a sharp growth in the fuel demand, reaching the average level of the 28 EU member countries in 2015 (which is 20.7 kWh/d per capita, Eurostat, 2016).*

As motor vehicle fuels, bioethanol and biodiesel are commonly blended with gasoline (petrol) and petroleum diesel, respectively. Under current Chinese regulations, only ethanol-gasoline blends of E10 (containing a concentration of 10% ethanol) are available in gas stations within certain provinces (including Heilongjiang Province) and cities (Wang et al., 2018). Presently, common biodiesel-diesel blends are B5 (containing a concentration of 1-5% biodiesel) and B20 (6-20% of biodiesel) (Wei & Fei, 2015). In 2016, Sinopec Shanghai Petrochemical Company has run a series of pilot biodiesel projects that start energizing vehicles in Shanghai with B5 (Zheng, 2018). The mass commercialization of biofuel engines is foreseeable in the future - a large number of vehicles in Brazil runs on E100 (hydrous alcohol). *In the conservative renewable energy scenario, 50% of all vehicles in Daqing applies internal combustion engines (ICE) that burn E10, the fuel consumption will be:*

20.7 × 50% = 10.4 kWh/d per capita

which contains anhydrous alcohol:
10.4 × 10% = 1 kWh/d per capita

In the liberal renewable energy scenario, 50% of vehicles are neat ethanol cars that consume 10.4 kWh/d per capita of E100.

The World Energy Outlook 2017 (OECD, 2017) made optimistic predictions about electric cars, projecting that China will experience a shift which 'sees one-in-four cars being electric by 2040'. *The 2050 scenarios assume that 50% of vehicles in Daqing is electrified, with an energy demand of:*

20.7 × 50% = 10.4 kWh/d per capita

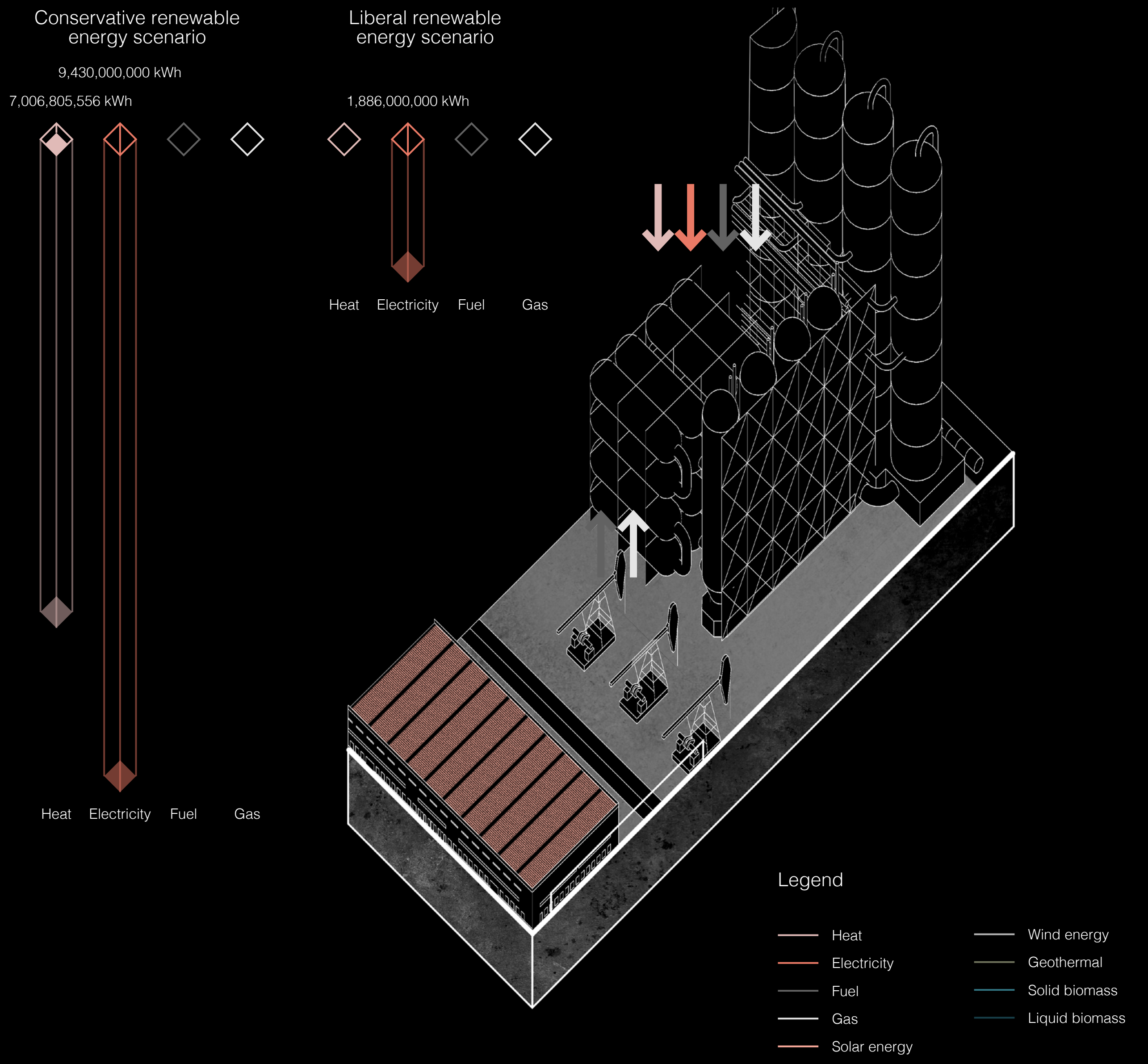
5.3.4 Industrial sector

The industry is the most energy-intensive sector of all the six categories. Presently, the pillar industry of Daqing is oil extraction industry and petrochemical industry. The former consumes electricity (to power oil wells) and natural gas (to heat underground oil pipelines); while the latter requires electricity, heat, and a variety of fossil fuels to process crude oil, including fuel, LPG, refinery gas, coal, and natural gas.

In the conservative renewable energy scenario, despite the absence of oil extraction industries, petrochemical industries manage to maintain their previous scale by processing Russian oil and gas. It is postulated that due to the cessation of production in oil extraction industries, as well as the energy efficiency improvement in the petroleum refining and petrochemical processes, the energy demand of the industry sector has reduced by 50%. The petrochemical industries have attained self-sufficiency in petroleum products; while the demands for coal and natural gas are partly satisfied by extra biofuels and biogas produced in the agriculture sector.

The crude oil, natural gas, and wind energy share similar EROIs (energy returned on energy invested, Sijmons, et al., 2014). Thus, if assume an extreme condition - where Daqing produces wind energy that is equivalent to its current crude oil production, the energy consumption of its renewable energy industries will almost be equal to that of the current petroleum industries. *In the liberal renewable energy scenario, it is assumed that the electricity demand in the industrial sector has reduced by 90%:*

18,860,000,000 × 10% = 1,886,000,000 kWh



5.3.5 Agriculture sector

(1) Consumption

Modern agriculture requires continuous energy (especially oil) inputs: the process of sowing, irrigating, harvesting and drying of agricultural products consume diesel, electricity, and heat.

① Electricity

About 40.5% of the cropped land in Daqing needs irrigation (calculated based on the data in National Bureau of Statistics, 2016, Figure 41). In 2015, per square meter of irrigated land consumes **0.4 kWh** (calculated based on the data in National Bureau of Statistics, 2016 and Daqing Bureau of Statistics, 2016) of electricity to power water pumps. *The 2050 scenarios assume that as one of the impacts of climate change, the area of irrigated land accounts for 75% of the cultivated land.*

② Heat

Nowadays, with the growth in the number of greenhouses (Figure 42), as well as the development of transportation infrastructure, people no longer have to store winter food in autumn[26]. Farmers use steel frame greenhouses covered with plastic film to produce off-season vegetables. In Daqing, greenhouses use primarily natural light; some are heated by coal-fired boilers beyond typical growing seasons, a small number of which are equipped with horizontal ground heat exchangers. In 2015, greenhouses consume 271.1 kWh of heat per capita[27] (National Bureau of Statistics, 2016). *In the 2050 scenarios, it is assumed that some greenhouses are heated by geothermal, others are equipped with combined PVT systems and ground source heat pumps, which can not only meet the heating demand but also work as solar power stations.*

③ Gasoline

From November to February, when the low temperature makes it uneconomical to maintain greenhouses, vegetables are transported from the south of China. According to Pellegrini & Fernández's (2018) statistics, the on-farm energy demand is generally much lower than that for transporting food, which in turn can be several times lower than the energy demand for heating and cooling greenhouses, refrigeration, and processing food. *In a post-petroleum era, it can be speculated that food will be produced much closer to consumers than it is now. regulations on the prohibition of urban agriculture (that are announced by the municipality due to aesthetic considerations) will be abolished, allowing urban residents (who have the willingness) to grow food in community green spaces, which not only contribute to the transportation energy saving for the food system, but also help reduce the energy input for maintaining green spaces in the high latitude climate.*

④ Diesel

As shown in figure 43, at the end of the 20th century, agricultural mechanization has led to a significant increase in the diesel consumption per square meter of cultivated land, which then, after a slight fluctuation, falls to 0.13 kWh/m^2 (calculated based on the data in National Bureau of Statistics, 2016 and Daqing Bureau of Statistics, 2016) in 2015 (from May 1st to October 31st). In Daqing region, agricultural mechanization has reached an advanced level that liberates farmers from heavy physical work - very limited manual labour is required on the farm unless a natural disaster occurs during a harvest season. *In the 2050 scenarios, it is assumed that the improvement in the efficiency of agricultural machinery has led to a 20% reduction in its energy consumption.*

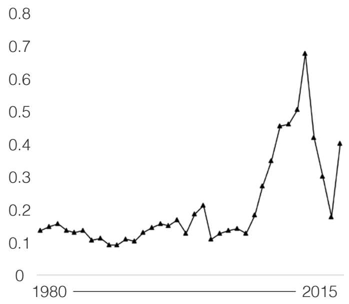


Figure 41 Ratio of irrigated land to total cultivated land in Daqing from 1980 to 2015. The ratio has experienced drastic fluctuations during recent years.

Data source: Daqing Bureau of Statistics, 2016

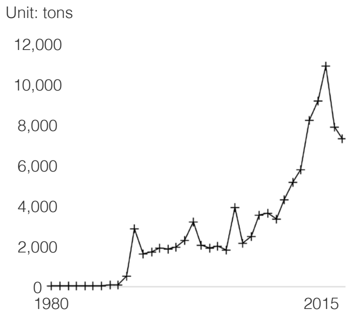


Figure 42 Plastic film consumption in Daqing from 1980 to 2015, which reflect the new construction area of plastic greenhouses.

Data source: Daqing Bureau of Statistics, 2016

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[26] A decade ago, people used to store food such as potatoes, scallions and Chinese cabbages from autumn. Urban residents use north-facing (closed) balconies for cold storage of vegetables and fruits, while rural residents have separate food warehouses.

[27] the combustion efficiency of coal is assumed to be 60%.

In the conservative scenario, farm machinery runs on B20 diesel. In the liberal scenario, 50% of the machinery is adapted to be powered by electricity instead of liquid fuels, while another 50% are methane powered. The energy required for powering the machinery will be:

0.13 × 80% = **0.1 kWh/m^2**

(2) Production

① Biomass: energy crop and waste straw

In the conservative renewable energy scenario, it is assumed that the area of cultivated land remains the same as 2015 (which is 7,522,530,000 m^2). In the liberal renewable energy scenario, an additional 30% of cultivated land is used for planting energy crops. Based on the data mentioned in section 5.2.4, The average dry straw yield in Heilongjiang Province is 0.6 kg/m^2, which equals to 0.4 kWh of electricity, 1.6 kWh of CH4, 1.3-3.2 kWh (2.25 kWh on average) of biogas, 1.1 kWh of biofuel or 1 kWh of bioethanol (1.05 kWh on average).

In the conservative renewable energy scenario, 50% of collected dry straw goes to direct combustion for power generation (Bentsen & Felby, 2012):
7,522,530,000 × 50% × 50% × 0.4 = 752,253,000 kWh

25% of collected dry straw is converted into bioliquids:
7,522,530,000 × 50% × 25% × 1.05 = 987,332,062.5 kWh
25% of collected dry straw is converted into biogas:
7,522,530,000 × 50% × 25% × 2.25 = 2,115,711,562.5 kWh

In the liberal renewable energy scenario, the bioenergy comes from energy crops will be:
7,522,530,000 × 30% × 3.2 = 7,221,628,800 kWh

50% of collected dry straw and energy crops goes to direct combustion for power generation:
(7,522,530,000 × 50% × 130% × 0.4 + 7,221,628,800) × 50% = 4,588,743,300 kWh
25% of collected dry straw and energy crops is converted into bioliquids:
(7,522,530,000 × 50% × 130% × 1.05 + 7,221,628,800) × 25% = 3,088,938,881.3 kWh
25% of collected dry straw and energy crops is converted into biogas:
(7,522,530,000 × 50% × 130% × 2.25 + 7,221,628,800) × 25% = 4,555,832,231.3 kWh

② Solar greenhouse

By installing transparent solar panels on greenhouses' roof, solar greenhouses can grow off-season vegetables and generate electricity simultaneously. In China, the first experimental solar greenhouse project (measured 12 hm^2, with an installed capacity of 1MW) is located in Shouguang, Shandong Province. The electricity generated by solar greenhouses is fed into the grid. *In the 2050 scenarios, it is assumed that there are 20 20MW solar greenhouse projects in Daqing, each of which covers 17 hm^2. The total annual electrical energy production is 500,000,000 kWh*[28].

③ On-farm wind turbine

The 2050 scenarios assume an extreme condition where all cultivated land is covered by wind turbines. According to the data in section 5.2.2, in the conservative renewable energy scenario, the electricity generated by on-farm wind turbines will be:

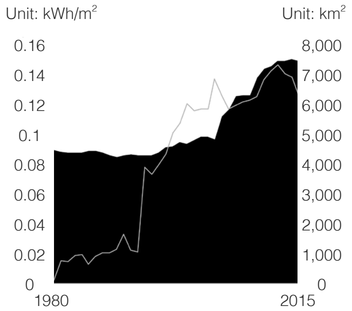

Figure 43 Gross cropped area and diesel consumption per unit area in Daqing from 1980 to 2015

Data source: Daqing Bureau of Statistics, 2016

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[28] Composed of 333 solar greenhouses (measured 60m*8.5m), each has an installed capacity of 60 kW. Data source: An introduction of main features and benefits of photovoltaic agricultural greenhouses, 2014

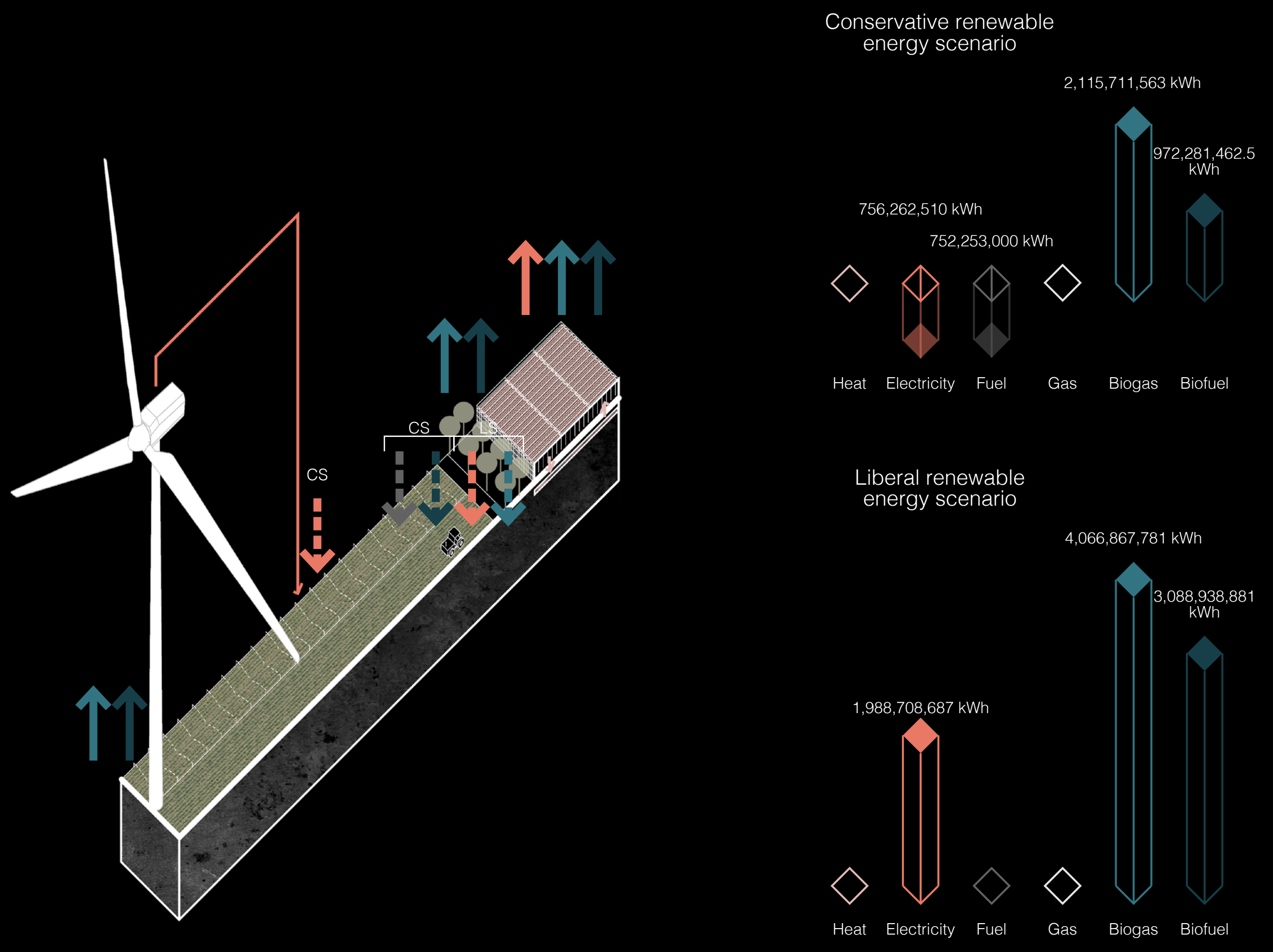


Figure 44 A section showing the energy flow in the agriculture sector.

0.033 × 7,522,530,000 = 248,243,490 kWh
In the liberal renewable energy scenario, the electricity generation will be:
0.033 × 130% × 7,522,530,000 = 322,716,537 kWh

(3) conclusion
In the conservative renewable energy scenario, the electricity consumption will be:
0.4 × 75% × 7,522,530,000 - 500,000,000 - 248,243,490 - 752,253,000 = 756,262,510 kWh
The diesel consumption of agricultural machinery will be:
0.1 × 7,522,530,000 = 752,253,000 kWh,
which contains biodiesel:
752,253,000 × 20% = 15,450,600 kWh
The bioliquid production will be:
987,332,062.5 - 15,050,600 = 972281462.5 kWh
The biogas production will be 2,115,711,562.50 kWh

In the liberal renewable energy scenario, the electricity production will be:
-(0.4 × 75% × 130% × 7,522,530,000 + 0.1 × 7,522,530,000 × 130% × 50% - 500,000,000 - 322,716,537 - 4,588,743,300) = 1,988,708,687 kWh
The bioliquid production will be 3,088,938,881.3 kWh
The biogas production will be:
4,555,832,231.3 - 0.1 × 7,522,530,000 × 130% × 50% = 4,066,867,781 kWh

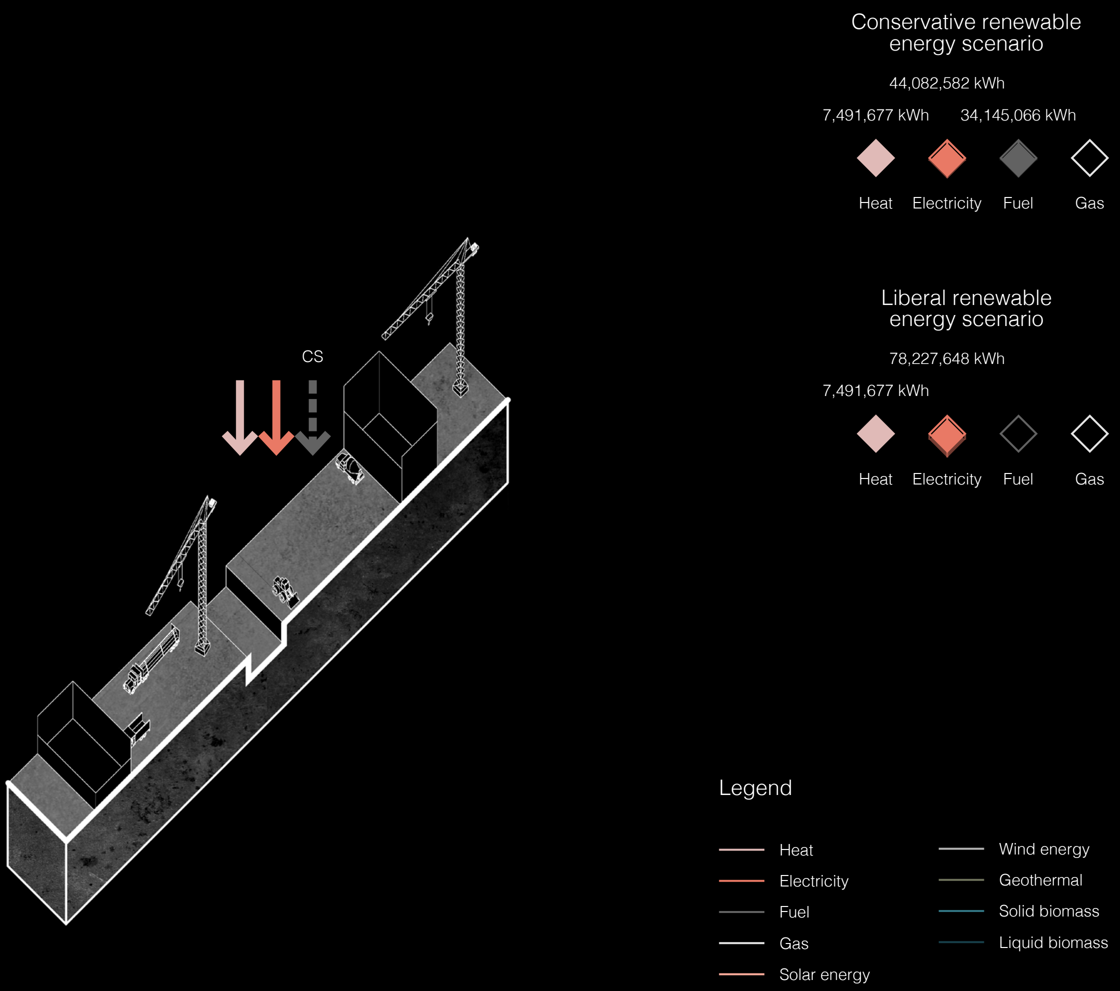


Figure 45 A section showing the energy flow in the construction sector.

5.3.6 Construction sector

In 2015, the construction sector consumed 88,165,163 kWh of electricity, 14,983,353 kWh of heat, and 68,290,132 kWh of diesel (National Bureau of Statistics, 2016). *In the 2050 scenarios, it is assumed that the slowing down of the urbanization process has led to a reduction of 50% in the energy consumption of the construction sector. In both two 2050 scenarios, the electricity consumption will fall to:*

88,165,163 × 50% = 44,082,581.5 kWh
The heat consumption will be:
14,983,353 × 50% = 7,491,677 kWh

Especially, in the conservative renewable energy scenario, construction equipments run on B20 diesel, the diesel consumption will be:
68,290,132 × 50% = 34,145,066 kWh,
which contains biodiesel:
34,145,066 × 20% = 6,829,013.2 kWh

In the liberal renewable energy scenario, the heavy machinery is adapted to be powered by electricity instead of liquid fuels, the electricity demand will be:

68,290,132 × 50% = 34,145,066 kWh

5.4 Conclusion

In 2015, Daqing's working population is 520245, 287073 of which is engaged in service industries (Daqing Bureau of Statistics, 2016). When calculating the employment loss in the post petroleum era, it is assumed that there exist linear relationships among the urban population (which is 1413300 in 2015, ibid.), working population, and service jobs: each working population corresponds to
(1,413,300 - 520,245) / 520,245 = 1.7 non-institutional population;

each urban residents corresponds to
287,073 / 1,413,300 = 0.2 service job.

In the conservative renewable energy scenario, the absence of working population engaged in mining industries has led to a reduction in Daqing's urban population:

1,413,300 - (119,710 × 2.7 × 1.2) = 1,025,440

If the green jobs in renewable energy industries are taken into consideration, the total population in 2050 will be:

$$P_{cs} = [(J_{pv} + J_{wt} + J_{bp} + J_{bf}) \times 2.7 \times 1.2 + 1,025,440] / 0.85$$

The number of green jobs can be calculated based on the following equation:

$$\frac{\text{Green jobs}}{\text{Employment multipliers}} = \text{Renewable energy production} =$$

[(Reduced) initial population + green jobs]
× renewable energy production per capita
+ Renewable energy consumption + Renewable energy exports

then,

$$J_{pv} = \underset{\text{Employment multiplier}}{\underset{\uparrow}{20.4}} \times [(\overset{\text{PV cells}}{\overset{\downarrow}{748}} + \overset{\text{PVT}}{\overset{\downarrow}{1,174}}) \times P_{cs} + \overset{\text{Solar greenhouses}}{\overset{\downarrow}{500,000,000}}] \times 10^{-6}$$

$$J_{wt} = \overset{\text{Employment multiplier}}{\overset{\downarrow}{1.7}} \times [(\underset{\text{Bladeless wind turbine}}{\underset{\uparrow}{329}} + \overset{\text{Wind farms}}{\overset{\downarrow}{3,882}} \times 50\%) \times P_{cs} + \overset{\text{On-farm wind turbines}}{\overset{\downarrow}{248,243,490}} + \underset{\text{Wind farms}}{\underset{\uparrow}{10,230,345,092}} \times 50\%] \times 10^{-6}$$

$$J_{bp} = \overset{\text{Employment multiplier}}{\overset{\downarrow}{4.1}} \times (\underset{\text{Biogas}}{\underset{\uparrow}{752,253,000}} + \underset{\text{Biomass power generation}}{\underset{\uparrow}{2,115,711,563}}) \times 10^{-6}$$

$$J_{bf} = \overset{\text{Employment multiplier}}{\overset{\downarrow}{13.8}} \times (\underset{\text{Biofuel}}{\underset{\uparrow}{987,332,063}} / 5) \times 10^{-6}$$

$$P_{cs} = 1,706,779$$

In the liberal renewable energy scenario, another 63,648 working population engaged in manufacturing industries has left the city:

1,413,300 - [(119,710 + 63,648) x 2.7 × 1.2] = 819,220

In 2015, Daqing exports 36,600,000 tons of crude oil, which equals to 425,658,000,000 kWh of energy[30]. *The liberal renewable energy scenario assumes Daqing exports 2% of equivalent electricity, 54% of which is generated by combustion of biomass, 31% is generated by wind farms, 15% by solar farms. If the green jobs in renewable energy industries are taken into account, the total population in 2050 will be:*

$$P_{ls} = [(J_{pv} + J_{wt} + J_{bp} + J_{bf}) \times 2.7 \times 1.2 + 819,220] / 0.85$$

$$J_{pv} = 20.4 \times [(\overset{\text{PV cells}}{\overset{\downarrow}{1,606}} + \overset{\text{PVT}}{\overset{\downarrow}{1,670}} + \overset{\text{Solar farms}}{\overset{\downarrow}{3,024}} \times 25\%) \times P_{cs} + \overset{\text{Solar greenhouses}}{\overset{\downarrow}{500,000,000}} + \underset{\text{Solar farms}}{\underset{\uparrow}{1,964,227,648}} \times 25\% + \underset{\text{Solar farms for energy export}}{\underset{\uparrow}{1,308,138,900}}] \times 10^{-6}$$

$$J_{wt} = 1.7 \times [(\overset{\text{Bladeless wind turbine}}{\overset{\downarrow}{329}} + \overset{\text{Wind farms}}{\overset{\downarrow}{3,024}} \times 50\%) \times P_{cs} + \overset{\text{On-farm wind turbines}}{\overset{\downarrow}{322,716,537}} + \underset{\text{Wind farms}}{\underset{\uparrow}{1,964,227,648}} \times 50\% + \underset{\text{Wind farms for energy export}}{\underset{\uparrow}{2,616,277,800}}] \times 10^{-6}$$

$$J_{bp} = \overset{\text{Employment multiplier}}{\overset{\downarrow}{4.1}} \times (\underset{\text{Biogas}}{\underset{\uparrow}{4,588,743,300}} + \underset{\text{Biomass power generation}}{\underset{\uparrow}{4,555,832,231}}) \times 10^{-6}$$

$$J_{bf} = \overset{\text{Employment multiplier}}{\overset{\downarrow}{13.8}} \times [\underset{\text{Biofuel}}{\underset{\uparrow}{3,088,938,881}} / 5] \times 10^{-6}$$

$$P_{ls} = 2,248,373$$

---

29 P_{cs}: Daqing's population in the conservative renewable energy scenario
J_{pv}: Green jobs in photovoltaic industries
J_{wt}: Green jobs in wind turbine industries
J_{bp}: Green jobs in biomass power generation and biogas industries
J_{bf}: Green jobs in biofuel industries

[30] The energy value of crude oil is 41868 kJ/kg

31 P_{cs}: Daqing's population in the liberal renewable energy scenario

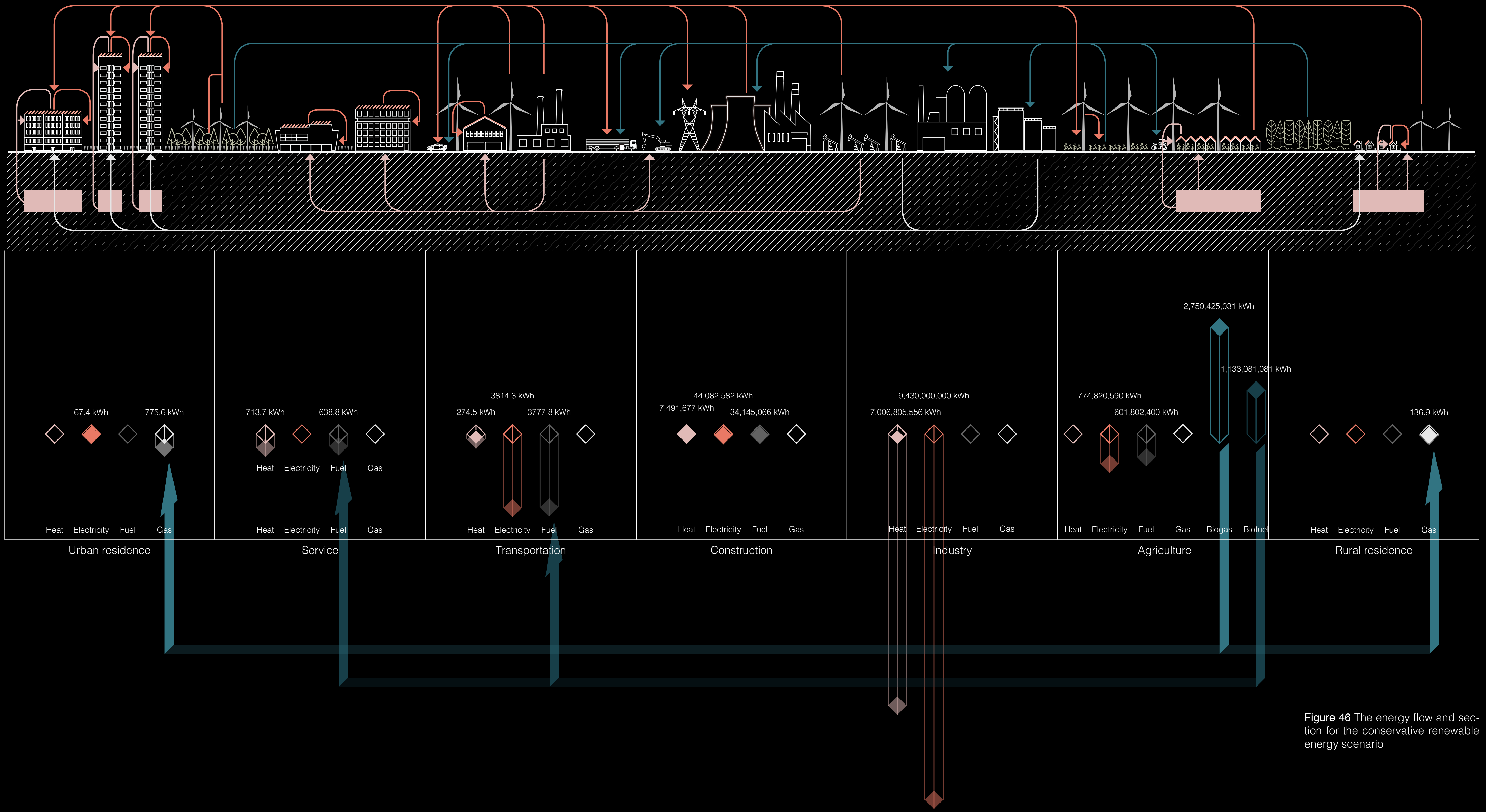


Figure 46 The energy flow and section for the conservative renewable energy scenario

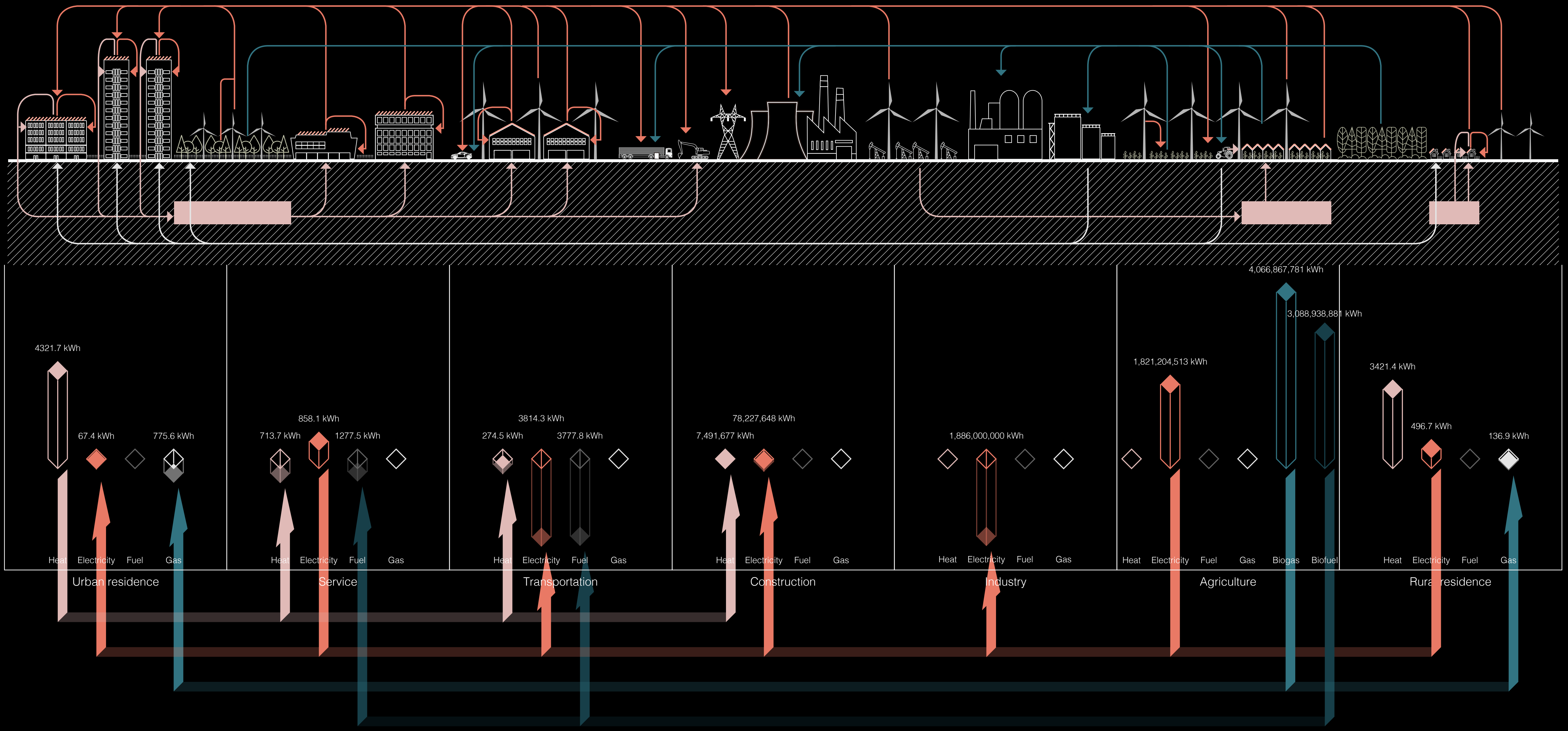
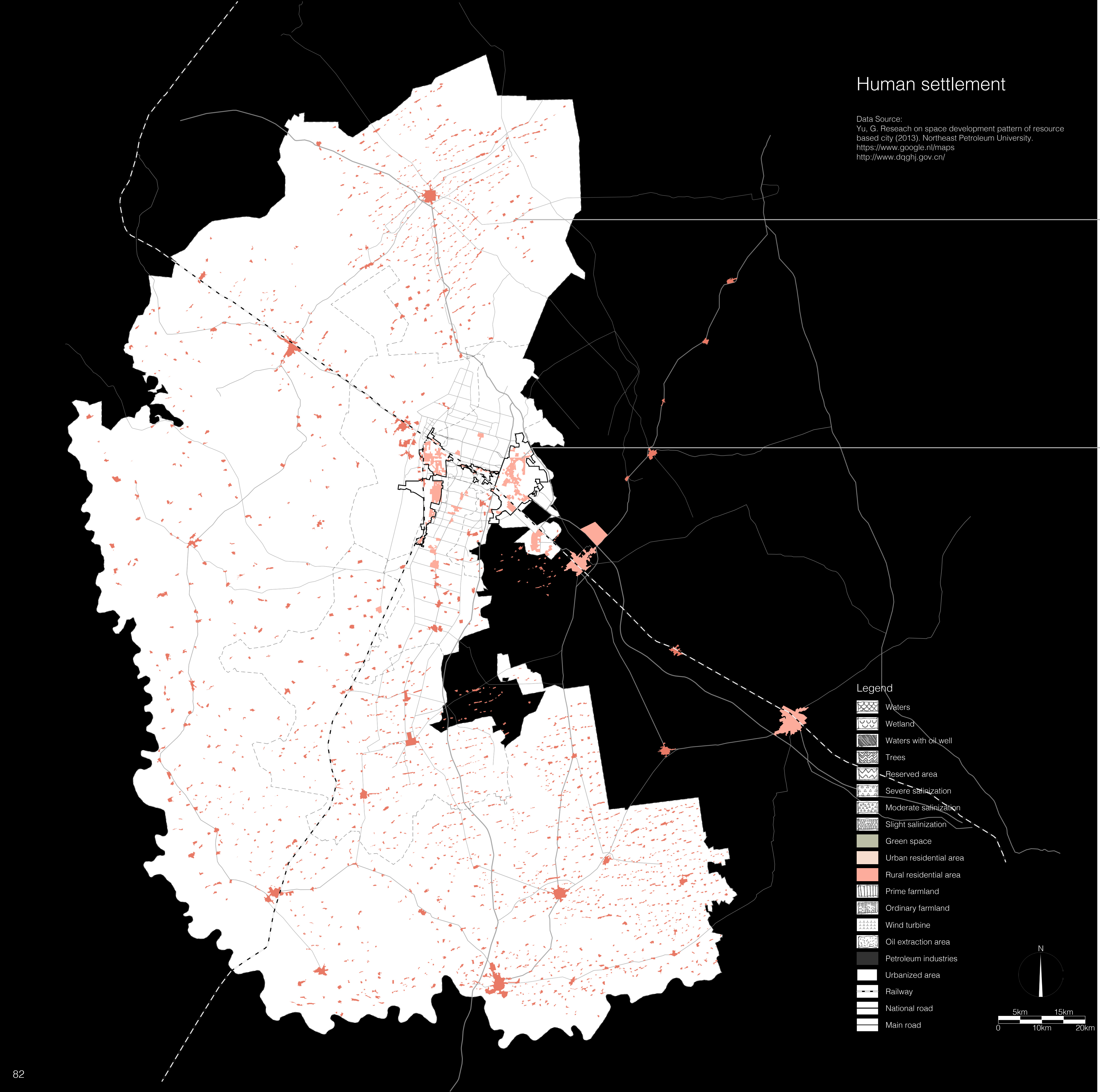


Figure 47 The energy flow and section for the liberal renewable energy scenario

Human settlement

Data Source:
Yu, G. Reseach on space development pattern of resource based city (2013). Northeast Petroleum University.
https://www.google.nl/maps
http://www.dqghj.gov.cn/



Rural residential area

Photograph by the author

Urban residential area

Photograph by the author

VI

Energy = Space

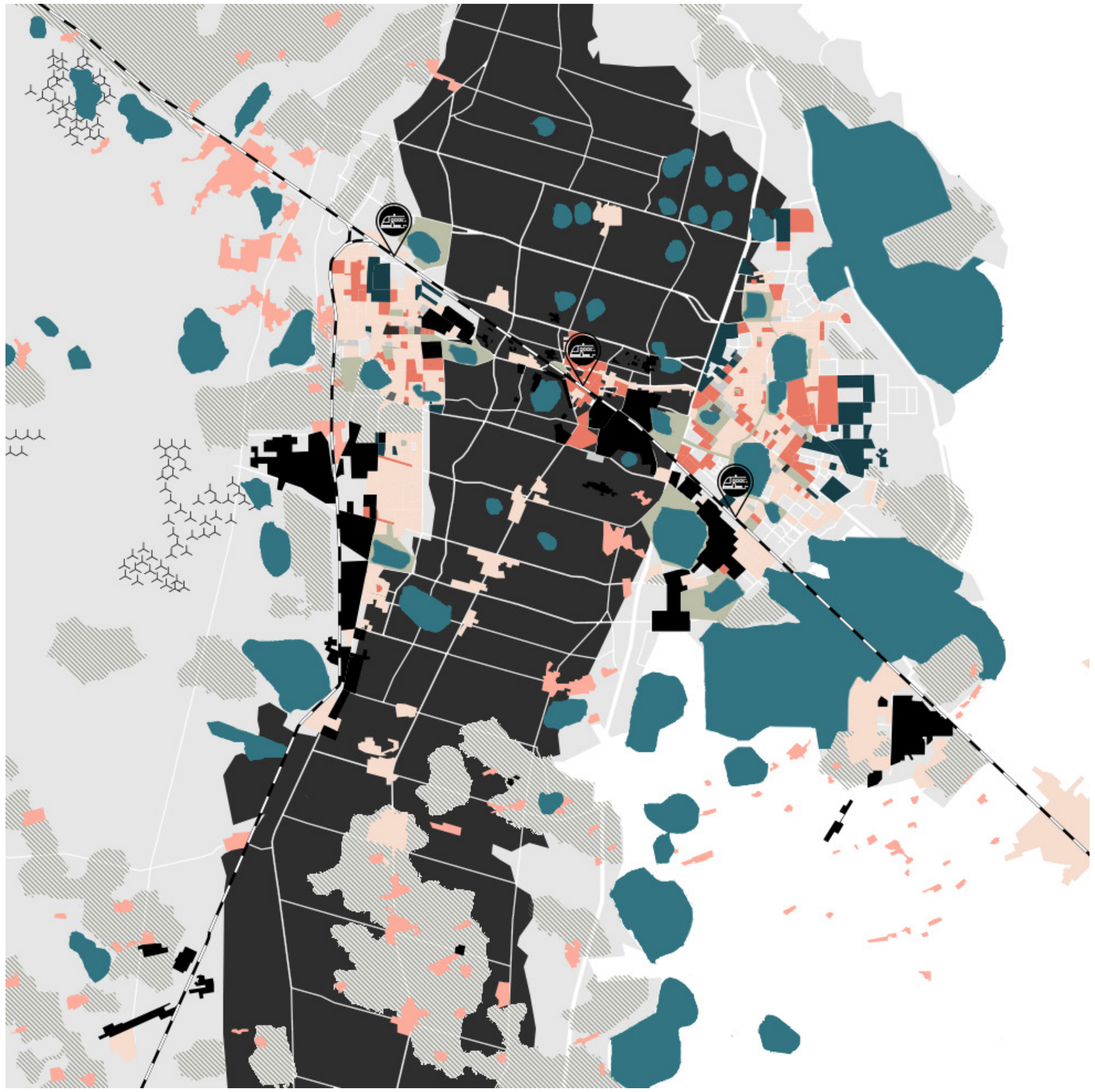


Figure 49 Present status

Legend

- 🟥 Service
- 🟥 Rural residential area
- ▨ Urban residential area
- ▨ Farmland
- 🟩 Green space
- 🟦 Water / wetland
- ■ Industry
- ■ Petroleumscape
- — Infrastructure

N

0 2km 5km 10km

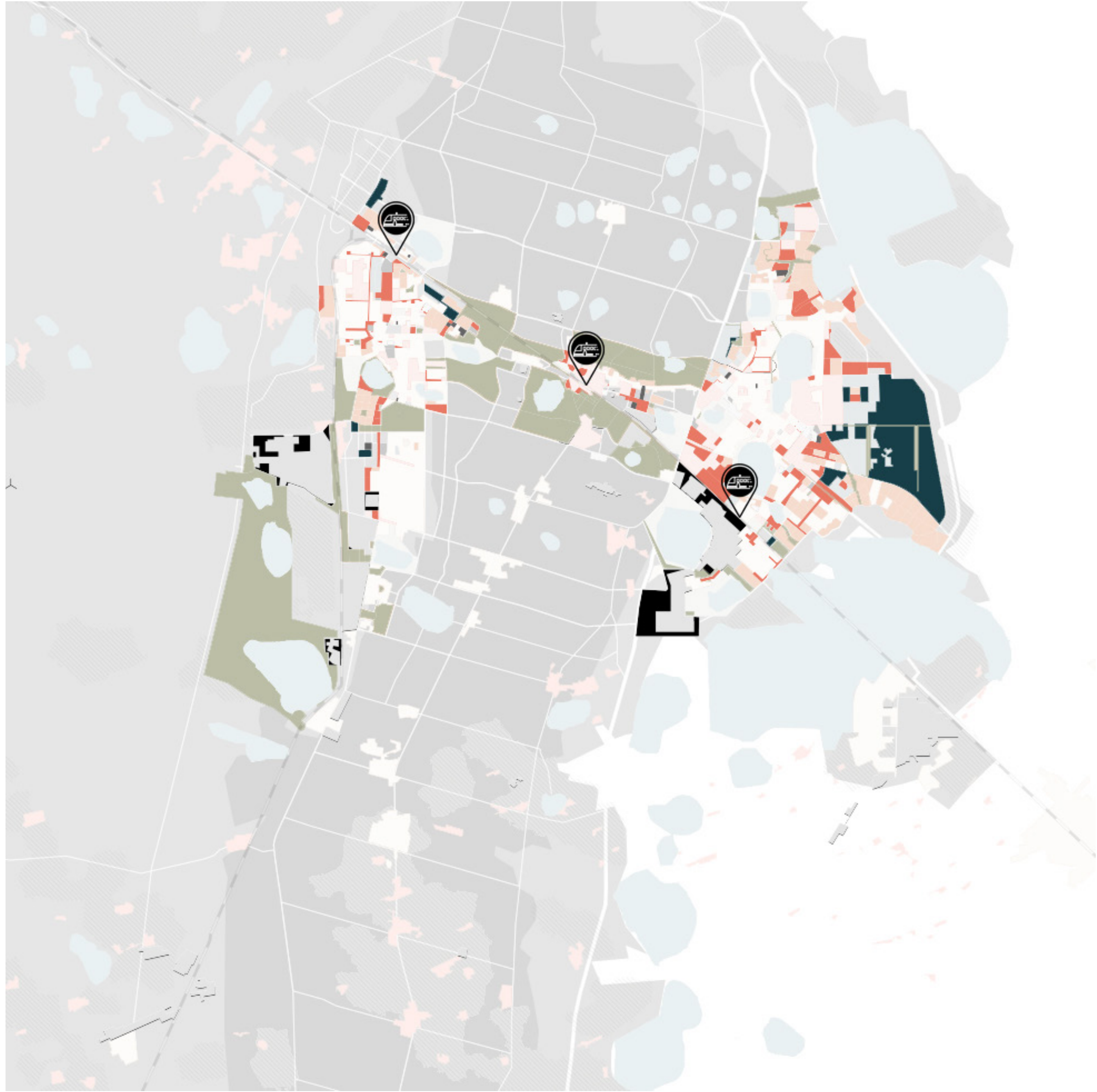


Figure 50 Mapping the near future

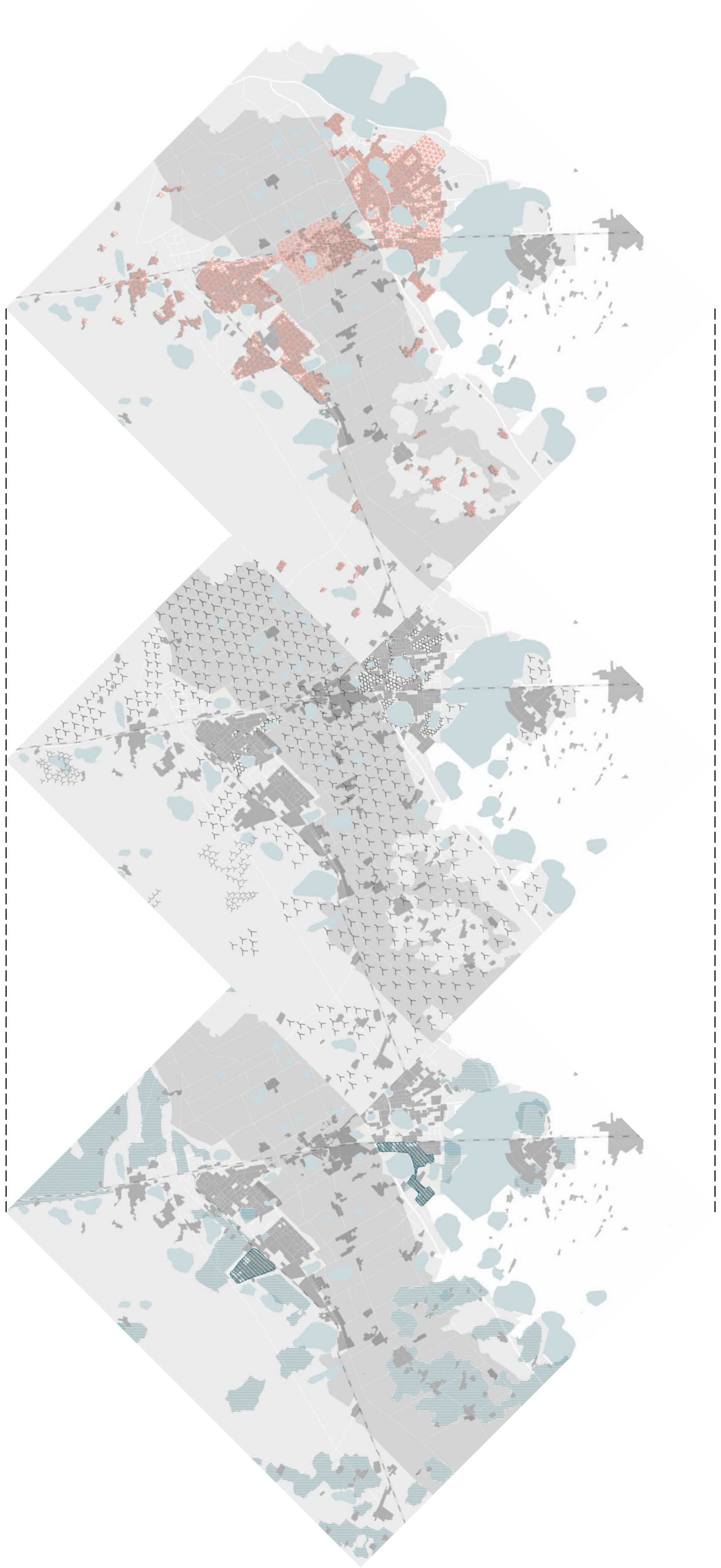
Legend

- 🟥 Service
- 🟥 Rural residential area
- ▨ Urban residential area
- ▨ Farmland
- 🟩 Green space
- 🟦 Water / wetland
- ■ Industry
- ■ Petroleumscape
- — Infrastructure

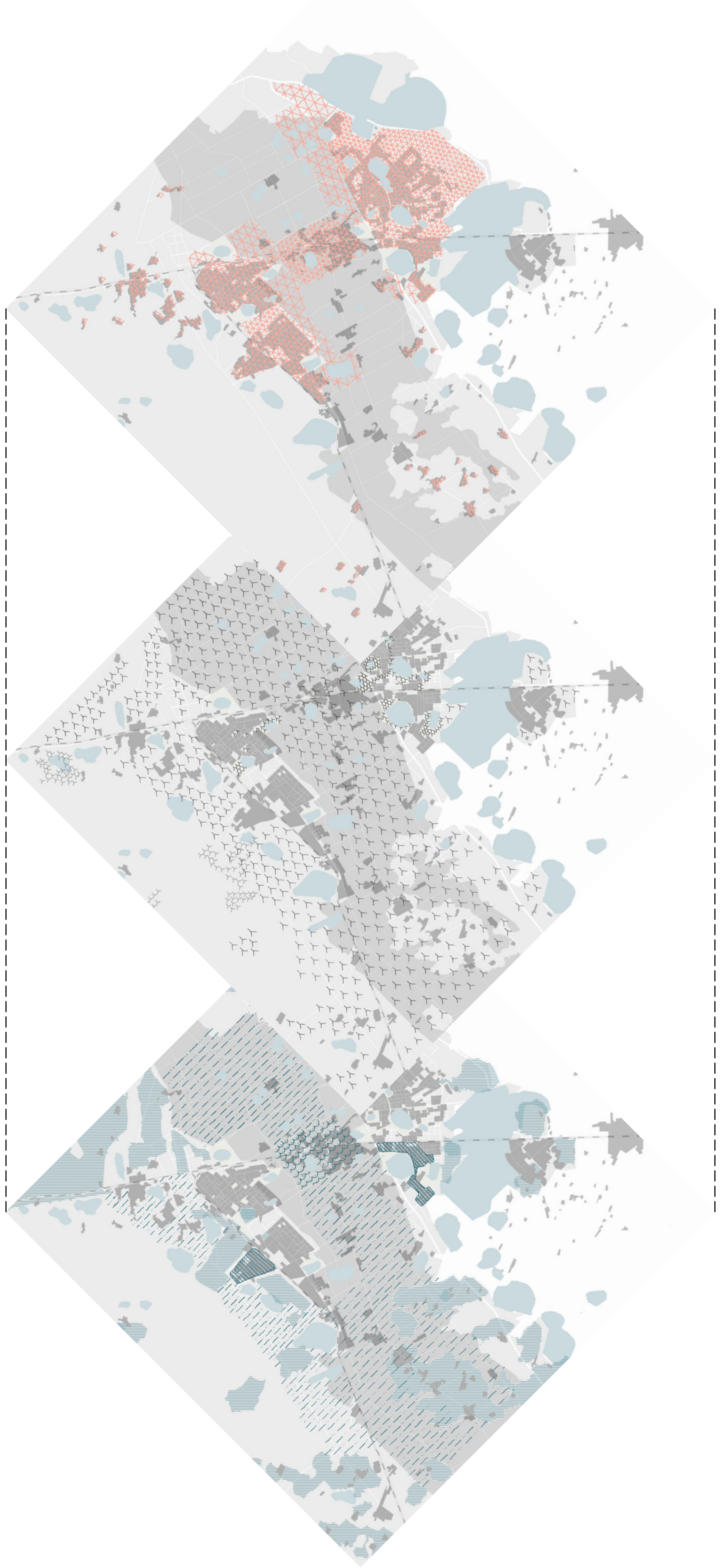
N

0 2km 5km 10km

Renewable energy landscape in
Conservative renewable energy scenario



Renewable energy landscape in
Liberal renewable energy scenario



Solar energy

▨ Roof-mounted or wall-mounted solar panels
▨ Solar farm

Wind energy

▨ Urban wind turbines
▨ Wind farm

Biomass

▨ Biorefineries
▨ Energy crop
▨ Geothermal green house
▨ Waste straw

Chapter 5 has discussed renewable energy production and consumption of the 2050 scenarios. In the post-petroleum era, it is assumed that renewable energy industries have become new sources of revenue for the city, and bring green jobs that compensate for the employment loss: both two scenarios have achieved economic and social sustainability. After petroleum industries leave the city, remediation programs are structured to improve environmental sustainability.

This chapter further discusses the spatial dimension of sustainability. Figure X maps the geographies of the urban development in the post-petroleum era, which is categorized into demolition, urban regeneration, and new construction, respectively.

In the past decades, the worker communities (area 1) located on the oil field have become less popular with oil workers due to their declining quality and remote locations. In both two 2050 scenarios, these communities are demolished due to the absence of oil extraction industries. The oilfield equipment manufacturing industries in area 2 and drilling companies in area 3 will also be abandoned and demolished after the cessation of production.

The 2050 scenarios assume that there are urban regeneration programmes in the vicinity of the west train station (area 4) and the old industrial districts (area 5 and area 6). Area 7 will be regenerated into recreational industrial heritage parks - which contain solar greenhouses that grow vegetables for the city. Furthermore, in the liberal renewable energy scenario, the petrochemical facilities in area 8 (which consist primarily petrochemical industries and petroleum refineries) will be adapted for electrochemical synthesis of ammonia, working as 'energy intermittency islands' (as mentioned by MacKay, 2008) that help store electricity. The refineries in area 9 will be regenerated into biorefineries.

In order to accommodate the increasing urban population, there will be new urban projects in the high-tech development zone (area 10, which already contains a wind turbine factory, a soy protein extraction company, and a biopharmaceutical company) and in the vicinity of the east train station (area 11). In the conservative renewable energy scenario, CHPs and (renewable energy production) parks are built on vacant lands in the urban area (area 12). In the liberal renewable energy scenario, as a result of a greater growth in the urban population, there will be more urban extension in area 13, 14, 15, and 15. Green spaces around lakes in the urban area are linked by green corridors and connected to the regional ecological belt.

Design principles for renewable energy facilities

Throughout the year, when the sunlight is abundant, it is essential to ensure that there are no shadows of objects such as buildings, trees or towers on the surfaces of solar collectors (GB 50794-2012).

Solar collectors installed in public space.

Solar collectors should be installed in places with the highest levels of sun exposure. In the northern hemisphere, solar panels are usually south facing (GB 50794-2012).

Solar collectors installed in business parks.

Solar collectors installed in wasteland

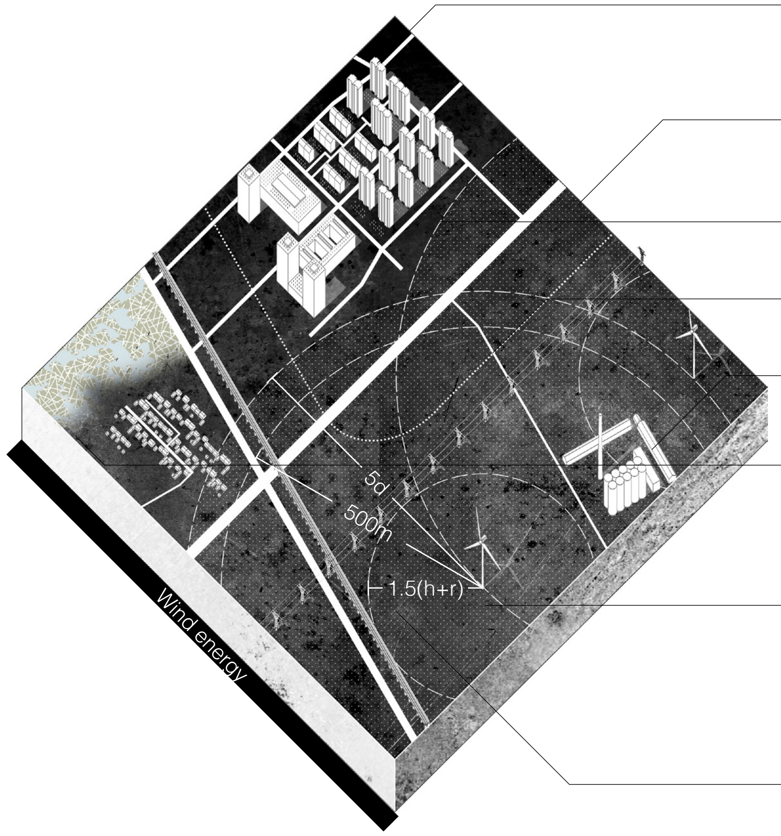
Solar collectors installed on the roof surfaces of industrial buildings.

Solar collectors installed by road surface.

Solar collectors installed collectively for an entire neighbourhood.

Solar collectors installed on the roof surfaces of individual homes.

Solar greenhouses.



Bladeless turbines are adopted by end consumers in the urbanized area.

Wind turbines are preferentially placed in wasteland, inferior land, and non-cultivated land (GB 51096-2015).

Wind turbines should be spaced at five times the blade diameter.

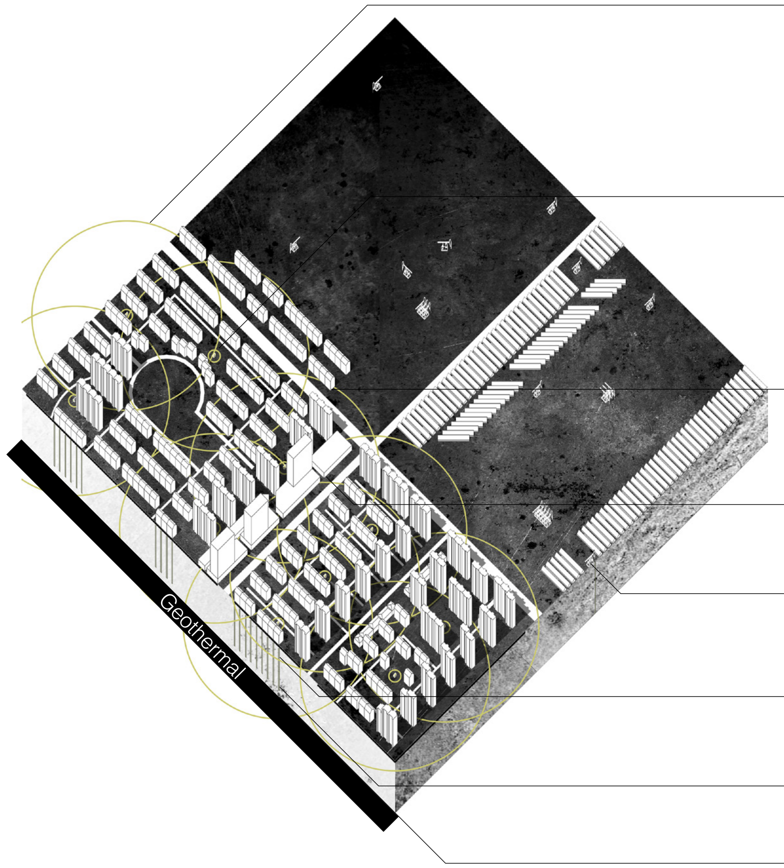
Make use of existing roads to assemble turbines (GB 51096-2015).

Wind turbines combined with large-scale industries.

Turbines cannot be placed within or adjacent to Nature reserves (GB 51096-2015).

The distance between turbines and dwellings has to meet the national standards for exposure to noise: 500 meters is generally considered as a safe distance (GB 51096-2015).

The distance between wind turbines and roads, railways, transmission lines, telecommunication circuits, crude oil & natural gas pipelines has to be more than 1.5 (h+r) (GB 51096-2015).



Geothermal water should not be transported over long distances. The temperature drop during transportation should not exceed 0.6 °C/km (CJJ 138-2010).

Ground source heat pumps should be installed in above ground separate pump houses that have maintenance space, adequate ventilation and good lighting. The distance between pump houses and the surrounding buildings should not be less than 10m (CJJ 138-2010).

Ground source heat pumps should be combined with PVT systems in residential buildings in order to maintain the underground heat balance.

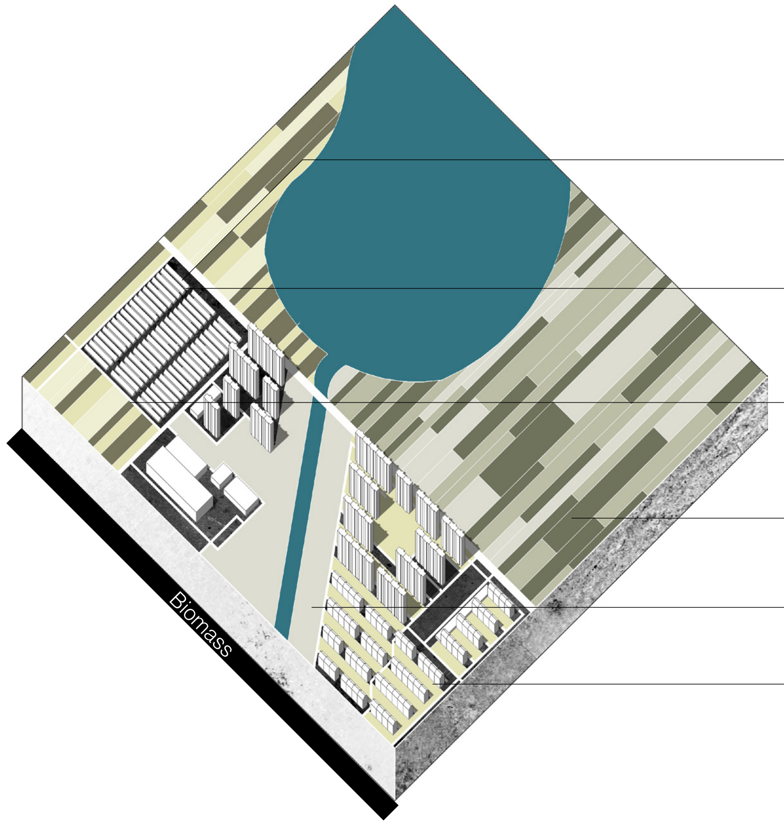
Ground source heat pumps applied in swimming pools.

Exploit geothermal energy from abandoned oil wells for surrounding dwellings and greenhouses.

Ground source heat pumps usually adopt (single U-shaped) vertical buried tubes (GB50366-2005).

Pipes buried below underground garages (GB50366-2005).

Pipes buried in the foundation of a building (GB50366-2005).



Urban agriculture parks should be equipped with sufficient transportation infrastructure, various tour routes, and adequate parking lots (GB/Z 32711-2016).

The area of an urban agriculture park should not be less than 6.67 hm2 (GB/Z 32711-2016).

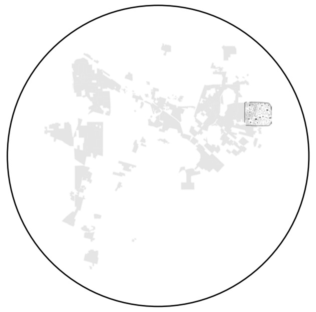
The vegetation fractional coverage (VFC) of an urban agriculture park should be more than 70% (GB/Z 32711-2016).

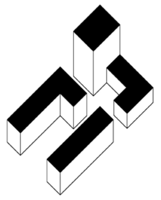
The cultivation of energy crops should not encroach on the land of original crops.

Productive landscape in public green spaces.

Productive landscape in the residential area.

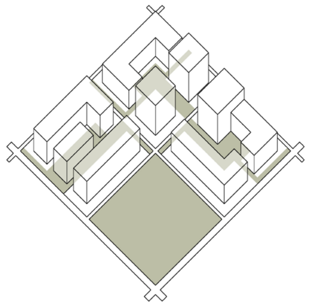
Urban code for the high-tech development zone





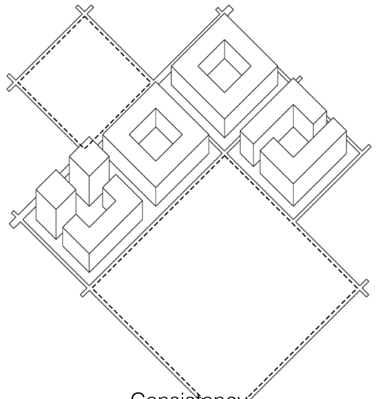
Flat roof

In order to maximize the use of roof space to install solar panels, all the roofs are intentionally designed to be flat.



Green necklace

All the green spaces are connected with each other, establishing an ecological corridor.

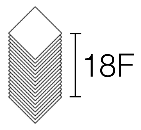


Consistency

In order to avoid excessive construction and the generation of enclaves, a vacant plot can only be developed when it is next to at least one built block.

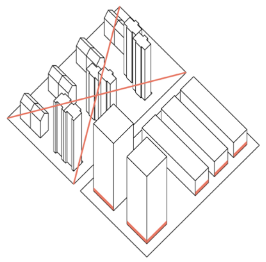
Open space

In one block, at least 20% of the GFA will be open space. In other words, the FAR should be less than 5.



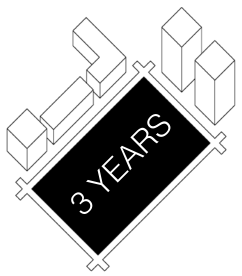
Limited height

The height of new buildings is limited to 18 floors: energy = space, the energy demand of a higher building is relatively less possible to be satisfied by renewable sources.



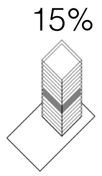
Mixed use architecture

In order to facilitate the energy exchange among different urban functions, buildings are designed to be mix-used. Ground floor spaces facing streets are for commercial use.



Wasted land

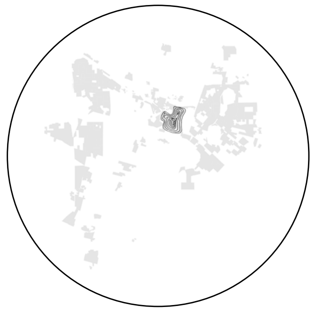
A plot is seen as wasted landscape after being vacant for 3 years, and will temporarily be used for renewable energy production.

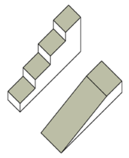


Affordable housing

In the post-petroleum era, in order to avoid social inequality (i.e. different economic accessibility to energy neutral buildings), 15% of the GFA is used as affordable housing.

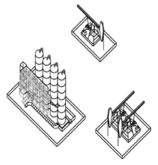
Urban code for the industrial heritage park





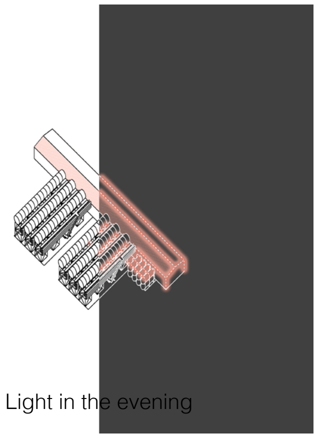
Green roof

Some buildings are earth-sheltered in order to be in harmony with the surrounding landscape.



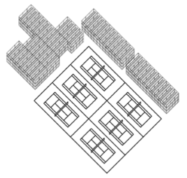
Industrial heritage protection

Valuable industrial buildings and facilities are treated as industrial heritage, protected and displayed in the landscape park.



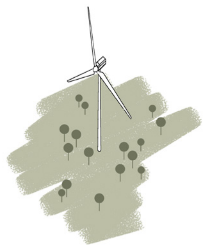
Light in the evening

Colourful lights powered by solar panels are installed on heritage buildings, giving attractive night scenes.



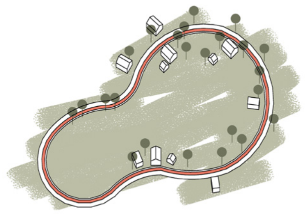
Recreation+production

The landscape heritage park serves both production and entertainment functions.



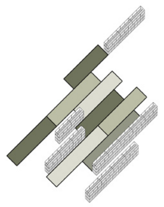
Renewable energy production

Renewable energy production facilities are combined with green spaces.



Walking and cycling routes

Every corner of the park is accessible by walking and cycling routes, visitors can travel around the park through low energy consumption ways.



Allotment

Part of the farmland and greenhouses are sold to citizens. Landowners can plant their own food or outsource the agricultural work to professionals.

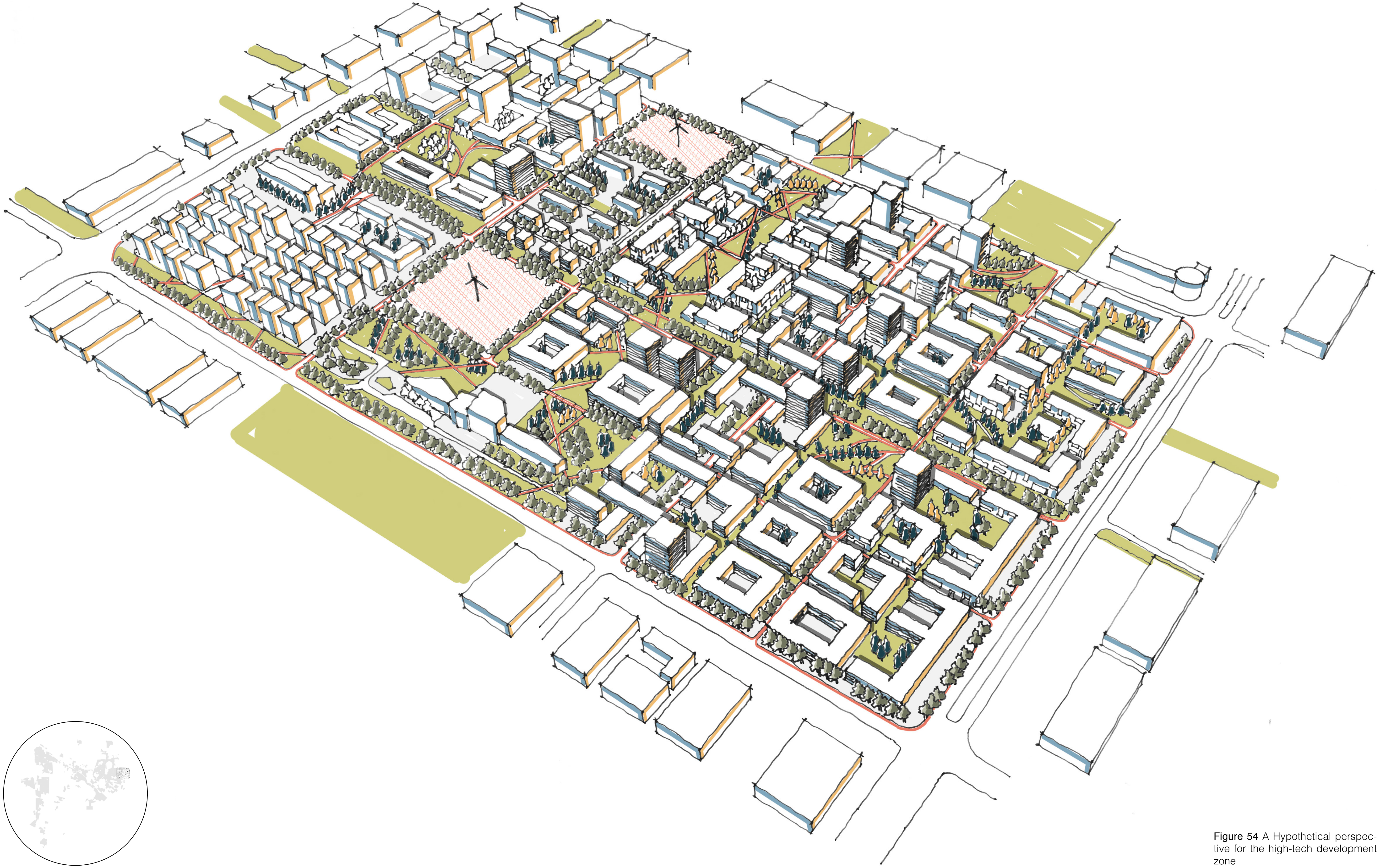


Figure 54 A Hypothetical perspective for the high-tech development zone

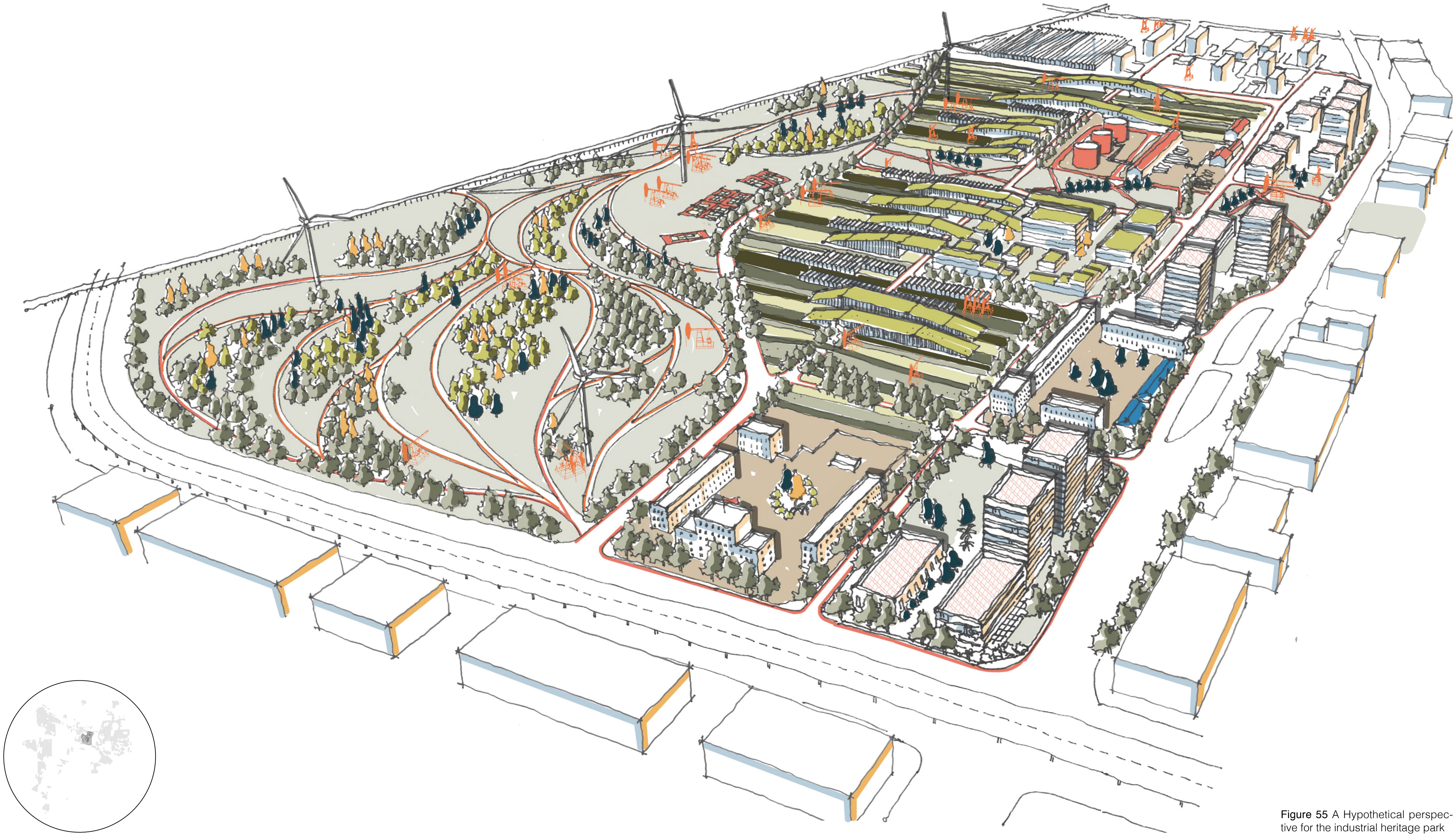


Figure 55 A Hypothetical perspective for the industrial heritage park

VII

Conclusion

VII Conclusion

This report aims to answer its main research question: How can Daqing's urban landscape facilitate renewable energy production and contribute to neutralising the energy and economic crisis of the post-petroleum era while extending its own sustainability? In this project, the renewable energy industry is seen as a solution to the energy and economic crisis, as well as a catalyst to promote Daqing's liveability. The following paragraphs further explain in detail how the sub-research questions are answered in the project.

Sub-research question 1: How is the present landscape, economy, and energy demand & production of Daqing shaped by petroleum industries?

Answer: Presently, Daqing's dependence on oil is twofold: on the one hand, petroleum extraction and processing industries are the main sources of revenue for the municipality. Oil industries provide 183358 jobs in 2015, accounting for 35 percent of the total employment. On the other hand, the city has been playing the role of an energy-exporter since its establishment in 1979. Its energy supply, just as most northern Chinese cities, is fossil fuel-based - electricity is generated by coal-fired power stations; houses are heated by coal-fired boilers; the vehicle market has been dominated by internal combustion engine cars. The urbanized area is split into three separated parts by the oil field, each has its own commercial centres, urban service facilities, and railway stations; On the oil field lies scattered clusters of worker's houses.

Sub-research question 2: How will the current landscape, economy and energy demand & production of Daqing change in the near future, when the depletion becomes evident?

Answer: With the decline in crude oil production, Daqing's economy will continue to deteriorate. The two state-owned oil companies - China National Petroleum Corporation (CNPC) and SINOPEC will probably slow down or even stop hiring. The domestic energy use patterns will not change much, while the industrial energy consumption is expected to reduce slightly with the reduction of oil production activities. Similarly, the urban expansion will also slow down - although the urbanization trend is expected to continue, the city will not grow to the planned size.

Sub-research question 3: How will post-petroleum era (and the possible introduction of renewable energy) reshape the socio-economy and energy demand & production of Daqing in the far future?

Answer: In order to deal with the future uncertainties, this report employs scenario planning to answer this question. After exhausting its own oil reserves, Daqing may become a petrochemical city that process oil and gas imported from Russia. It is also possible that the petroleum industry will disappear completely. The emerging renewable energy industries may prosper and eventually become new sources of revenue. But it also seems likely that renewable energy industries are not as promising as estimated. Of all the four possible futures, this report selected two scenarios that are optimistic about the market penetration of renewable energy. Renewable energy industries are supposed to become (one of) the pillar industries of Daqing. The energy demand and production has been discussed in detail in the report. In order to reduce the energy loss during transmission, renewable energy is preferentially produced and stored close to consumers by decentralized facilities, which are complemented by centralized renewable energy farms when seems insufficient to meet the demand.

Sub-research question 4: What will be the spatial consequences on the landscape of powering Daqing with renewable energy in the post-petroleum era?

Answer: This report discusses four renewable energy solutions - solar energy, wind energy, geothermal and biomass, respectively. In the urbanized area, rooftops are seen as a new layer of the urban space, which is primarily used to install solar collectors. Wind turbines in small size and bladeless wind turbines are installed in open spaces. Urban growth (in different sizes) will occur in both two scenarios. The oil field has become a large wind farm, in combination with energy crop cultivation in the liberal renewable energy scenario. Some wind farms and solar farms are located in the vicinity of the city, others lie in areas that are not suitable for farming, and are kept at a distance from human settlements. Farmland, as the source of biomass, is combined with wind turbines. In the liberal renewable energy scenario, the area of farmland has expanded by 30% - the newly reclaimed area is used for growing energy crops.

Sub-research question 5: How will the spatial changes affect the sustainability of the landscape?

Answer: This question is answered by a combination of the two 2050 scenarios. In the post-petroleum era, the new built urban area will be mixed-use, in order to facilitate the energy exchange among different urban functions. Green spaces are integrated and connected through green corridors. Economic prosperity promotes urban regeneration development in the old town with low spatial quality. The urban code further defines other livability rules, including affordable housing, consistency of urban fabric, open space rate, building scale, aesthetic considerations, cultural heritage protection, recreation, and non-motorized mobility.

VIII

Reflection

VIII Reflection

(1) The relationship between research and design

This project follows the research-based design methodology. The research part - including problem statement, theoretical framework, and methodology framework - is the theoretical foundation of this project: the problem statement clarify the present status and the main problem to be addressed; the theoretical framework chapter defines the position of this research in relation to existing theories; the methodology framework then discusses the steps and methods to be followed. The scenario building chapters are a combination of research and design. These chapters discuss the quantitative employment impact, as well as analyze and calculate the potential of existing renewable energy solutions. The analysis and calculation then supply a base, upon which quantitative and qualitative renewable energy scenarios are delineated. The scenarios are then transferred and combined as the basis for designing sustainable urban codes.

(2) The relationship between my graduation (project) topic, the studio topic, my master track, and my master programme.

The topic of this project is investigating the potential of renewable energy in a certain post-petroleum oil city. The theme is directly related to the topic, urban metabolism, of my research group, in the aspect of energy flow analysis and renewable energy production. This project also agrees to another idea of the research group: 'spatializing urban metabolism'. The research object of urban metabolism, namely the energy and material input and output is rather abstract. This project then makes concrete spatial analysis and interventions based on urban metabolism research.

Master of science requires the spirit of exploration and academic attitude, while the role of urban planners and designers is investigating the spatial aspect of the built environment. This project explores these multiple roles during its research-based design process: it attempts to be both creative and evidence-based.

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

In the initial stage of my research, my mentors helped me to understand the interrelationship among problem statement, theoretical framework, and methodology. These chapters demonstrate the results of the literature review: existing theories, methods and insights relevant to the research topic, as well as information on the present status of the selected city are investigated and summarized. My mentors' guidance also helped me clarified different schools of scenario building, which is introduced as a research method to deal with future uncertainties. The scenario building chapters collect and analyze secondary data from multiple sources. Mapping, as a common research technique, is used to track the spatial limitations, potentials, and suitabilities of renewable energy production. Regarding scientific relevance, this project studies the possible energy and economic transition of an oil city in the post-petroleum era, exploring the possibility of combining energy landscape theory and scenario planning in a post-petroleum urban plan.

(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 on-going energy transition is not only an energetic problem but also a social-economic challenge to an oil city like Daqing. This project discusses a common unfavorable condition that energy-exhausted cities are faced with: the city loses its pillar industry, which further leads to mass unemployment and population loss. The project explores the possibility of introducing renewable energy industries as a catalyst to a post-petroleum oil city; discusses the potential of triggering its economy while improving spatial quality. This approach also applies to other resource-based cities that are suitable for developing renewable energy. Such cities can properly use remaining resources to fund their transformation into renewable energy hubs.

(5) The ethical issues and dilemmas I have encountered in (i) doing the research, (ii, if applicable) elaborating the design and (iii) potential applications of the results in practice.

This project helps me realize the social inequality in the energy and economic transition: different income groups have different abilities to cope with the transformation. In the face of the economic deterioration, mid-class families and youngsters can simply avoid social problems by leaving the city; while low-income groups and seniors are more vulnerable and have less ability to improve their unfavorable situation. Furthermore, the market penetration of renewable energy can create new inequalities: high-income groups always have more choice to avoid the visual effects of renewable energy facilities. Urban design and planning play a minor role in solving such social and ethical problems without policy support.

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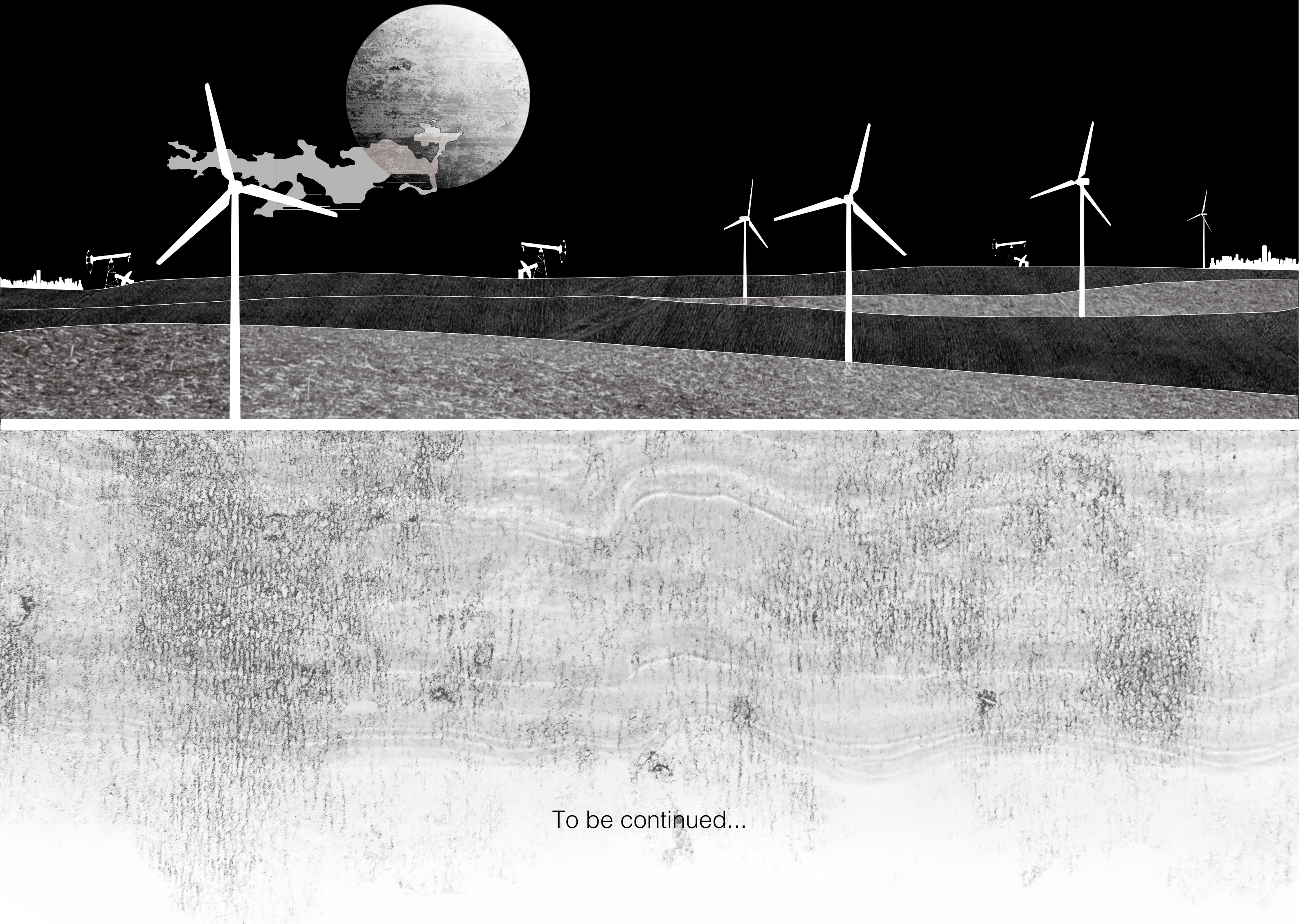

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