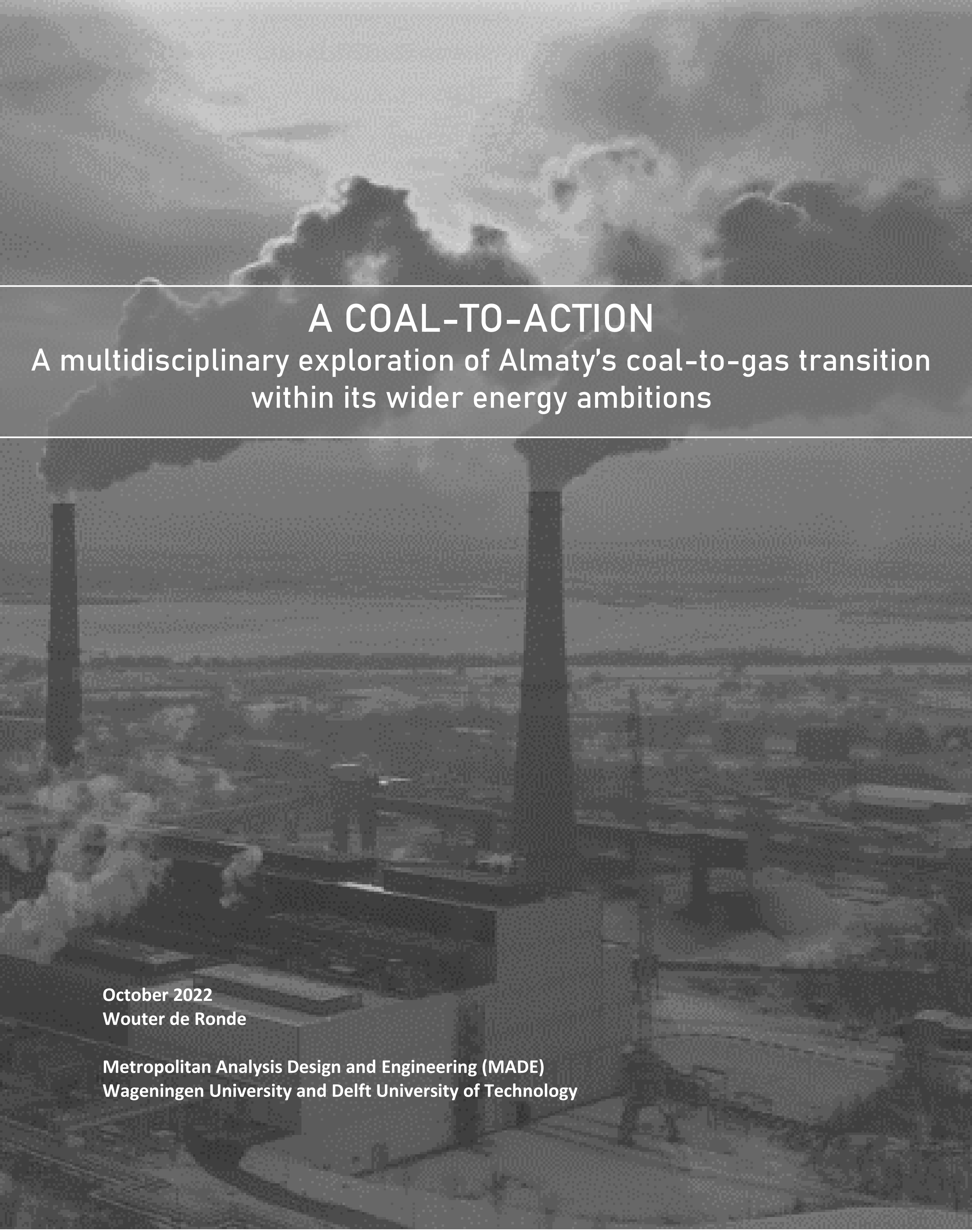

A COAL-TO-ACTION

A multidisciplinary exploration of Almaty's coal-to-gas transition within its wider energy ambitions

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The thesis project is conducted in collaboration with Witteveen + Bos, with special assistance of Laurens Frowijn.

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ALES	Almaty energy system	**HDI**	Human development index
CCUS	Carbon Capture Utilisation and Storage	**HOB**	Heat only boiler
CHP	Combined heat and power plant (cogeneration)	**HPP**	Hydropower plant
CtG-transition	Coal-to-gas transitions	**KEGOC**	Kazakhstan electricity grid operating company
DH	District heating	**KZT**	Kazakh Tenge
EBRD	European bank of reconstruction and development	**LCOE**	Levelised cost of electricity
EFR	External framework report	**MW**	Megawatt
FEC	Final energy consumption	**MWh**	Megawatt hours
Gcal	Giga calories	**NDC**	Nationally determined contributions
GCAP	Green City Action Plan	**PEC**	Primary energy consumption
GDP	Gross domestic product	**PV**	Photovoltaic (solar power generation)
GHG	Greenhouse gasses	**RE**	Renewable energy
GWh	Gigawatt hours	**RES**	Renewable energy sources
		TAS	Technical assessment section

List of concepts

Energy Transition

The International Renewable Energy Agency (IRENA) identifies the energy transition as follows **(IRENA, n.d.)**: *"The energy transition is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century. At its heart is the need to reduce energy-related* CO_2 *emissions to limit climate change"*

Gielen et al. (2019) state that, currently our society is in the midst of an energy transition towards low-carbon and renewable energy sources. World-wide climate change and (local) air pollution are the key driver of this transition. The global energy transition must reduce (GHG-)emissions significantly, while also ensuring energy security and availability. Two essential factors of the energy transition towards a low-carbon energy system are the efficiency and a major increase in the share of renewable energy.

Primary Energy

Energy is a term that has to be defined precisely, since it can be interpreted in various forms. A good way to approach energy is using the concept of primary energy. Blok and Nieuwlaar (2020) state that primary energy is the original energy found in its natural form (e.g. crude oil, natural gas, coal, harvested wood for biomass, etc.) before conversion, such as fossil fuels to electricity and crude oil to petrol (Blok & Nieuwlaar, 2020). Due to various processes that have less than 100% conversion efficiency, the total demand for primary energy is higher than direct energy use (Blok & Nieuwlaar, 2020). Since primary energy is the original quantity of energy before al conversion processes, it is a logical starting point for energy analysis. During this thesis, when talking about energy, primary energy is meant, unless otherwise stated.

Final Energy Consumption

The total energy consumed by the end user (e.g. industry, agriculture, households). Final energy consumption excludes energy usage of the energy sector, such as internal usage, production inefficiencies, network losses and transmission losses. For example, fuel transformed into electricity experiences inefficiency losses that are not included in the final energy consumption of the end users **(Eurostat, 2018)**.

Renewable Energy

Although general consensus is similar, various definitions of what renewable energy is exist. IRENA describes renewable energy as (IRENA, 2009):

"renewable energy includes all forms of energy produced from renewable sources in a sustainable manner, including bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy."

The IEA uses a slightly different definition, which defines renewable energy as: (International Energy Agency (IEA) & World Bank, 2014):

"derived from natural processes" and "replenished at a faster rate than they are consumed" The IEA definition includes the following sources: *"electricity and heat derived from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources"*

Carbon neutrality

The European Parliament explains carbon neutrality as (European Parliament, 2021):

"Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration."

So if carbon is emitted somewhere in the supply chain, one has to compensate for this or change the activities in such a way that carbon is not emitted anymore.

Energy transition pathways (ETPs)

Energy Transition Pathways can be defined as broad analysis and assessments of potential options and alternatives for future energy systems, often based of quantitative methods. These energy transition studies are valuable instruments to inform decision-makers about possible pathways, the options and their consequences (Naegler et al., 2021).

"The broad analysis and assessment of possible options and alternatives is usually done by means of quantitative scenarios. For decades, such model-based studies have been an established instrument to inform decision-makers about possible pathways, options and their effects"

Coal-to-gas transition

Almaty's electricity and heat provision comes mainly from four sources, namely three Combined Heat Power Plants (CHP), heat generated from ATKE, and imported electricity from 'State Kazakhstan Electricity Grid Operating Company (KEGOC). The three CHPs together form the Almaty Energy System (ALES). They generate 63% of Almaty's electricity (and 75% of the heat). The additional 37% is provided by KEGOC. The majority of Almaty's energy is coal-based energy. However, Almaty is converting its CHPs from coal to gas based energy production. CHP-1 (145 MW) has been converted to gas in 2017. The plan is to convert CHP-2 (510 MW) to a gas-fired power plant as well, and to increase CHP-3 (173 MW) its capacity and efficiency. The conversion of CHP-2 from coal-based to gas-based electricity generation should lead to GHG-of around 50% **(EBRD, 2022)**.

Levelised Cost Of Electricity (LCOE)

Levelized cost of electricity represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating the power plant, respectively during an assumed financial life time. Often the concept is used to compare the level of competitiveness of various energy technologies (EIA, 2022).

Carbon Capture Utilisation and Storage (CCUS)

Carbon capture, utilisation and storage (CCUS) involves the capture of CO_2 from production sources, such as power generation or industrial facilities, or direct capture from the atmosphere. The captured CO_2 can be used for a range of applications (e.g. synthetic fuels, chemicals material), or permanently stored in deep geological formations (e.g. depleted oil and gas reservoirs or saline formations) (IEA, 2021f) .

Green City Action Plan (GCAP)

The Green City Action Plan of Almaty is an urban sustainability initiative to mitigate and adapt to current environmental and urban challenges in a systemic way. Almaty's GCAP is part of a global program of the European Bank of Reconstruction and Development (EBRD), which assists cities to tackle these challenges.

The Energy Efficiency Transformation Program of Almaty (EET)

The EET provides various energy reduction and efficiency measures to reduce the energy intensity of Almaty. The program provides various measures per energy sector, the amount of reduced energy, the costs, and the planning.

Executive Summary

Almaty is positioned in a challenging situation with regard to increasing sustainability of their energy system. Similar to various urban areas in Eastern Europe and post-Soviet states, the city highly depends on coal-based energy for their heat and electricity. However, various factors stimulate for phasing out coal-based energy in Almaty, such as severe air pollution, damaging effects on public health, and (inter)national climate commitments. A fundamental project in this coal phase-out is the conversion of CHP-2, Almaty's major heat and electricity production plant, from coal-based to gas-based energy. Although, a transition from coal-to-gas (CtG) is regarded to be a significant improvement, this transition project majorly affects future development of the city. Almaty has several ambitious energy and climate goals that are affected by the CtG-transition.

This study positions Almaty's CtG-transition, and in specific the CHP-2 conversion, within its wider energy goals and to become energy neutral in 2060. The structure of the study results in bilateral outcomes. First, most importantly, the study provides additional insights, extension of the assessment framework and recommendations on the CtG-transition for the city council, policy makers and urban planners. Secondly, Almaty functions as a representative case study for various urban areas positioned in a similar situation. The research framework enables local authorities and urban planners to analyse their energy situation and to conclude on most urgent aspects for catalysing their development.

The research methodology consist of multidisciplinary analysis that include three fundamental dimensions of energy transitions, the socio-technical, techno-economic and political dimension. These dimensions are individually analysed based on qualitative desk research and descriptive and correlational quantitative data. Next, the outcomes and interrelatedness of the dimensions is interpreted. Research is conducted with secondary data sources. Prior to studying the three dimensions, specifics of the CtG-transition and Almaty's current energy situation are described.

According to the research framework, the **techno-economic dimension** is characterised by the available resources, energy flows of supply and demand, and existing infrastructure. For Almaty the techno-economic dimension is mainly typified by low-cost, subsidised and abundant fossil fuel reserves, and unexploited potential for renewable energy. Current system is dominated by and developed for (mainly) coal-based energy, which results in low-costs and energy intensive sectors. However, although, current activities are highly pollutant, inefficient and energy intensive, Almaty has clear energy ambitions of 30% RES in 2030, 50% RES in 2050, and carbon neutrality in 2060.

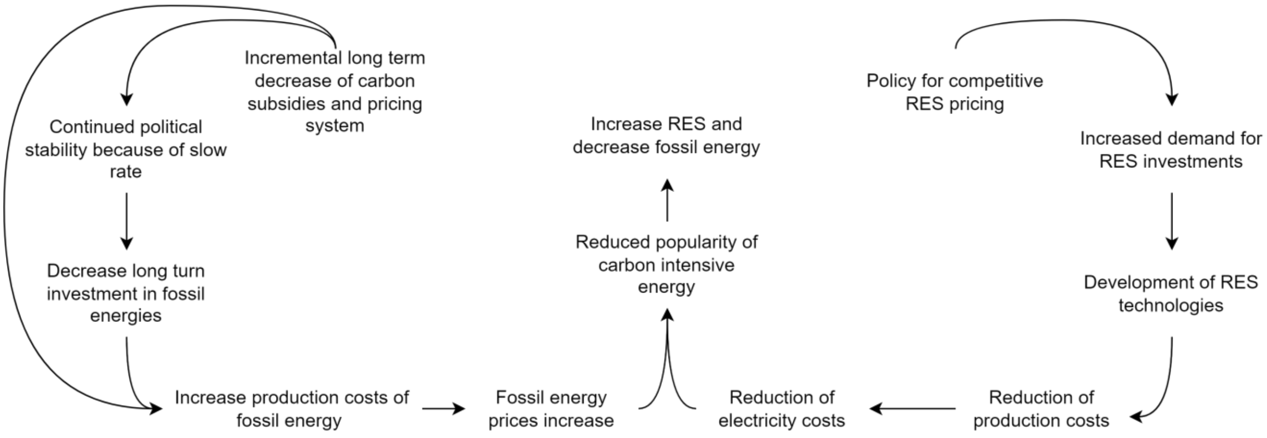
Existing infrastructure is highly outdated and substantial financial investments are urgent, which provides a window of opportunity for substantial unexploited RES potential, as various analysis conclude that a RES alternative based on solar and wind energy, is favourable (over the CHP-2 conversion) on the long term from a financial and sustainable (reduced carbon emission) point of view. Implementation of solar and wind as compensation for CHP-2 appears to be technically feasible for Almaty because of substantial alternative sources to back heat and electricity production for variable renewable energy production.

According to literature, the **socio-technical dimension** includes (the presence of) innovation systems, technological diffusion, the structure of existing systems and resources for technological innovation. Regarding the energy transition, socio-technical aspects concern the emergence of new (clean) technologies within the embedded existing energy system, which is often coal and gas-dominated. For Almaty, this dimension is typified by being stuck in a carbon lock-in. This entails the self-maintaining process of a fossil fuel based energy system because of significant interests of various societal aspects (e.g. political, economic, technical, social). For example, political parties are bounded to the habit of providing low-cost coal-based energy to households, and industrial parties are heavily invested in coal-based activities that are economically rewarding. The conversion of CHP-2 is an investment that assumably enhances the carbon lock-in and reinforces Almaty's path dependence towards fossil energy. Substantial investments are required as well, and the gas power plants have an assumed (financial) life expectancy of c. 30 years. Though, probably even longer, as some of current power plants are already operational since 1970.

On the other hand, the obsolete infrastructure and need for financial investment provide a possibility to breach this lock-in and avoid renewed path dependence towards fossil energy by investing in long term plans for increased renewable energy. However, currently there is a lack of sufficient RES stimulating measures, and existing measures are insufficient and uncompetitive with fossil energy. Various arguments promote for RES stimulation on the long term, such as improved public health for citizens, decreasing the fossil fuel dependency, (inter)national climate commitments, ambitious energy transition activities of major international trade partners (e.g. Europe), and diversification of economic activity.

The **political dimension** explains the political landscape of the city, consisting of current policies, stated ambitions, and political dynamics. This includes three variables; state goals (e.g. economic growth, energy security and climate change mitigation), political interest (e.g. voters preference and party ideologies), and institutions and capacities (e.g. political stability, economic resources, trade relations, international treaties).

For Almaty, action in the political dimension is required to catalyse the energy transition, promote RES implementation, breach with the carbon lock-in, and prevent renewed path dependence on fossil energy. (Local) political actors have to decide between short term economic growth and political stability, or long term planning and gradual development towards a sustainable and diversified energy system. Two policy cycles have to be adapted. First, regulations of fossil fuel energies have to gradually be phased out. The emphasis on 'gradual' is important since economic growth and political stability are major drivers for remaining the status quo and existing policies. Second, competitive and catalysing policy to stimulate RES development and implementation is required. Currently, RES cannot compete with fossil alternatives, and therefore cannot penetrate the heavily fossil dominated markets.



Current energy systems contains many barriers that oppose reaching Almaty's energy goals. Most important is to breach the dependency on fossil energy from an economic, technical, and political point of view. This dependency is identified as a carbon lock-in, and additional investments in Almaty's gas-based energy infrastructure lead to renewed path dependence on fossil energy and a remained carbon lock-in. Progressively stimulating and implementing solar and wind energy as alternative for the CHP-2 conversion is an important step towards phasing out fossil energy and breaching the carbon-lock in. Development towards increased RES is motivated by various long term economic, technological, sustainability and (public) heath advantages. Therefore local government should consider heavily investing in implementation of renewable alternatives and stimulating policies instead of converting CHP-2, in order to seriously work towards their climate ambitions, and to prevent another carbon lock-in.

I. Introduction

1. Energy transition goals of Kazakhstan

In December 2015 a sense of global unity and collective celebration echoed through the newspapers. 191 countries had signed commitments to *"[…]reduce their emissions and work together to adapt to the impacts of climate change, and calls on countries to strengthen their commitments over time."* in the Paris Climate Agreement (Nations, 2021). Optimism, however, turned into scepticism soon after, when commitments had to be translated into realistic, practical goals. In 2018 the International Renewable Energy Agency (IRENA) stated that renewable energy needed to be scaled up at least six times faster globally to start meeting the goals that were set in 2015 (IRENA, 2018). Although progress is being made as IRENA (2021) states that more renewable electricity has been added to the grid than nuclear and fossil fuels collectively for the past seven years, still renewable electricity should reach 10,700 gigawatts (GW) in 2030. 10,700 GW means that we have to quadruple the global amount of renewable electricity in the coming decade (IRENA, 2021c).

Kazakhstan is one of the countries that signed the Paris agreement (PwC, 2021). These commitments are challenging since the country heavily relies on the fossil fuel exporting industry. Since the Soviet era, the exploration of oil and gas, refinement and distribution have been the corner stone of the economy. The fossil fuel dependency is stressed by the President of Kazakhstan's Central Bank as well in 2018 since he confirmed that 85% of the economy was dependent on oil and gas exports (Clingendael, 2021). Although the oil and gas sector is economically predominant at the moment, the Kazakhstani government committed itself to various renewable energy and CO_2 reduction goals in the previous years. These goals structure the energy transition in comprehensive phases. The most important goals are shown in table 1 (PwC, 2021):

Year	Goal
2013	In 2013, Kazakhstan adopted a plan for transitioning to a green economy. According to this plan, the **share of renewable energy sources** in total electricity production should be **3% by 2020**, **30% by 2030**, and **50% by 2050.**[1]
2016	In 2016, Kazakhstan signed the Paris Agreement on Climate Change, making a commitment to **reduce greenhouse gas emissions by 15% by 2030** relative to the level of 1990.
2020	A low-carbon strategy until 2050 is currently being developed (Yessekina, 2022). Besides, at the climate action summit of December 2020, Kazakhstan pledged to achieve **carbon neutrality by 2060**.[2]

Table 1: Kazakhstan's renewable energy and carbon reduction goals introduced in previous years

[1] The goal of 3% renewable energy by 2020 is met regarding ex-director of the RES Department at the Ministry of Energy. RE is generated by hydropower (9%), solar (1%) and wind (1%) (PwC, 2021).

[2] A definition of *energy neutral* is not giving yet and plans towards this energy neutrality are being developed (2021)

2. Energy transition challenges

Despite high potential for renewable energy generation due to suitable natural circumstances, especially for wind and solar power (Bogdanov et al., 2019), various (national) challenges need to be overcome in order to achieve the 2030 and 2050 goals. Often occurring challenges concern limiting policy/legislation, investment risks, limited balancing capacity, uncompetitive tariffs, lack of sufficient renewable energy infrastructure (especially in urban areas), and limited stimulation of micro level renewable energy generation (Clingendael, 2021; MacGregor, 2017; PwC, 2021; World Bank Group, 2018). However, overcoming the challenges, and committing to set goals, is especially important since major trading partners are actively transitioning to clean energy as well. Most importantly Europe, as biggest trading partner, which is an active frontrunner in the energy transition. Currently, 80% of Kazakhstan's energy export is directed to Europe (Clingendael, 2021). The expectation is that the demand for oil imports will decrease by 78% and natural gas by 58-67% after 2030 (Clingendael, 2021). The economic impact of the falling demand by Europa will majorly impact Kazakhstan. Besides, the dropping demand will have high deflationary effects on global energy prices, and therefore negatively impact the profitability of hydrocarbon exports (Clingendael, 2021). The importance of transitioning to renewable energy sources (RES), and reducing dependency of fossil fuel sources, for Kazakhstan may be clear. But reliable renewable energy supply, and a decreasing supply of fossil fuel energy, in the future are important for Europe as well. Both parties have recognised this, and momentarily Europe is the largest investor in renewable projects in Kazakhstan. Besides they provide technical support (Clingendael, 2021). So, the challenges may be significant, but the urgency to transform as well - and the risks of not transforming may be unsurmountable.

3. Coal dependency

Although many countries signed the Paris Climate Agreement, coal is still a dominant resource for energy generation, accounting for 35% of the global electricity generation (IEA, 2021e). Despite their efforts to increase the use of low-carbon and renewable energy sources, China (53%) and India (12%) together, account for two-thirds of the global coal consumption (IEA, 2021a). Though, many other countries still heavily rely on coal for their electricity production as well. Especially in Eastern-Europe, post-Soviet-states, and (Middle-)Asia, such as Poland (70%), Serbia (70%), and Indonesia (60%) (EMBER, 2021). Kazakhstan finds itself in a similar situation. According the IEA (2021f), their energy supply depends for around 50% on coal based energy production, followed by natural gas and oil both for around 25%.

Natural gas is frequently considered as a transition fuel in the trajectory of reaching energy neutrality (IEA, 2019b; Stephenson et al., 2012). Because on the one hand, natural gas is significantly less pollutant than coal, relatively easy to implement, and more stable, reliable, and financially feasible than renewable sources currently. On the other hand, natural gas-generated power is still a fossil fuel and not carbon neutral (Abbess, 2015; IEA, 2019b; Safari et al., 2019). According to the IEA (2019), a coal-to-gas (CtG) transition results in an average reduction of GHG-emissions of 50% when generating electricity and 33% when used in industrial activities. However, realizing this is an average is important, as multiple variables are in play, and therefore the specific reduction varies from case to case. For example the age, size, and efficiency of the coal-fired plants, the chemical composition of the natural gas and coal, and the infrastructure influence the exact reduction(IEA, 2012). But in general switching from coal to gas-fired powerplants lead to reduced GHG-emissions. In line with these ideas, the Kazakhstani government set op national policies to drastically reduce the use of coal-fired power plants, and substitute them for natural gas-fired powered plants (World Bank Group, 2017), as intermediary result to eventually become energy neutral.

Kazakhstan's CtG-transition can be interpreted as a logical step forward in reducing GHG-emissions in the energy sector. Due to its very large coal infrastructure and time pressured energy goals, the CtG-transition can be seen as a transition within a transition. Various examples of countries who transformed their energy infrastructure towards renewables, such as Germany and Denmark, stipulate the challenge and timeliness of such a transition (Meyer, 2004; Pahle, 2010). Therefore analysing the current position and timing of this CtG-transition within the wider energy goals, is very interesting.

4. Almaty's coal-to-gas transition

One of the regions where the coal-to-gas (CtG) transition and the implementation of environmental sustainability plans is actively undertaken is former capital, Almaty. Various policy plans in Almaty are focused on increasing its sustainability and mitigating climate impact in line with national policies, the Paris Agreement and related *National Determined Contributions* (NDCs). For example the Municipal Energy Efficiency Transformation (EET) report and the Green City Action Plan (GCAP) (RWA, 2021). Developing a more sustainable and efficient energy system is central in this process, since Almaty is infamous for its sever air pollution, mainly due to the transport and energy sector. They cause respectively 64% and 35% of emissions (RWA, 2020b). Although Almaty has a relatively good natural gas infrastructure compared to various other regions and cities of Kazakhstan (IEA, 2020c), their electricity sector still relies for 85% on coal, and their district heat sector for 60%. This is including electricity import from the national energy producer (World Bank Group, 2017). The city council (Akimat) plans to convert the biggest coal-based power plant (CHP-2), accountable for 29% of air pollution, into a natural gas plant. This transition may be a good alternative, since natural gas emits around 50% percent less than coal (RWA, 2021), but altering to a different primary fuel comes with high costs, is time consuming and investments entail extensive payback times. The idea of large investments in a coal-to-gas (CtG) transition might be a suitable option, but it can also distract and decreases funds for sustainable options, and therefore work counter effective for sustainability goals.

Various scholars highlight the multidisciplinary challenges related to the energy transition. The need of a multidimensional (techno-economic, socio-technical, political) approach of low-carbon transitions (e.g. CtG or RES) that support and adds to current techno-economic models is frequently promoted (Bolwig et al., 2019; Cherp et al., 2018; Geels et al., 2017; Gielen et al., 2019). Although, techno-economic analysis are certainly necessary in low-carbon transitions, the process cannot be reduced to a merely technical or financial matter due to its non-linear, disruptive and contested nature. Therefore techno-economic factors, such as technical deployment challenges and financial incentives, often leading in decision processes, do not suffice. Political, social and cultural processes, and consumer behaviour practices should be included to structure the transitions (Geels et al., 2017).

5. Knowledge gaps

The aim of this research is to provide insights for two relevant topics with regard to energy transition processes. In order to obtain these insight a case study is conducted on the CtG-conversion of CHP-2 in Almaty city, Kazakhstan.

First, the Almaty case provides information on the position of CtG-transitions within a broader scope of the energy transition and related goals that many countries committed themselves to. Multiple urban areas, especially in Eastern Europe and post-Soviet states, heavily rely on coal. On the one hand, CtG-transitions are a logical step since it reduces the amount of polluting GHG-emissions. On the other hand, climate goals have to be fulfilled in the near-future, and a CtG-transition would merely be a temporarily option towards carbon neutrality. Studying the implications of such a timely and costly temporarily transition and exploring alternative scenarios is insightful since various countries are on the verge of adapting their energy infrastructure.

Second, research on energy transitions are often conducted from a techno-economic approach for specific target groups with a primary focus on technological possibilities and economic feasibility. However, various socio-technical and political aspects are influencing and important in energy transitions as well since social, political and cultural aspects and changes in consumer practices are involved. And regarding Geels et al. (2017) additional research should complement the techno-economic approach with the socio-technical and political dynamics within low-carbon transitions. In short the definition of the three dimension are stated below. The theoretical framework elaborates on the concepts, their interrelatedness, and frameworks to study them (Bolwig et al., 2019).

1. **Techno-economic systems** are characterised by flows of energy, such as energy conversion, production and consumption directed by the energy market.
2. **Socio-technical systems** identified by socio-technical dynamics that influence the emergence and embeddedness of technological innovations.
3. **The system of political actions** shape the formulation and implementation of energy related policies

6. Problem statement

From a practical casus-oriented point of view, the city council (Akimat) of Almaty committed itself to ambitious energy plans of the CtG-transformation and significantly increasing the share of RES to eventually became carbon neutral. The combination of these transformations, and the relation to stated energy goals, is complex and interesting.

Firstly, the dynamic between these ambitions are kind of contradicting since gas-power energy is still fossil energy and GHG-emissions are still emitted, while poor air quality is a major problem in the city and increasing the air quality is urgent according to the city council (World Bank Group, 2017). On the other hand, GHG-reductions are significant when switching from coal-to-gas.

Second, challenges of the energy sector predominantly concern depreciation and poor connectivity of current fossil infrastructure and insufficient (financial) stimulation and policies for the implementation of renewable energy. So, revisioning the existing infrastructure and the penetration of RES to network, both require increased focus and therefore, compete with each other (RWA, 2021).

From an academic point of view, Almaty's CtG-transition is relevant since decisions in the energy transition are regularly, predominantly, based on techno-economic analysis supported by quantitative energy models. However, many other socio-technical and political variables influence the process as well, such as lock-ins, policy frameworks, political dynamics, behavioural change, and industrial and public opposition (Geels et al., 2017). These challenges are often poorly represented. It is important to take these dimensions into consideration in such a complex and timely process as energy transitions. According to various academics, socio-technical and political aspects should be incorporated in energy transition analysis and assessment frameworks (Bolwig et al., 2019; Cherp et al., 2018; Gielen et al., 2019). Besides, switching from coal to gas is already a transition in itself (Geels et al., 2017). For example, Denmark and Germany, who are concerned as leaders within the energy transition, the process is going on for decades, and they still partly rely on fossil sources (Meyer, 2004; Pahle, 2010). So, taking Almaty's carbon neutrality goal of 2060 into account, researching the impact and strategy of a coal-to-gas transition at this stage is relevant. The more since various countries and cities find themselves in a similar situation.

To conclude, analysing the coal-to-gas transition of Almaty from a multidisciplinary - techno-economic, socio-technical and political - perspective is interesting within current energy landscape, and practically adds to the local assessment framework of Almaty.

7. Research question:

A research question is defined in order to clarify the end-goal of the research and its aim to provide information and insights for the existing knowledge gaps in the energy field, within a specific case study. The research question is:

How does Almaty's CtG-transition of CHP-2 fit in the wider energy goal to become carbon neutral in 2060 from a multidisciplinary - techno-economic, socio-technical and political - perspective? And what are alternative energy transition pathways?

The definitions and dynamics of a multidisciplinary approach, and the techno-economic, socio-technical and political perspectives are elaborated on in the theoretical framework.

8. Sub-questions:

The research question is broad and contains various dimensions that need elaboration to eventually answer the full question. Sub-questions help to narrow down the scope and provide information on distinctive elements. Eventually the sub-questions collectively enable us to answer the research question. Specific aspects studied within the sub-questions are elaborated on in the methodology section. The sub-questions are:

Sub-questions
1. What is the current state of literature on the role of a multidisciplinary approach - techno-economic, socio-technical, political - of energy transitions?
2. What is the current energy situation of Almaty?
3. What are specifics of the coal-to-gas transition
4. What are Almaty's energy policy (goals) and political dynamics regarding the CtG-transition and its wider energy ambitions?
5. What are characteristics of the socio-technical dimension for Almaty's CtG-transition? And how does this comply with their wider energy goals?
6. How do techno-economic aspects of the CtG-transition relate to a RES alternative for Almaty?

II. Theoretical Framework

This theoretical framework section provides the outcomes of the literature study on multidisciplinary dynamics of energy transitions conducted for this research. Second, concepts of energy modelling and energy transition pathways are explained. The complete literature study can be found in the appendix A. Page 8 and 9 provide an overview of important abbreviations and energy related concepts to understand the energy situation and the CtG-transition of Almaty.

1. Current state of literature of energy transitions

The literature study concluded that established studies on energy transitions stipulate the importance of integrating multiple disciplines through system thinking because of its complex and interdisciplinary nature (Gielen et al., 2019; Köhler et al., 2019; Turnheim et al., 2015). Leading in this debate is the fact that many energy transition analysis predominantly focus on techno-economic elements, but that interdisciplinary approaches that include, social, economic, technical, political and cultural aspects are required to represent reality (Geels et al., 2017).

An especially relevant challenge is to include interdisciplinary variables within energy system modelling since this widely-used method remains heavily techno-economic focussed, using vast amounts of quantitative data (Gielen et al., 2019; Li et al., 2015). Although, techno-economic energy modelling can be relevant for studying the impact of Almaty's CtG-transition and the wider energy ambitions, plural other aspects (e.g. economic, technical, social and political) that are actively involved in Almaty's energy situation, should be included. Therefore studying a method for interdisciplinary energy system modelling is highly interesting. Li et al. (2015) evaluated various modelling tools focussed on integrating techno-economic, socio-technical and political elements to quantitatively analyse energy transitions. Secondly, Cherp et al. (2018) designed a comprehensive framework involving three first-level variables of energy transitions (socio-technical, techno-economic, and political), and assigned second-level characteristics to them. These first- and second-level variables are integrated in a interrelated meta-theoretical framework. Geels et al. (2017) reasons in line with this and discusses the three perspectives within energy transitions. They concluded that the socio-technical and political dimension should be intensively included in the debate, and suggest lessons to consider in future low-carbon analysis. Lastly, Bolwig et al. (2019) designed a framework that includes the dynamics between the three perspectives, that function as a recommendations for implementing the interrelated perspectives in (quantitative) models.

Research on various multidisciplinary energy transition approaches are studied for three reasons. First, to understand the three dominant dimensions of energy transitions - techno-economic, socio-technical and political) Second, to obtain knowledge about the dynamics between the three dimensions within energy transitions. Third, to conclude what multidisciplinary frameworks are relevant for the Almaty case study. The section below elaborates on these three aspects to elaborate on structure of this research.

2. Multidimensional energy transitions

Dimensions of energy transitions

Studies towards energy transitions have been conducted from distinctive theoretical perspectives. But various studies conclude that energy transitions are a coevolution of three varying systems, namely (Bolwig et al., 2019):

1. **Techno-economic systems** characterised by flows of energy, such as energy conversion, production and consumption directed by the energy market.
2. **Socio-technical systems** identified by socio-technical dynamics that influence the emergence and embeddedness of technological innovations.
3. **The system of political actions** shaping the formulation and implementation of energy related policies

1. The techno-economic perspective

The techno-economic perspective approaches energy systems, as an entity of energy flows of energy inputs that deliver services. Energy inputs (e.g. natural gas, coal, nuclear, biomass) enable conversion devices and processes (e.g. engines, burners, CHPs) to supply heat or electricity to activate passive systems (e.g. buildings, machines, computers, vehicles) to deliver services for end-users (e.g. transportation, (thermal) comfort, assistance). Moreover, it includes material consumption and many technical aspects, such as transmission and distribution systems, road infrastructure, railway signalling systems, gas and pipelines, etc. The techno-economic dimension consists of material goods, factories, infrastructures, and input and output flows of supply chains (Geels & Turnheim, 2022). Due to its material and financial character techno-economic systems are relatively easy to quantify (e.g. Sankey diagrams), and therefore economic norms can be applied to these services. This makes techno-economic models and theories suitable for application in energy processes and flows, as the physical energy flows and conversion processes are traded in markets and can be considered as production and consumption goods. However, due to this economic nature, subject to supply and demand dynamics, it is also prone to economic lock-in mechanisms, such as sunk investments, economic competition standards, and economies of scale. For example, it is likely that large and powerful industries will protect their vested interests and when their position is pressured, and therefore oppose change (Köhler et al., 2019). The above characteristics makes it challenging to catalyse change and implement new technologies and standards in existing stable markets (Geels & Turnheim, 2022).

A limitation for the techno-economic perspective in energy transitions is that various dimensions and societal aspects are excluded. First, techno-economic (quantitative) approaches have sophisticated instruments to explore decision-making processes and policy targets. However, it limitedly considers social and institutional challenges, and the interplay between interests and politics in a real-world context (Turnheim et al., 2015). Policy is encountered as a fixed number of measures with clear outcomes, but in reality policy is non-linear and capricious. Second, challenging phenomena as inertia, path dependence, and technological innovation cannot be overcome from a techno-economic perspective. Inertia and path dependence occur due to powerful economic, political and social interests, embedded in current systems (Turnheim et al., 2015). The techno-economic perspective tends to neglect intangible factors of transitions, for example institutional and cultural aspects of socio-technical development, political power and willingness, and the non-rationality (irregularity) of real-word processes (Geels, 2014). Thus in order to comprehend energy transitions are mere techno-economic perspective does not suffice, due to its limited thinking and exclusion of political and socio-technical factors.

2. The socio-technical perspective

Socio-technical transitions

The socio-technical perspective tends to depict a more holistic and integrated look on societal changes, that analyses multiple dimensions of change, which include a wide variety of technological, economic, political, and socio-cultural aspects at different levels (Turnheim et al., 2015). Socio-technical systems provide societal functions that co-evolve and have interdependent interactions between technologies, supply chains, markets, infrastructure, user practices, cultural meanings, regulations, and policies. Examples of urban socio-technical systems are buildings, heating, mobility, and food systems. Since many societal actors are included in socio-technical systems, their development is a long term process which stretches over decades (Geels et al., 2017).

The socio-technical perspective is closely related to socio-technical transitions, and research on these systems and transitions are motivated by the recognition that many environmental problems (fossil fuel depletion, decreasing biodiversity, global warming) are caused by unsustainable socio-technical systems. These systems elicit unsustainable consumption and production patterns that cannot be solved merely by technological fixes, but require radical societal shifts towards new sustainable socio-technical systems. These transitions are called sustainability transitions, and the energy transitions plays an major role in it (Köhler et al., 2019).

Four major research strands can be distinguished within the field of socio-technical transitions, namely *transition management* (TM), *strategic niche management* (SNM), the *multi-level perspective* (MLP), and *technological innovation system* (TIS). The literature study (appendix A) touches upon the various research strands. However, the MLP is mostly relevant for this study. First, because of its wide acknowledgment and fitting characteristics for the Almaty case. Second, the framework is mentioned by various scholar involved in energy transitions, e.g. Bolwig et al. (2019), Turnheim et al. (2015) and Geels et al. (2016). Although the framework is not directly implemented in the study, a basic understanding is favourable since the MLP provides a good understanding on the robustness of existing socio-technical structures (e.g. energy systems), including embedded actors and their interests, the introduction of innovations, and the overall complexity of sustainability transitions.

The multi-level perspective (MLP)

The *multi-level perspective* explains technological transitions through the interaction between three different levels: niches, regimes and landscape. In general the theory concludes that landscape dynamics might pressure existing regimes and create windows of opportunities for niche innovations, that might find their way into the hard-to-disrupt regime. The niche break through can contribute to shifts and fundamental change at the regime level. The niche-regime-landscape interaction highly depends on different dynamics, characteristics and timing.

The *socio-technical regime* (hereinafter referred as regime) is fundamental in the MLP. Regimes are resilient and hard to disrupt, and can be defined as societal systems where incumbent actors are guided by deeply entrenched rules, regulations and institutions (Geels et al., 2017). For example, various actors are active in the regime of the car industry (manufactures, dealers, policy makers, engineers, users), and together they form a strong balance with rules (policies, production standards, traffic rules), infrastructure (roads, factories, car oriented cities), economic interests (retailers, dealers, garages) and socio-cultural aspects (user behaviour, transportation standards). Regimes are resilient and stable in order to overcome external pressures, internal breakdowns and disruptions. The interaction between the niche (innovations), regime, and landscape within socio-technical transitions is interesting (illustrated in appendix A figure A). The role of the regime is to ensure that systems can fulfil their important social functions (Markard et al., 2012).

The *niche level* is rapidly developing, but does not often prevail. They focus on radical social or technical innovations that highly differ from the existing socio-technical system and regime. However sometimes, with particular applications or with help from policy instruments for example, these innovations can prevail in the existing regime. Niches are fundamental in the emergence of novel technologies, which can occur in protected environments (e.g. market regulation, subsidies, etc.) where radical innovation can develop without being pressured by prevailing regimes and existing market competition (e.g. subsidies for electric cars). Windows of opportunities - momentum of disruption in existing regimes - provide possibilities for niches to compete with existing technologies and to eventually stabilise in new regimes (Markard et al., 2012).

The socio-technical landscape level refers to wider societal contextual developments that impact the regime level and over which regime actors have little or no influence. Landscape level developments involve both slow changing movements (e.g. ideology, geopolitics, demographics, etc.) and exogenous shocks (e.g. financial crises, large scale accidents, wars, political unrest, etc.). The MLP describes the occurrence of transitions through the alignment of processes between the interdependent three levels (Geels, 2002). This is illustrated in figure 1.

Innovations might be beneficial for regimes to survive or expand. For example upscaling of renewable energy to become less dependent on fossil fuels. However, penetrating or changing socio-technical regimes (e.g. current fossil fuel energy system) is difficult since new innovations that threat the regime's stability may be blocked (e.g. market parties with vested interest). The robustness of socio-technical regimes results in two dominant phenomenon that complicate and oppose adoption of changes, new market players and innovation, namely *lock-ins* and *path dependence.* Lock-ins refer to mechanism that seduce actor to rather promote incremental change than radical change. They oppose actors to change their activities due to vested interests, and thus stabilise existing systems and thus negatively influence change. Various forms of lock-ins exist, such as techno-economic lock-ins (e.g. sunk investment costs, low variable costs, material obduracy), social and cognitive lock-ins (e.g. behavioural routines, habits, mindsets), political lock-ins (e.g. existing regulations, standardisation of existing system, rules creating unequal playing field for innovations) (Geels & Turnheim, 2022). The *carbon lock-in* refers to a positive feedback loop towards stabilising the existing fossil fuel system. It refers to economic, political and institutional lock-ins that reinforce current fossil fuel system (Geels, 2014). Mahoney (2000) identifies path dependence as *"that has happened at an earlier point in time will affect the possible outcomes of a sequence of events occurring at a later point in time"*. So, political, technical or economic decisions previously made, are influencing todays energy system. And decisions made today are forming future energy systems. Since societal transitions often take decades, these are important factor to take into account for the Almaty case study.

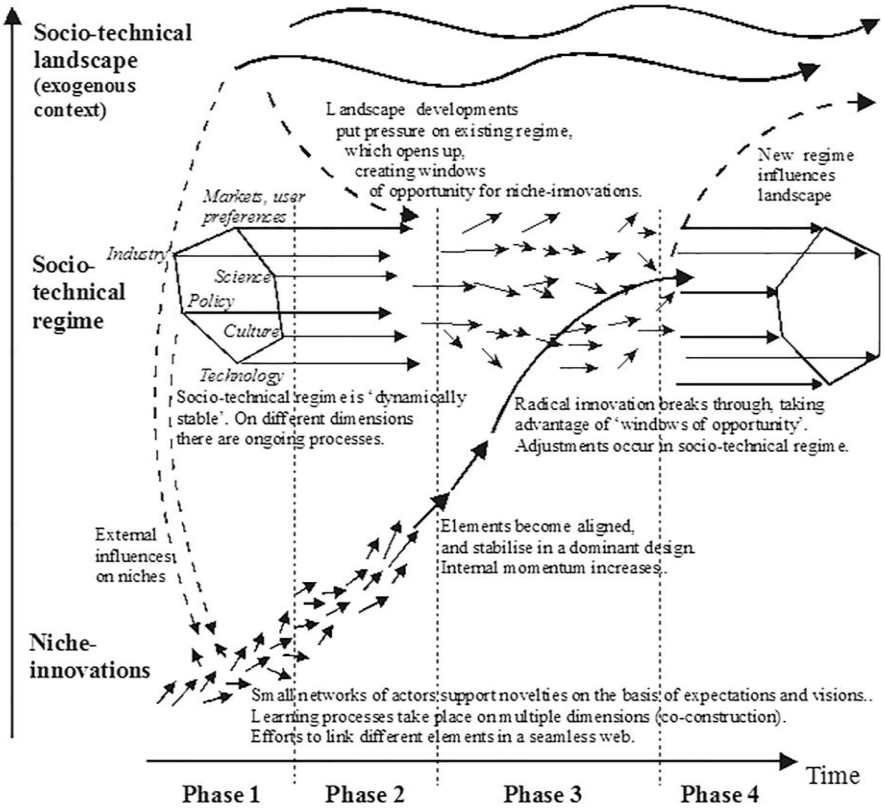


Figure 1: Illustration of the multi-level perspective on socio-technical transitions
Source: Geels et al. (2017)

3. The political perspective

The political dimensions is often regarded as an integrated part of the socio-technical perspective in transition studies instead of a separate perspective. However, Turnheim et al. (2015) concludes that these socio-technical analysis have limited forward orientation on political goals. Moreover Meadowcroft (2009) states that the political dimension deserves a more prominent role in sustainability transitions. He argues that political aspects in sustainability transitions contain more than just the interrelatedness of economic interests, technological feasibility and policy on which the economic and socio-technological dimension react. The political arena entails more than just policies and holds great potential in sustainability transitions (defining the landscape, (de)stabilising regimes, protecting or exposing niches), and should therefore be a separate dimension to attain explicit attention. Besides he concludes that without crucial political power certain decisions and transitions directions would not have been possible (e.g. CCUS projects in the Netherlands; solar PV in Germany) (Meadowcroft, 2009, 2011).

The political perspective within energy transitions focusses on how policy adaptations come to existence and how implementations affect energy systems. For energy transitions the political perspective regularly focusses on the national level, as the majority of energy policies are implemented by the government who act in interest of the state. Regional governmental bodies mostly have to design and implement policy regulations for policy goals set by the national government. For example, the Kazakhstani government signed the Paris Climate Agreement, obtained *Nationally Determined Contribution* (NDCs), which are mostly translated into detailed and specific plans by regional governments (IEA, 2020c). This central role of the state distinct the political perspective from the techno-economic and socio-technical perspectives, where the state usually functions as a normal economic actor, an element of the external landscape, or a steering factor for normative guidelines (Cherp et al., 2018). Within political perspective the motivation of political parties and a lack of political will can greatly influence the pace and realisation of transitions (Geels et al., 2017).

The complexity of the political dimension with various influencing factors is elaborated on in the appendices where Hall's *state-centric* and *state-structural* typologies are explained. These typologies regard the sphere of influence and whether policies come to existence through best national interests or through competing interests of various actors (e.g. voters, lobby groups, NGOs). Geels (2014) for example, states that incumbent industrial parties use their power to prevent transitions from happening. Regarding the Almaty case study, fossil fuel companies and actors are highly involved in the regime, and thus play a fundamental role in the energy transition, which with their role in society, power and competing interests results in a socio-political struggle. The political landscape of Kazakhstan with various influencing factors internally, but also internationally with predominantly China, Russia and the European Union, makes this dimension relevant for the study.

Dynamics of the three perspectives in sustainability transitions

Although the three perspectives discussed are semi-autonomous and have different boundaries, their changes are mutually interdependent and they evolve collectively. Despite this acknowledged interrelatedness and co-evolving nature of the systems, most existing energy transitions models lack inclusion of socio-technical and political factors. They frequently focus on quantitative techno-economic inputs, and lack inclusion of political aspects, involvement of societal actors, and poorly represent the co-evolving dynamics between technology and society (Li et al., 2015). For example they do not comprehensively consider the unpredictability of innovation, behavioural aspects of actors, policy steering mechanisms, and the spatial dimension of energy transitions (Cherp et al., 2018). They are often techno-economic models that entail quantitative analysis focussing on energy flows, conversion of energy, and market dynamics that influence energy consumption (Li et al., 2015). However, to fully comprehend energy transition dynamics one should address all three systems since various studies concluded that the transition is not merely a technical matter, but is influenced by values, strategies and behaviour of individual actors, and rely on policies, regulations and markets as well (Bolwig et al., 2019; Geels et al., 2017; Li et al., 2015). This is illustrated in figure 2.

Cherp et al. (2018) discussed how energy transitions analysis, frameworks and models can become more realistic by integrating the fundamental techno-economic, socio-technical and socio-political dimensions. Their framework has a central role in this research since it comprehensively studies the dynamics of energy transitions, is conducted recently, is acknowledged by many scholars, and they appear to relate to the Almaty case study. Cherp et al. (2018) designed a meta-theoretical framework to study energy transitions based on literature on the techno-economic, socio-technical, and political dimensions. This interrelated framework (from now on referred to as *the research framework*) includes essential elements of each individual dimension provided in a table (See figure 2 & table 2). These primary and secondary level variables function as a starting point for Almaty's CtG-transition analysis.

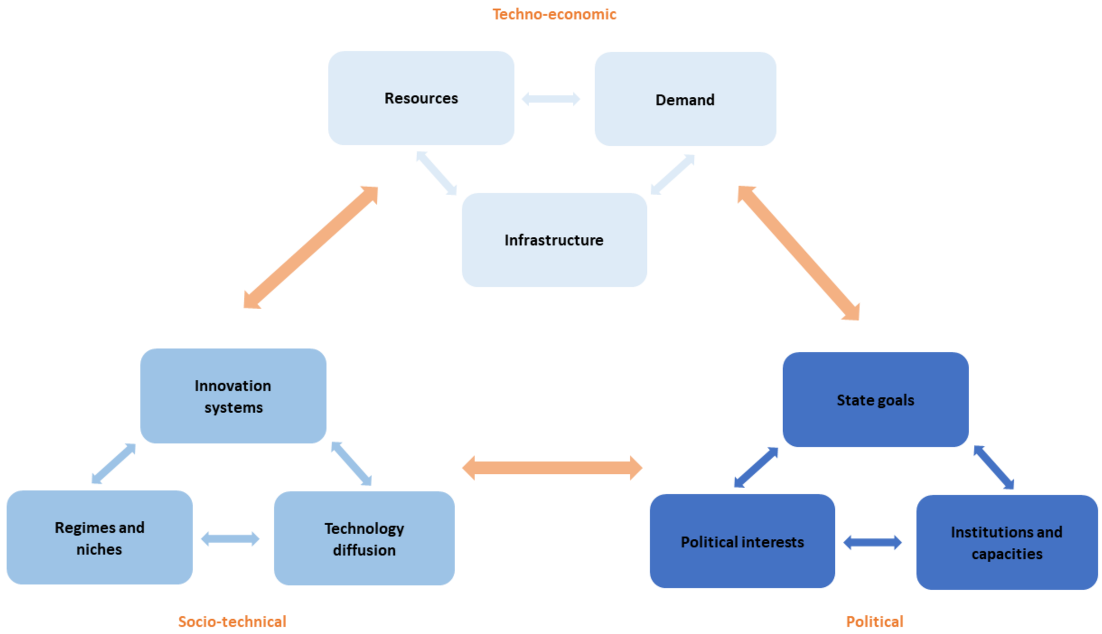
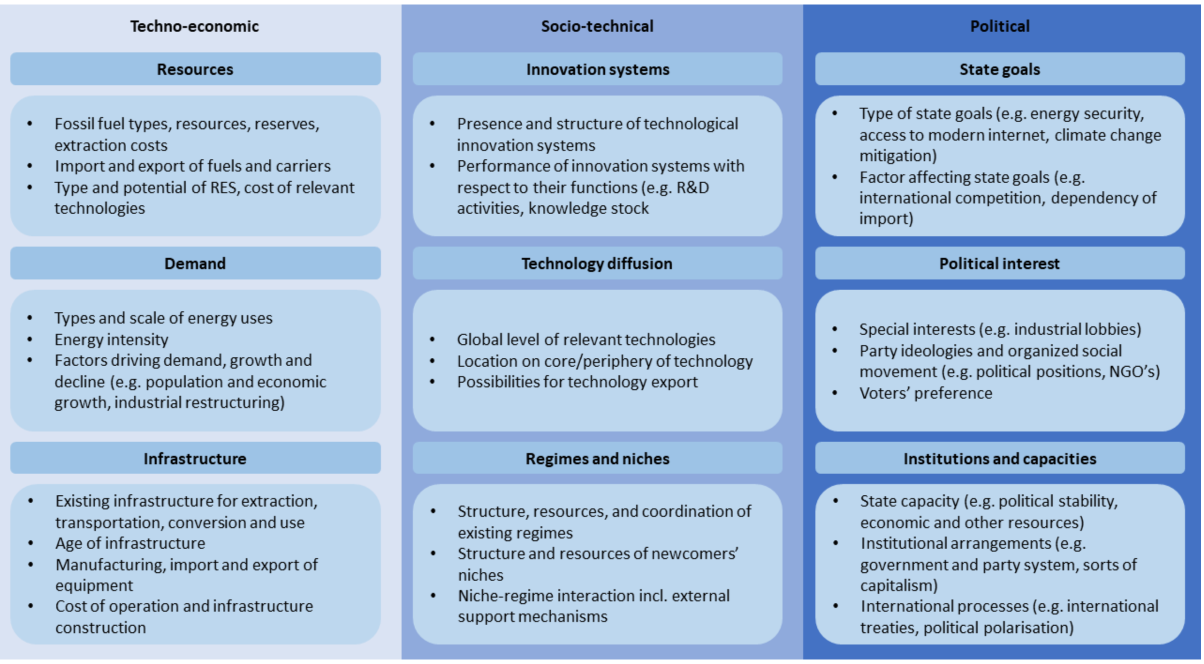


Figure 2: First level variables related to (national) energy transitions from three perspectives
Source: Based on Cherp et al. (2018)



Techno-economic	Socio-technical	Political
Resources	**Innovation systems**	**State goals**
• Fossil fuel types, resources, reserves, extraction costs • Import and export of fuels and carriers • Type and potential of RES, cost of relevant technologies	• Presence and structure of technological innovation systems • Performance of innovation systems with respect to their functions (e.g. R&D activities, knowledge stock	• Type of state goals (e.g. energy security, access to modern internet, climate change mitigation) • Factor affecting state goals (e.g. international competition, dependency of import)
Demand	**Technology diffusion**	**Political interest**
• Types and scale of energy uses • Energy intensity • Factors driving demand, growth and decline (e.g. population and economic growth, industrial restructuring)	• Global level of relevant technologies • Location on core/periphery of technology • Possibilities for technology export	• Special interests (e.g. industrial lobbies) • Party ideologies and organized social movement (e.g. political positions, NGO's) • Voters' preference
Infrastructure	**Regimes and niches**	**Institutions and capacities**
• Existing infrastructure for extraction, transportation, conversion and use • Age of infrastructure • Manufacturing, import and export of equipment • Cost of operation and infrastructure construction	• Structure, resources, and coordination of existing regimes • Structure and resources of newcomers' niches • Niche-regime interaction incl. external support mechanisms	• State capacity (e.g. political stability, economic and other resources) • Institutional arrangements (e.g. government and party system, sorts of capitalism) • International processes (e.g. international treaties, political polarisation)

Table2: First- and second level variables of the research framework from the three dimensions
Source: Based on Cherp et al. (2018)

Bolwig et al. (2019) provides a theoretical framework that comprehensively shows the effects and complexity of the three dimensions of energy transitions, by including behavioural changes, policy and governmental influences, infrastructural development and other socio-technical and political variables within their framework. It illustrates relations through feedback loops in which variables positively (+) or negatively (-) influence other variables. Collectively the variables create feedback loops that are reinforcing (R) or balancing (B). The framework provides understanding of the non-linear nature of energy transitions, which by including socio-technical and political insights present a more realistic - and complex - envisioning of energy transitions (See figure 3). An extensive explanation is included in the literature study of appendix A.

The theories and frameworks of Cherp et al. (2018) and Bolwig et al. (2019) are suitable for this research for various reasons. First, the theories are acknowledged by various scholars for studying the multidisciplinary nature of energy transitions. Second, the frameworks enables to execute analysis with limited information, since either qualitative or quantitative analysis can be included. Third, the frameworks, especially Bolwig et al (2019), provide insight on specific relations and effects between the various dimension. This is valuable when integrating the various dimensions active in the CtG-transition.

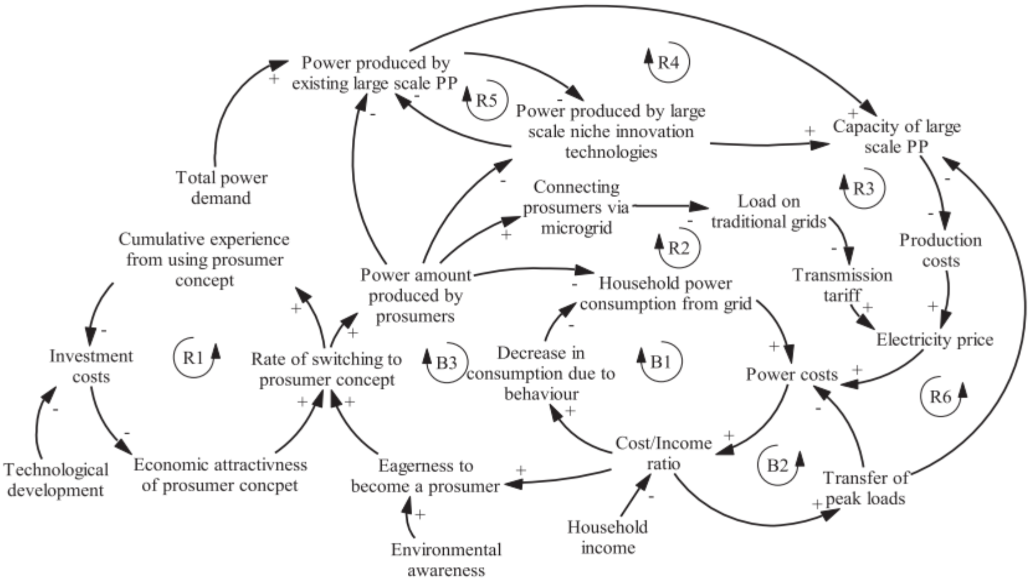


Figure 3: Dynamic model of feedback loops between actors in the electricity system
Source: Based on Bolwig et al. (2019)

Integrating models to analyse the CtG-transition of Almaty

The aim of this study is the analyse the CtG-transition within the wider energy transition ambition of Almaty to become energy neutral in 2060 from a multidisciplinary approach. However, since energy transitions are mainly analysed and quantitatively modelled from a techno-economic perspective, exploring methods to realise this is challenging. The research consists of three phases that include the three perspectives - techno-economic, socio-technical and political - that are present in Almaty's energy landscape. The phases collectively enable to analyse the CtG-transition from a multidisciplinary approach. The phases are discussed in the methodology section (see table 3)

III. Methodology

1. Research Method

Since this study aimed to analyse the CtG-transition from a multi-disciplinary perspective that focusses on techno-economic, socio-technical and political aspects, the central research method was a *socio-technical system design*. This research method focusses on systems that involve a complexity of interactions between human actors, machines and environmental factors. Socio-technical system design suits this research because of five characteristics that comply with Almaty's CtG-transition, as it involves systems that (Baxter & Sommerville, 2011):

- Have interdependent parts;
- Adapt to and pursue goals in external environments;
- Have an internal environment comprising separate but interdependent technical and social subsystems;
- Have goals that can be achieved by more than one means. This implies that there are design choices to be made during system development.
- Which performances relies on the joint optimization of the technical and social subsystems. Focusing on one of these systems to the exclusion of the other leads to suboptimal solutions.

Within the scope of this research the last aspect is probably most relevant since the success of energy transitions relies on mutual cooperation between social and technical systems (Geels et al., 2017). Realizing the most optimal energy transition pathway probably fails when focusing merely/majorly on one element. Joint optimization with consensus between technical, economic, social and political variables must be made to achieve optimal results.

As mentioned in the theoretical framework, analysis that comprehensively integrated techno-economic, socio-technical and political perspectives of the energy transition are limited, so additional insights and recommendation were relevant. Therefore, the theoretical framework provided an overview of relevant and recent findings on various approaches of energy transitions. Academic papers were selected based on their relevance, recentness and frequency of appearance in other academic paper. A selection of relevant papers can be found in appendix B .

Although models exist that integrate techno-economic and socio-technical elements in quantitative models (Li et al., 2015), using them was beyond the scope of this research. Almaty was a suitable case to exploratively analyse energy transitions from multiple perspectives because of its specific coal to gas transition, similar circumstances (e.g. coal dependency) and challenges as various cities in Eastern Europe, post-Soviet states and Asia, and the available data and plans. However, although data was available, the amount of (reliable) quantitative data and a relatively short period made this a exploratively study, that highlights points of attentions, possibilities and challenges for further research. Despite limited data, the recommendation and insights are still relevant, since other cities probably face similar challenges.

Cherp et al. (2018) and Bolwig et al. (2019) stipulate the need for multidisciplinary approaches of energy transitions, and provide frameworks to analyse them. Supported by their frameworks, a combined effort of qualitative research (literature and interviews) and quantitative modelling provided insights on the multi-dimensional dynamics of the CtG-transition of Almaty. The research was conducted with mainly secondary data obtained from the national statics database, institutional reports, policy documents, scientific literature and exploratory interviews.

2. Methodological approach

Methodological steps

This research was divided in three major methodological steps (see table 3). These steps are linked to the sub-questions that were developed to analyse Almaty's CtG- transition, provide insights and recommendations, and finally answer the research question. The steps are a combination of qualitative and quantitative methods, which were aligned with the multidimensional nature of energy systems.

Step 1 consisted of a qualitative and quantitative overview of Almaty's current energy situation, future energy prospects and specifics on the CtG-transition. The analysis mainly focussed on sectors related to the CtG-transitions, thus the energy production and distribution sector and the build area. Data is obtained through secondary qualitative and quantitative sources. Step 1 provided background information of the CtG-transition for further analysis on individual dimensions.
Step 2 focussed on analysing the three dimensions (political, socio-technical and techno-economic) individually, their involvement in the CtG-transitions, and relatedness to Almaty's energy ambitions. These analysis are based on the first- and second level variables the research framework. The socio-technical and political analysis are conducted with secondary qualitative data and output of a semi-structured exploratory interview. The result is a selection of the main factors influencing the CtG-transition. The techno-economic analysis was conducted with secondary qualitative and quantitative data in which the CtG-transition was compared to RE alternatives, which several graphic outputs as outcomes.
Step 3 was characterised by interpreting and interlinking previous analysis to conclude on recommendations and insights on Almaty's CtG-transitions within their energy ambitions. The research frameworks and Bolwig et al. (2019) supported interpretation of interrelations between the various perspectives and what lessons can be obtained similar cases. Since various assumptions were needed during the research, this part reflects on various limitations as well.

Table 3: Methodological steps to structure the research and finally answer the research question.

Methodology for answering sub-questions

Sub-questions were identified to structure the step. Collectively, the sub-questions enabled to come to insights and recommendations on the interplay of the interrelated dimensions and multidisciplinary challenges of the CtG-transitions, and thus to answer the research question. Specifics on the methods per sub-question are discussed in the section below, and an overview of the questions, research types and methods is presented in table 4.

What is the current energy situation of Almaty?

The current energy situation of Almaty was crucial to analyse the impact of energy measures, to place the coal-to-gas transition into perspective, and to make recommendations for future scenarios. The total current energy situation functioned as a baseline for the climate commitments, since it for example determined the amount of GHG-reduction and renewable energy production that are needed to reach policy commitments. The analysis mainly focussed on the following three aspects in relation to the CtG-transition:

- What are the dominant sectors involved in Almaty's CtG-transition?
- What are the characteristics of the current energy infrastructure, source and consumers?
- What are the forecasts of future energy usage?

Insights on these matters presented opportunities and challenges within current energy system, and therefore advantages and disadvantages for the CtG-transition. This section aimed to explore and familiarise ourselves with Almaty's energy situation by using qualitative and quantitative data.
Qualitative data was collected to study Almaty's energy activities and the CtG-transition. So, what the energy infrastructure looked like, what parties are involved, and why certain climate goals and policy implementations were needed. Data was mainly obtained from literature, and explorative interviews. Literature mainly consisted of policy documents and academic reports, and thus consisted of secondary data. The exploratory interview consisted of a semi-structured interview with experts from the planning and energy field and people that were involved in climate mitigation plans of Almaty.

Quantitative data was obtained to understand and visualise current energy situation and to roughly analyse future energy demand. Quantitative data was collected from governmental statistic databases and policy documents, as these sources provided most valuable, extensive, and recent data. The main data source was the *Energy Efficiency Transformation* report supported by the World Bank and the city council (World Bank Group, 2017). The report includes data on energy production, consumption and reduction measures of Almaty. First, some basic characteristics, comparisons between sectors, and challenges regarding the energy situation were discussed. Second, data concerning the energy sector were analysed. This includes comparisons and characteristics on various energy production sources, the electricity network, (district) heating distribution, and energy consumption of the build area. During this phase data was also structured for analysing specifics on the CtG-transition and later the techno-economic dimension.

What are specifics of the coal-to-gas transition?

Specifics on the goal-to-gas transition were gathered for familiarising with the context and for interpreting the multidisciplinary analysis within Almaty's energy goals later in the process. The CtG-transition was leading in this research and therefore set a reference framework for other sustainability measures, recommendations and transition pathways. The following specifics of the CtG-transition were investigated:

- What is the overall situation and cause for converting to natural gas?
- What is the time horizon and current state of the conversion?
- What are the total estimated costs of the conversion?
- What is the total emission reduction after conversion? And what are the consequences for the carbon neutrality goals of 2060.

The characteristics were obtained through qualitative and quantitative, secondary, data gathering. Qualitative data described the context of the plans, the planning and the political motivation for the operation. This data was collected from literature sources, such as policy documents from the city council, institutional reports from the World Bank, market reports from ALES (Almaty's Energy System), and a semi-structured interview with energy experts. The quantitative data gathering was needed to analyse the CtG-transition within the wider scope of the energy transition. This part consisted of descriptive quantitative analysis on various characteristics of the electricity system, such as the amount of electricity and heat produced, by what type of energy sources (e.g. coal, gas, hydropower), electricity and heat infrastructure. This data gathering and structuring phase formed the basis for analysis of the socio-technical, political and techno-economic dimensions.

What are Almaty's energy policy (goals) and political dynamics regarding the CtG-transition and its wider energy ambitions?

For the political dimension, current policies and policy goals were analysed based on the first- and second level variables of the research framework. Current policies presented insights on Almaty's visions, designs, implemented plans, and the political dynamics. An overview of the policy ambitions defined the arena in which all energy transition measures and innovations occur since it sets the baseline for energy transition development.

The political analysis was divided over international, national and regional policies. Policies from the three scales were separately appointed to the variables of the research framework since this created a better overview of where certain political decision should be made and specifics on the dynamics within the energy transition.

The political overview was created through qualitative desk research with the use of secondary data, mainly policy documents. The analysis focused on aspects as the publication date, the time horizon of the policy plans, relation to the CtG-transition and the motivation of the policy plans - technical, economic, political, etc. The overview resulted in a complete table of current obtained goals, responsible actors, target groups, and political dynamics.

What are characteristics of the socio-technical dimension for Almaty's CtG-transition? And how does this comply with their wider energy goals?

The socio-technical environment clarifies emergence of the current energy situation, and why certain alternatives can or cannot come to existence. Dynamics of the socio-technical dimension were mainly defined by regime and niche characteristics, such as the development of technical innovation, support of technological diffusion and the protection of certain markets. These type of aspects were studies based on the first- and second level variables of the research framework.

Analysing the socio-technical dimension was conducted by qualitative desk research, which focussed secondary literature sources on the energy sector, mainly institutional reports. Sources were selected based on their relevance to the CtG-transition, publication date and their assumed reliability based on the source. Eventually a table was created that comprehensively showcases the dynamics of the socio-technical dimension within the energy sector of Almaty. The table was based on the research framework to compare the various dimensions.

How do techno-economic aspects of the CtG-transition relate to a renewable alternatives for Almaty?

The third and final analysis concerned the techno-economic dimension. The analysis consisted of qualitative and quantitative results. Qualitative aspects analysed potentials for renewable energy options near Almaty. Data was obtained from various secondary literature sources, mostly academic and institutional. The qualitative parts presented the context for quantitative analysis, and selected specific renewable alternatives that were most potential.

The quantitative part consisted of descriptive and correlational quantitative analysis. This contained analysing fossil and renewable energy options, by comparing emitted CO_2 emissions, average costs per kWh, electricity capacities, and spatial consequences. The methods and limitations of these analysis are further explained in the *'Analysing methods and limitations'* section.

Sub-question	Research	Method
What is the current state of literature on the role of multi-disciplinary approach - techno-economic, socio-technical, political - of energy transitions?	Qualitative	Academic literature review
What is the current energy situation of Almaty?	Qualitative	Desk research
	Quantitative	Energy modelling
What are specifics of the coal-to-gas transition?	Qualitative	Desk research
	Quantitative	Energy modelling
What are Almaty's energy policy (goals) and political dynamics regarding the CtG-transition and its wider energy ambitions?	Qualitative	Desk research
What is the socio-technical landscape for Almaty's coal-to-gas transition? And how does this comply with the wider energy goals?	Qualitative	Desk research
How do techno-economic aspects of the CtG-transitions relate to a renewable alternative for Almaty?	Quantitative	Energy modelling

Table 4: Overview of methods for answering the sub-research questions

Appendix A (p. 100, figure E and F) present and elaborate on the conceptual framework that is designed for this study. The framework visualises the intention of the research and how the sub-questions and intermediary results assist in finally answering the research question, which assist in analysing the CtG-transition from a multi-disciplinary perspective.

Although this study obtained valuable insights, it still experienced various limitations. Some limitation were linked to analysing methods that experienced a lack of local specific data. Limitations that were expected because of selection processes are discussed in the next section. The discussion sections reflects on the limitations that were not covered beforehand.

3. Analysing methods and limitations

First of all, since this research concerned a case study. The biggest limitation was to obtain local specific data that was up-to-date and reliable. This accounted for both qualitative and quantitative data. Especially, since due to the pandemic, visiting the city, doing observation and interviewing people in person was not an option. This is a compromise that always exists when conducting research. On the one hand, conducting large scale research with plenty available data, but mostly come to generalised, non-location specific conclusions. Or on the other hand, focus on a local case for which often limited reliable data is available. Local specific data can be collected first handed, which is time consuming and costly. Or secondary data can be obtained, which often means taken assumptions when local data is not available. Since this study used secondary data, the availability of the data and the necessity to make assumption were the major limitations, for both the qualitative and quantitative methods.

The qualitative methods mainly consisted of desk research based on academic and institutional literature, and experienced two major limitations. First, data was regularly not available on local scale. However, local characteristics on the energy infrastructure, political dynamics, and socio-technical systems were valuable. Therefore, assumptions were made based on national (or even global) literature. Second, some local reports focussing specifically on Almaty were available. However, the amount was limited, so reliability of the content could not always be verified. Although, two fundamental reports were supported by the city council, international institutions and field experts. Besides, most data could be compared to national or even global data. But still the verification of data remained a limitation.

Quantitative methods experienced the same limitations of local data availability, and therefore the necessity of making assumption. Four major quantitative analysis are conducted to explore the CtG-transition and to compare with renewable alternatives, namely a financial comparison on project investments and LCOE, an spatial analysis of renewable alternatives, a carbon reduction comparison, and an analysis of electricity reliability and peak demand for renewables. Collectively, the analysis represent three aspects central to the energy transitions; energy security, affordability and sustainability (IEA, 2020b). These aspects are also frequently recurring in policy documents of Almaty (World Bank Group, 2017, 2018). The analysis together aimed to cover these three principles, for which the methods and limitations are elaborated on below.

Financial analysis (energy affordability)

As for most projects, financial aspects are important in Almaty's CtG-transition. This was Almaty's main reason for using CHP-2 as main production source, as coal had to lowest production costs. However, the negative external effects (e.g. air pollution) were heavily impacting the city, and therefore the city council aimed for cleaner options in line with their ambitions.

Various aspects impact project costs, and thus the price of energy. Important are the total installed costs, maintenance and operation costs (M&O) and, for investors, the costs of capital (WACC). A comprehensive method that is widely available and includes all these aspects is the *levelised cost of electricity* (LCOE). This method is used every year by IRENA to compare various energy sources, since it is relatively simple and therefore present an overview of energy technology costs over many countries. It measures the costs of electricity per kilowatt hour taking into account the total installed costs, M&O, WACC, and an assumed life time of the production source (IRENA, 2022). IRENA calculates the LCOE based on specific costs of realised projects. The formula for calculating the LCOE is shown below. Though, during this research, results of IRENA (2022) are used for comparing alternatives.

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

LCOE = the average lifetime levelised cost of electricity generation
I_t = investment expenditure in year t
M_t = operations and maintenance expenditures in year t
F_t = fuel expenditures in year t
E_t = electricity generation in year t
r = discount rate
n = lifetime of system

Figure 4: Formula of LCOE with explanation of the variables *Source:* IRENA (2022)

However the LCOE does not include all factors involved for investment decisions and it generalises project costs. For example, when other installations are already installed in the area, the relative costs of adding a similar plant is relatively cost efficient. However, installing a new installation, with new grid or infrastructural needs, the costs rise. A method that compares the costs that are avoided by installing a specific technology is the *levelised avoided cost of electricity* (LACE). In general when you are replacing an expensive alternative, the LACE are higher, and when you are replacing a inexpensive alternative the LACE are lower. This often means that current fossil-based (and especially coal-based) power plants are relatively expensive to replace, since these costs are relatively low. For LACE comparisons are better to compare specific generation alternatives. However, for these comparisons local specific data is required. Besides, the LACE is less relevant in Almaty's case since the coal-based energy plant (CHP-2) is being replaced despite the alternative.

For these reasons, despite its limitations, this research used the LCOE to conduct financial comparisons between energy alternatives. Since local data is not available for cost analysing methods, which is required for LACE, while data availability of numerous global projects is available for the LCOE. Besides, the LACE is assumably less relevant in this case, due to aforementioned arguments.

Now it is reasoned that the LCOE is a suitable method to compare energy production sources, it is important to be aware of some specific LCOE limitations. Firstly, the LCOE oversimplifies project costs and project specific context. Every project has specific costs depending on the specific area, therefore these cannot be compared generally beforehand. Within that specific area for example, certain financial standards are leading and energy policies vary, such as specific tax benefits, subsidiaries, and local wages (EIA, 2022). Secondly, LCOE ignores the flexibility and inflexibility of certain energy sources, although this can play an important role. Variability of certain renewables can increase project costs due to energy storing systems or balancing techniques. Besides the LCOE calculates with a certain utilization rate. But, this rate depends on the electricity demand over time and the existing resource mix in the area (EIA, 2022). Third, the LCOE does not take externalities into account. For example, changing policy to tackle negative externalities of fossil fuel energy can favour renewable energy implementation. The socio-technical and political aspects can be decisive despite the fact that it is hard to account for them in a formula. Uncertainties such as, future fuel prices, future policies and trading relations may lead to divergent investments decision. Lastly, the LCOE excludes project risks, though this is important for financial decision making. Renewable energy production is not largely integrated with Almaty's energy system yet, which could bear extra risks. However, volatile energy prices can increase fuel prices for fossil fuel energy. These kind of risks are not concluded in the LCOE .

Despite these limitation, the LCOE comprehends many variables and therefore is quite elaborated, and represents future trends relatively good. The LCOE generates a broad picture of costs per specific energy source.

Lastly, the LCOE for Kazakhstan (or Almaty) are not available. Therefore future LCOE references are based on prices of China and Europe , and presented as a range. China and Europe are selected because of Kazakhstan's geographical location, some comparable natural circumstances and the fact that these two countries are the most important trading partners. Therefore knowledge, techniques and financial resources are likely shared, but also their trading standards are probably demanded. Besides, production costs are lower in China than in Kazakhstan, while the wages of Kazakhstan are lower than in Europe. Moreover, transportation costs are probably lower than for Europe, but higher that for China. Therefore, the average LCOE of China and Europe is expected to realistically approach the LCOE of Almaty. Sometimes, when data is available, a specific country in Europe is selected since the natural characteristics are expected to better represent Almaty, for example solar energy in Spain.

Spatial analysis (energy security and affordability)

The spatial analysis presented an impression of total space required to compensate the energy CHP-2 generates every year by renewable alternatives (solar and wind), taking energy losses into account. For this analysis four steps are taken, that all contain assumptions and limitation that need clarification. 1.) Identifying and selecting renewable options for Almaty, 2.) determining the ratio of various renewable energy options, 3.) calculate the required energy to compensate for CHP-2, and 4.) calculate the needed space for the required amount of installed capacity.

Step one consisted of exploring various renewable energy potentials nearby Almaty. Academic literature, energy modelling tools (e.g. ThinkGeothermal, SolarGIS, Global Wind Atlas) and institutional reports were used to explore various renewable options and the potential they contain for future implementation. Step two determined an optimal balance between various renewable options as alternative for CHP-2. Academic literature and the model.energy tool were used to determine a balance between renewable energy sources. The ratio is not fixed, and adapting it is merely a matter of prioritizing criteria (e.g. capital investment costs, energy balance, etc.). In step three the required amount of electricity to compensate CHP-2 is calculated. However, since the renewables (wind and solar) only generate electricity, the amount required to transform electricity to heat was calculated. These calculation are based on assumptions, since specific information was missing. These assumption are based on Almaty's current loss rates, energy reduction measures planned for 2030, and converting power-to-heat efficiencies. Step 4 determined the required energy demand into needed installed capacities for renewable alternatives. Since empirical local data was not available, energy modelling tools are used to calculate the required land areas. The used energy modelling tools are SolarGIS for solar energy, and Global Wind Atlas for wind energy. These models calculate local energy yields for wind or solar energy, based on local data and local yearly averages. For solar this means local solar irradiation intensity, yearly average sun hours and assumed inefficiencies (dirt and transmission). For wind this mainly entails annual wind speed averages. The expected averages per installed capacity (wind and solar) in specific areas are subsequently calculated into required area sizes. For required land size per installed capacity it is assumed that the global averages of IRENA (2022) are applicable for Almaty as well.

Expected limitations within these steps mainly entailed the presumed energy loss rates on planned energy measures, assumptions based on IRENA (2022) global averages, expected efficiency rates for power-to-heat conversion, and land availability for renewable energy installations.

Carbon emission analysis (energy sustainability)

Since Almaty's main goal of the CtG-transition is to reduce air pollution, analysing future carbon emissions is relevant. Besides, the cities policy of the green economy (2013) and the GCAP (2020b) both promote cleaner energy and a less energy intensive economy.

Various methods exist to measure carbon emissions. For this research we compared two techniques. A simple absolute measuring method and life cycle measuring method (European Commission et al., 2020; Varun et al., 2009). During this research a simple carbon emission measuring approach was selected for the purpose to get an impression of the emission per scenario within the time constraints. Therefore the absolute carbon emissions are measured during the expected years of operations (European Commission et al., 2020). With this method carbon emissions arising from production processes, transport and other secondary process are not included. For such calculation *life cycle assessments* are required (Varun et al., 2009). Although, this method in general is more specific, the calculation are beyond the scope of this research. Though, overall, the total carbon emissions emitted during the lifetime of an installation is significantly lower for renewable plants than for gas-fired plants. With emissions of gas-fired plants around 607 grams of CO_2 per kWh, solar PV between 9.7 and 250 grams CO_2 per kWh, and wind between 9.7 and 124 grams of CO_2 per kWh in 2009 (Varun et al., 2009).

There are two limitations to this method. First, as mentioned, it is simplified calculation of the carbon emission, excluding the full life cycle emissions. Second, the carbon emission rates per year are based on a single source, the *Energy Efficiency Transformation* report of the World Bank Group (2017). Though, the overall carbon emission reduction of a CtG-conversion is normally around 50%, which is near the 46% from the report. Taken these limitations into consideration, it is expected the method represents a realistic view of the carbon emissions.

Baseload and peak demand production analysis (energy security)

Fourth, the impact of the RES scenario on the energy security is measured. A constant and reliable electricity network are a prerequisite for alternatives. The reliability and constancy of the electricity network is measured by two fundamental concepts: the baseload and the peak demand.

Baseload can be defined as the constant minimum amount of electricity demand. First, the baseload demand covers certain industrial processes that are constantly active, but also residential appliances such as refrigerators, freezers and appliances in stand-by mode. Secondly, an substantial share of the demand is the result of simple statistics, since (especially in urban areas) 24-hours-a-day somewhere, someone is using electricity. At any moment people charge devices, use washing machines, and switch on lights. These two factors results in a minimum constant required amount of electricity, the baseload (EIA, 2021; IRENA, 2015).

Peak demand is more straightforward and refers to times during the day where most energy demand exists. Times of peak demand differ per global region, since different circumstances lead to different electricity demands. For example, seasonal characteristics that influence heating and cooling activities are important factors determining peak demands (EIA, 2021; IRENA, 2015).

Historically, baseload electricity was typically produced by fossil fuel sources (e.g. coal and gas), since production was assured and variable costs were low (Forsberg, 2019). However, with the energy transition ambitions and increased renewable energy installed capacity, research on renewable energy as baseload producer is increasing as well (IRENA, 2015). Renewable energy production is infamous for the variability of its electricity production since it often depends on natural circumstances (e.g. sun and wind). Logically, variability has to be taken into account for Almaty when installing solar and wind energy sources instead of the CtG-conversion. Therefore the effects on the baseload and peak electricity supply for the RES alternative are analysed.

Limited data is available on standards about baseload or peak demand capacity. Besides, data specifics on the baseload and peak demand of Almaty, or similar cases, were not available. Therefore, although this is an important aspect for energy security, the starting point of the analysis is based on assumption. According to IRENA (IRENA, 2015), typically the baseload consists of more than half of the total yearly electricity demand. For now we assume a baseload of around 60% of the annual electricity demand, although is probably is less. Besides, complementary RES, such as wind and solar, are also providing a certain baseload since almost always there is some wind or solar energy generated. . Although, this is not measurable and therefore not taken into account, it is an important aspects to consider. IRENA (2015) show a baseload of around 40% of its peak generation for solar and wind energy between 2012 and 2015.

For peak demand, in general, baseload consists of approximately 50% of the peak electricity demand (IRENA, 2015). When comparing to other countries, Germany’s baseload consist of around half the peak load capacity (IRENA, 2015). And in the US peak demand during summer increasing around 75% (EIA, 2021). For Almaty it is assumed that the baseload is half of the peak demand, and thus electricity demand increases 100% during peak hours.

The analysis of baseload and peak production consists of various assumption and should be analysed thoroughly with local data and knowledge. On the one hand the baseload and peak load scenario could be more negative, but on the other hand the constant production rates of current power plants (CHP-1, CHP-3, HPP-1 and HPP-2) are also not precisely known. Besides, increased energy import by KEGOC could be an option for a transition period.

Conclusive, this method provides an impression of the current baseload and peak demand capacities, but these should be considered as a starting point for in-depth local research and exploring the possibilities.

IV. Introduction to Almay's CtG-transition

The CtG-transition is one aspect of various energy transition measures. Others measures are: stimuli for RES implementation, increased building energy efficiency, and increased efficiency of energy infrastructure (transmission and distribution). Eventually these measures should increase the cities energy efficiency and sustainability, with the ultimate goal to become energy neutral in 2060. However, conversion towards gas-based energy is a temporarily transition measure towards a carbon neutral energy system (IEA, 2019b; Stephenson et al., 2012). The CtG-transition of Almaty fulfils this role as well (Samruk Energy, 2022c). This section introduces specifics of the CtG-transition and provides the framework for further analysis on its place in Almaty's wider energy ambitions.

1. Context of the CtG-transition

The CtG-transitions concerns the conversion of CHP-2 (510 MW) from coal-based to gas-based energy production by 2025 and infrastructural improvements. The conversion is considered as a priority investment to be implemented (RWA, 2021). CHP-2 is located in the western area of Almaty, almost directly connected to the Alatau district. The total site area covers 506 ha, divided by the CHP-2 industrial area (93 ha) and three ash dump areas (413 ha) (Samruk Energy, 2022c). See figure 5 for an overview of the power plant site.

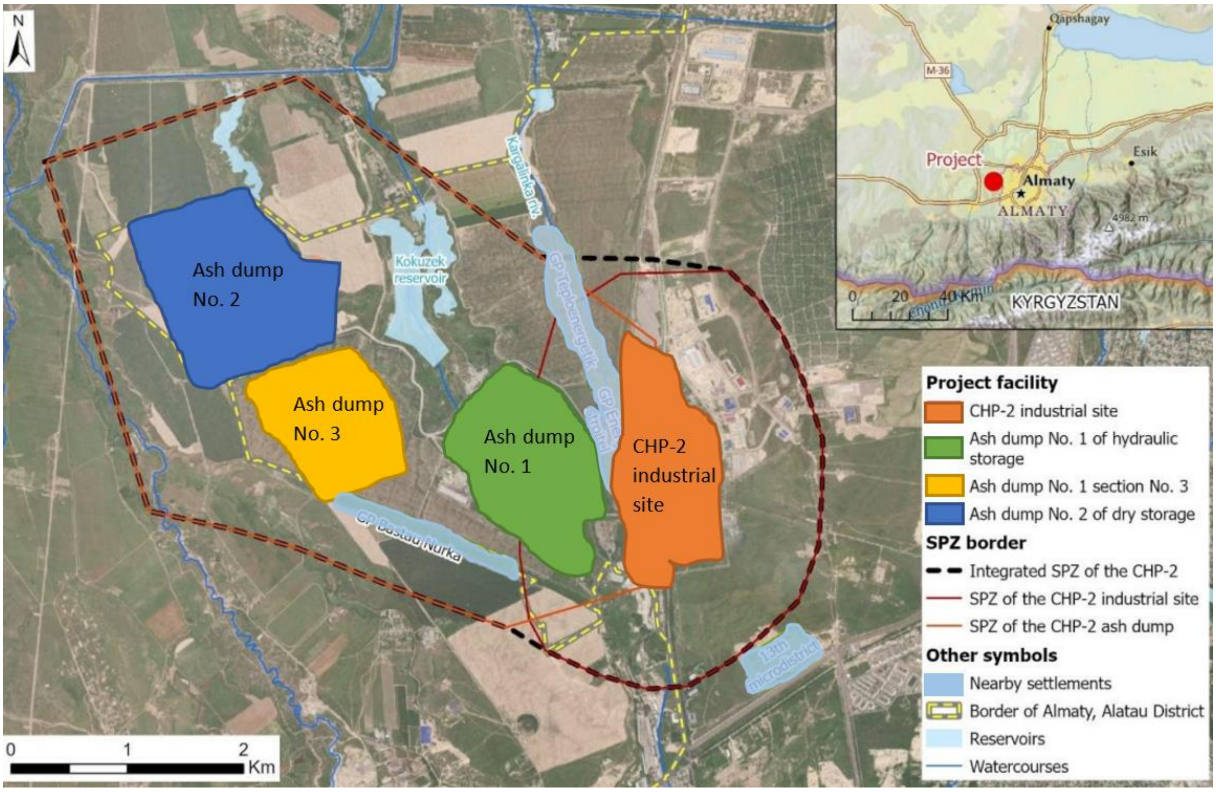


Figure 5: Total area used for energy production of CHP-2 site
Source: Samruk Energy (2022)

With a generating capacity of 510 MW, CHP-2 is significantly the biggest power plant of the city. Generating around 37% of the cities electricity and 48% of the cities heat demand, with an annual coal consumption of 2.5 million tons which emit circa 6.5 million tons of CO_2 (Samruk Energy, 2022c; World Bank Group, 2017).

The CtG-transition is mentioned in various transition documents of Almaty. The *Technical Assessment Section* (TAS) of the GCAP (produced by the municipality, EBRD and consultants) and the *Resettlement Framework* (produced by Samruk Energy, ALES and EBRD) are the most recently published documents concerning the CtG-transition. The former was published in Juni 2021 and the latter in February 2022 (RWA, 2021; Samruk Energy, 2022b).

2. Goal of the CtG-transition

CO_2 reduction is the primary goal of the CtG-conversion, aiming to cut emissions down by 46% (c. 3 million tons CO_2) and to completely abandon emissions of particulate matter and NO_x. Avoiding nitro oxides (NO_x) is essential since 24% of adults and 57% of children suffer from chronic pulmonary disease, significantly higher than Kazakhstan's average and 2-3 times higher than other urban areas of CIS (Commonwealth of Independent States) (EBRD, 2022). Total project costs are c. 680 million USD (325 bln KZT), of which the EBRD finances c. 265 million USD (122 bln KZT).

3. Planning of the CtG-transition

The perceived planning consists of various phases in which CHP-2 eventually is fully converted to a gas-based fire plant, generating heat and electricity. The first phase consists of replacing a 200 MW unit, and takes approximately 4 years. The second phase should be completed in around 2 years. In total the CHP-2 conversion project is planned to be realised in 6 years (Samruk Energy, 2022c). Although the plan was to finish the conversion in 2025, on the 28th of February 2022 the plans for conversion were still not officially approved (Samruk Energy, 2022c). Besides, in June 2022 a resettlement framework with project specifications was published. According to this document, the project is in its 'initial stage of development' consisting of pre-feasibility studies and national public hearings. Moreover, mid-November the Board of the EBRD plans to review the project documentation and funding plans, and take a vote. If the vote passes and the project plans and fundings are accepted the implementation phase starts (EWS, 2022). Therefore, if construction phases develop according to plan, and we assume that the project will start in the beginning of 2023, the project would be finished mid-2027. See table 5 for an overview of specifics on the CHP-2 conversion.

4. Overview of the CtG-transition

Type subject	Amount	Unit
Technological characteristics		
Installed capacities	510	MW
Energy production (EET)	6,267	GWh/year
Environmental impacts		
Coal consumption (current)	2,500,000	tons/year
Gas consumption (after conversion)	1,100,000	Nm^3/year
Current CO_2 emissions	6,500,000	tons CO_2 /year
Estimated CO_2 emissions after conversion	3,500,000	tons CO_2 /year
Percentage emissions reduction CtG-conversion	46	%
Financial facts		
Total project costs	680,000,000	USD
EBRD financial support	265,000,000	USD

Table 5: Overview of the characteristics of the CHP-2 coal-to-gas conversion

V. Current energy situation Almaty

Information on Almaty's current energy situation is required in order to analyse the CtG-transition from a multi-perspective approach. This section sheds light on the energy situation of Almaty and planned energy reduction measures.

1. Characteristics of Almaty's energy situation

First of all, as nearly all upcoming countries and cities, Almaty uses vast amounts of fossil fuel sources in an inefficient manner. Economic growth has led to an increase of primary energy consumption and a growing electricity demand (Karatayev & Clarke, 2016). This is also a national trend (See figure 6).

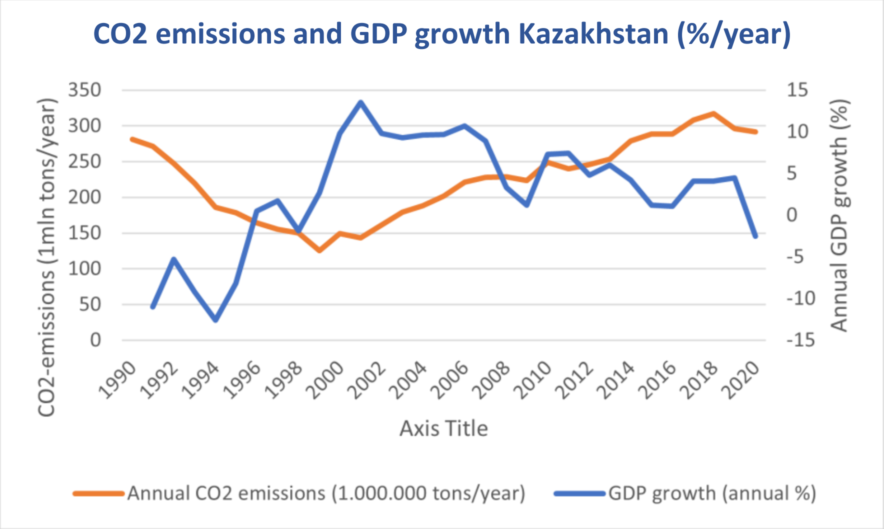


Figure 6: CO_2 emissions and GDP growth per year for Kazakhstan (1990 - 2020)
Source: Data retrieved from Our World in Data (2020) and The World Bank (2020)

Compared to other Kazakh cities, Almaty has a relatively high connectivity of residential buildings to natural gas supply. Though, it still depends for around 60% on coal-based energy (Aidapkelov, 2020; World Bank Group, 2017). With one of the largest coal reserves and forthcoming low costs, it is hard to breach the path dependence of a fossil fuel based infrastructure. However, various laws, strategies and reports of Almaty prove the motivation and plans to transform towards cleaner alternatives and efficient energy usage, mainly motivated by local health implications of fossil fuel usage.

Characteristics of current energy infrastructure are dominantly influenced by aged technologies and outdated urban structures, and therefore often lack efficiency, clean(er) technologies and sufficient insulation. The intensive usage of many out-dated and obsolete private cars, trucks and buses, and the emissions of nearby coal fired power plants and combustion by households, are considered to be the main contributors to poor air conditions for citizens (Assanov et al., 2021; Carlsen et al., 2013). The effects are even more severe due to climatological circumstances, as the geographical position of Almaty results in calm weather and strong inversion-layers that suppress vertical exchange, which results in limited air ventilation and thus lead to high emission rates in the air (Zakarin et al., 2021). The World Bank (2017) concludes that Almaty, with a PEC of 24,907 kWh/capita in 2015, scores low-to-medium compared to peer cities. They mention four main reasons for it:

1. Climatological circumstances that require a long heating period
2. An abundance of available coal and gas resources
3. Necessary industrial, service and trade activities that require vast amounts of energy
4. High losses in energy (electricity and heat) generation and distribution, and inefficient energy use in the end-users phase

In the city, four sectors can be distinguished that contribute most to the energy intensity: transport, energy production and distribution, build area, and industry & commerce (World Bank Group, 2017).

The transport sector, with intensive use of public and private vehicles, has been a major issue for the energy intensity, air pollution and negative public health effects. Transport consumes 37% of the total energy demand with diesel and gasoline usage. The reasons are high rates of private car usage and a heavily outdated vehicle fleet. First, private car usage accounts for 98% of total transport energy consumption. Second, the vehicle fleet has an average of 8 years old (RWA, 2021). Lastly, 95% of all cars and busses is gasoline-based (See figure 7 & 8). (World Bank Group, 2017).

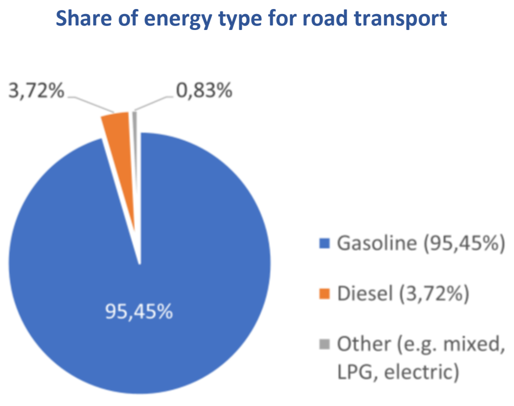


Figure 7: Share of energy type for road transport
Source: The World Bank, 2017

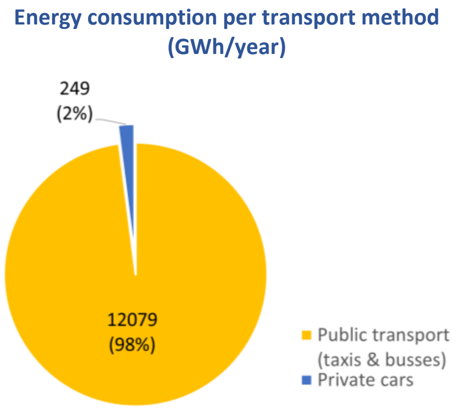


Figure 8: Energy consumption per transport method
Source: The World Bank, 2017

Second, the next most consuming energy sector is the energy production and distribution sector. Electricity and district heating consist of respectively 18% and 19% of Almaty's final energy consumption. The electricity and heat production sector is characterised by obsolete and highly inefficient infrastructure and power plants. Specifics concerning this sector is discussed in coming section.

Third, nearly all electricity and district heating is consumed by the build area, including residential, municipal, and industrial & commercial buildings (See figure 9 and 10). The housing stock is characterised by around 80% 'old' buildings, that are poorly insulated and consume a lot of energy. The total build area consumes more than a third of the primary energy demand, namely 16.4 TWh of a total of ca 42.1 TWh. Around 50% of the energy savings of the *Energy Efficiency Program* are resulted by improving the build area, including residential, municipal, and commercial & industrial buildings. More details on the build area are provided in the next section.

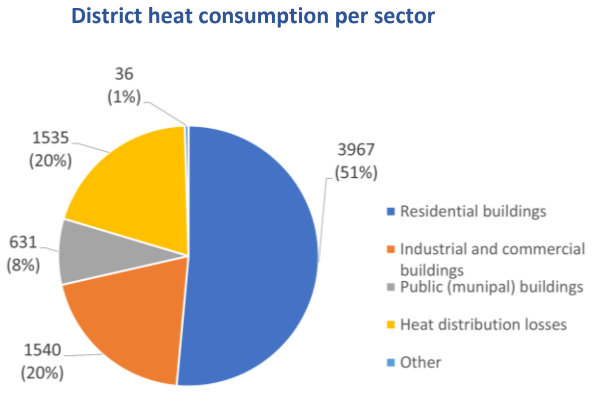


Figure 9: District heat consumption per sector
Source: The World Bank, 2017

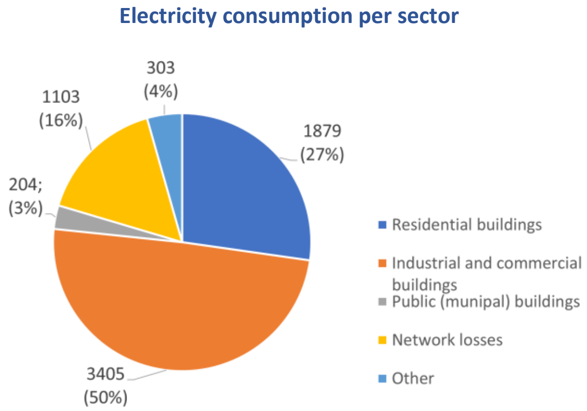


Figure 10: Electricity consumption per sector
Source: The World Bank, 2017

The commercial and industrial activities in Almaty are combined in one sector with regard to energy analysis, because the share of industrial activities is relatively small. Industry accounts for only 5% of Almaty's total Gross Regional Product (including the 'food industry'), compared to more than 50% from the service sector, 35% from trade, and 5.5%. Moreover (World Bank Group, 2017). The major challenge for the industrial and commercial is increasing energy efficiency for the build area since most energy is consumed in district heating (19%) and electricity (42 %) (World Bank Group, 2017).

Overall, this research focusses on the energy production and distribution sector and the build area (i.e. residential, public (municipal), and commercial & industry buildings) sector, as these sectors consume the absolute majority of energy related to the CtG transition, namely electricity and district heat. The energy consumption of the commercial & industrial sector is included in the build area, because of their substantial consumption of electricity and district heating. The transport section is thus excluded from the analysis, despite their extensive energy consumption. This is because this energy include gasoline and diesel, which is not related to the CtG-transition. Next section elaborates on these two sectors in order to collect information on the CtG-transition.

2. Energy production sector

Electricity and district heat production

The energy production sector of Almaty is very energy intensive and completely fossil fuel dependent Besides 60% of the DH-system is depreciated and 45% is more than 25 years old. In total around 18,800 GWh/year of energy is involved in the production process of electricity and heat for consumers in Almaty, this includes heat distribution losses, network losses, and internal energy usage. The final share of energy loss and internal usage is around 22%. In total the electricity and heat production industry uses approximately 60% of coal and 40% natural gas, and an insignificant percentage of heating oil (mazut) (See figures 11 and 12).

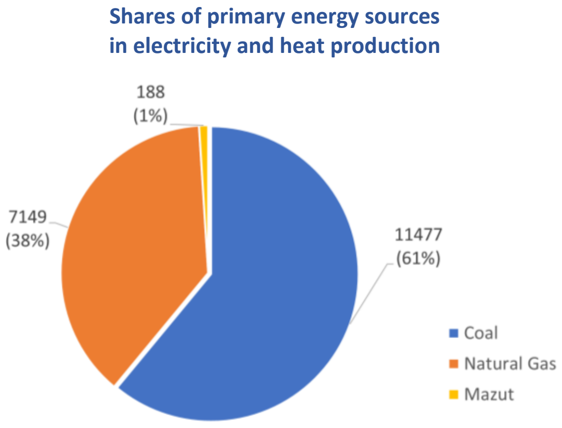


Figure 11: Shares of primary of energy sources in electricity and heat production
Source: The World Bank, 2017

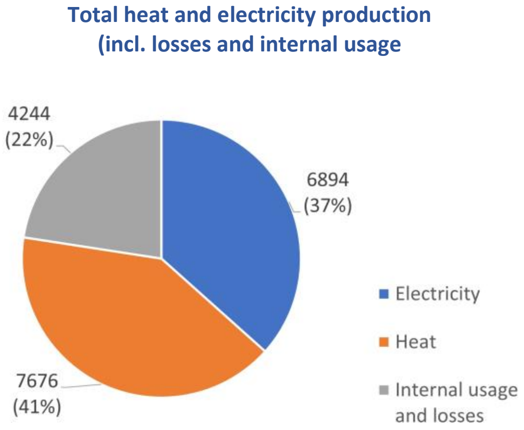


Figure 12: Total amount of heat and electricity production (incl. losses, and internal energy use)
Source: The World Bank, 2017

The energy production and distribution system, that generates heat and electricity, is a complex system. The majority of heat and electricity is produced by the Almaty Energy System (ALES). ALES produces electricity and heat, mainly through three combined heat power plants (CHP-1, CHP-2, and CHP-3) and marginal share from two hydropower plants (HPP-1 an d HPP-2). The Kazakh government is sole shareholder of ALES, as it belongs to the state owned Samruk-Kazyna welfare fund. 63% of Almaty's electricity is produced by ALES, and the other 37% of electricity is imported from the **State Kazakhstan Electricity Grid Operating Company (KEGOC)**.

ALES also produces 75% of Almaty's district heat. The other 25% is produced by **Almaty Teplo Kommun Energo (ATKE)**, an organisation under municipal authority (See figure 13 and 14). Distribution of electricity and heat is executed by two separate parties. Distribution to end-users (residents, commercial, public and industrial parties) is done by **Almaty Zharyk Company (AZhK)** for electricity and **Almaty Teplo Seti (ATC)** for heat**.** An overview of the system is provided in appendix E.

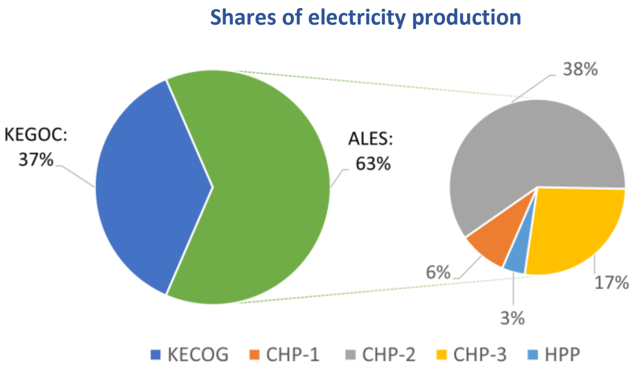


Figure 13: Shares of electricity production Almaty (left) and shares of ALES electricity production (right)
Source: The World Bank, 2017

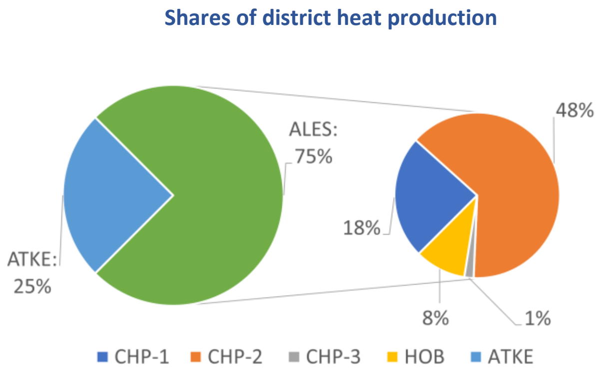


Figure 14: Shares of district heat production Almaty (left) and shares of ALES district heat production (right)
Source: The World Bank, 2017

The share of heat and electricity production varies per source. On average ALES produces around 43% of electricity and 57% heat, with CHP-1 and CHP-3 running on natural gas and CHP-2 on coal. CHP-2 generates the majority of the energy, with 60% of ALES electricity and 64% of ALES heat. The heat produced by ATKE comes from 78 HOB, of which 73 use natural gas, one each using coal, diesel, and electricity, and two are oil-based. The imported electricity from KEGOC comes for 90% from Pavlodar-Ekibastuz which produces electricity on coal, and 10% from hydropower plants in the Almaty region (Global Energy Monitor, 2021, 2022).

Energy production losses

Almaty's energy sector is characterised as highly inefficient, experiences high production and distribution loss rates. Overall efficiency losses in the heat sector account for 20% (ALES + AKTE) and 16% in the electricity sector (ALES + KEGOC) (World Bank Group, 2017). Efficiency rates vary highly per source, with CHP-1 being most efficient (81%), second CHP-2 (60%) and CHP-3 (38%). CHP-3's inefficiency is probably caused by a focus on electricity production, and thus residual thermal energy is not used for district heating. The energy imported from KEGOC is even less efficient, and pollutes 1.5 times more CO_2 than ALES (World Bank Group, 2017).

Challenges and reduction measures production losses

The main challenge in the energy generation sector is to generate cleaner energy, and increase the generation and distribution efficiency. Experts estimate an increased efficiency potential of 50% by installing generation and distribution technological improvements. For example, HOBs that run on electricity, coal or oil can be replaced by natural gas. (RWA, 2021; Samruk, 2021; World Bank Group, 2017). In the DH-system, rehabilitation and modernisation of heat pipes are the biggest challenge. Efficiency of the heating system can be improved by modernisation and rehabilitation of pipelines, insulation of pipelines, heat regulating valves, automated heat transfer combined with individual automated heat systems (IHS). Lastly, with beneficial climate conditions solar power has lots of potential through solar heating systems and solar power production.

Together all interventions of the *EET* report should lead to reducing **34% of district heat losses** (1712 GWh/year) and **41% power system losses** (1589 GWh/year) in 2030.

3. The build area

Overview of the build area

The build area can best be distinguished in three categories; public (municipal), residential, and commercial & industrial buildings. The amount of houses is depicted in figure 15. The number of houses of the residential area includes around 640,000 apartments. The total housing stock is relatively old, with 80% of old buildings in the residential sector and around 20% new buildings. The older buildings are often poorly insulated and contain inefficient heating regulation systems. Compared to other cities with a same HDI (e.g. Kiev, Sofia, Belgrade and Astana) Almaty is one of the largest heat energy consumers (209 kWh/m^2).

The residential area is the biggest energy (electricity + heat) consumer (53%), followed by the industrial & commercial area (42%). The least amount of energy is consumed by the public (municipal) buildings (5%)(figure 16). However, the industrial & commercial sector consumes the most electricity.

Smart metering, insulation and individual heat regulation are measures that the EET and GCAP reports mention to improve energy efficiency (RWA, 2021; World Bank Group, 2017).

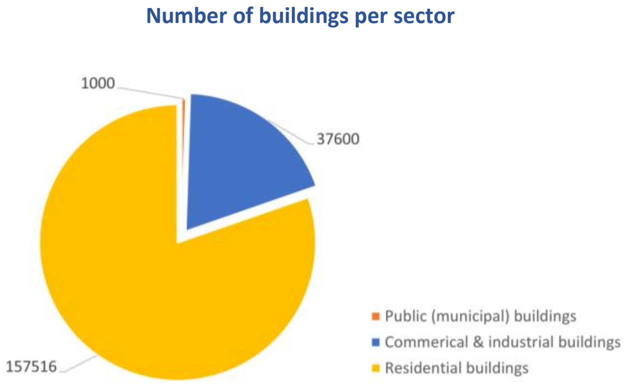


Figure 15: Amount of buildings per sector
Source: The World Bank, 2017

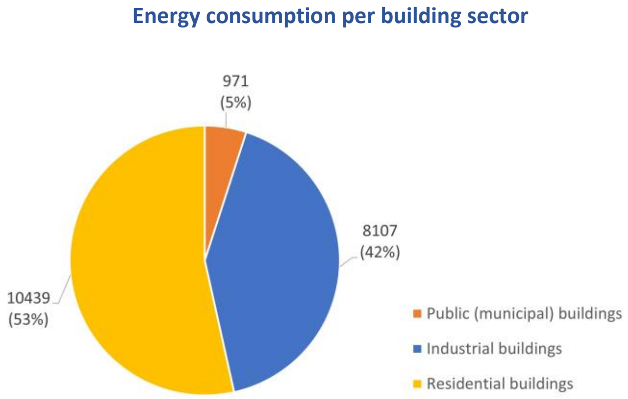


Figure 16: Energy consumption per building sector
Source: The World Bank, 2017

Electricity and heat consumption

The total build area concludes more than a third of the primary energy demand, namely 19.5 TWh of a total of ca 42.1 TWh. The amount and shares of energy consumption per building sector is illustrates in figure 17. The vast majority of energy in the building stock is consumed in the form of district heat, and electricity, and some smaller amounts of solid coal and other fuels (natural gas, LPG, oil). (World Bank Group, 2017).

Another important aspect is that only 72% of households is connected to the DH-network. So, more than a quarter relies on individual heating system for which little data consists. However, it is likely these individual heating consists mainly of a natural gas connection, but also small portions of other sources, such as propane, butane, coal and wood heaters (World Bank Group, 2017). Though, 95% of the apartments is connected to district heating (RWA, 2021). According to the EET program, residents prefer to be connected to the district heating. Connection could be realised through individual boilers

The conclusion remains that nearly two-thirds of the energy is consumed on electricity and district heating of which the majority is produced by coal.

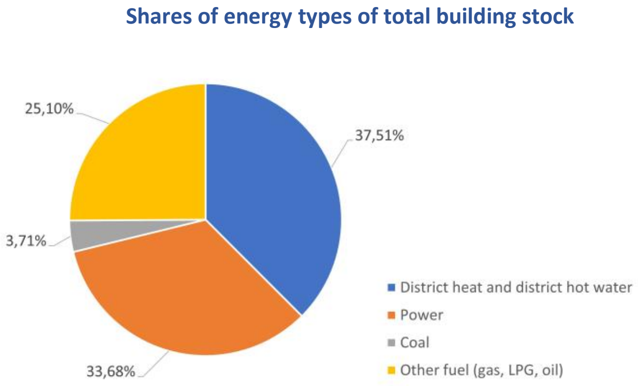


Figure 17: Shares of energy consumption of building stock
Source: The World Bank, 2017

Energy reduction measures

The energy reduction potential in the building stock is substantial with an estimated total energy reduction of 40-50%. Most savings concern technical improvements that simultaneously improve living comforts. Potential measures include heat distribution systems with individual adaptive heat control, insulation of buildings and heat pipes, and LEDs (World Bank Group, 2017). Overall, the EET plans an energy reduction of **42%** (412 GWh/year) for the municipal sector and **31%** for the residential area (3,233 GWh/year) in 2030.

The municipal energy saving program mainly focusses on retrofitting and insulating schools, medical centres and other public buildings. For the residential area the energy efficiency measures focus on individual automated heating stations in multi-story buildings, individual heat meters, retrofitting multi-story buildings, and solar PV on rooftops. Overall building norms and energy efficiency labels should encourage energy efficiency measures for new buildings and renovation projects, and should provide insight on the property characteristics.

3. Energy efficiency measures for production and build area sector

Table 6 presents and overview of the total energy reduction from measures for the district heating, energy sector and build area of Almaty presented in the EET and the calculated reduction. The measures are evaluated and selected for the CtG-transition analysis. Specifications on the measures for all sectors is provided in appendix C.

Overview of energy efficiency measures				
Sector	District heat	Electricity	Build area: Residential buildings	Build area: Public buildings
Energy saving (GWh/year)	1,712	1,589	3,233	412
Energy saving (%)	34%	41%	31%	42%

Table 6: Overview of total energy reduction in 2030 for district heating, electricity and the build area.
Source: The World Bank, 2017

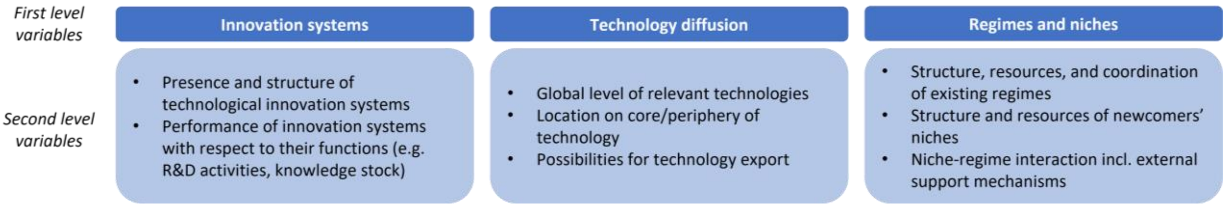
VI. Political dimension

Energy policies and political dynamics Almaty

The political context in which societal development takes place is important for understanding decision making processes and implemented policies. In order to understand, analyse and develop pathways for the CtG-transition, an analysis of political dynamics and policies is provided. The policy overview concerns international, national and local policies and presents an overview of political commitments and goals, clarifies strategical choices and therefore sets the political arena.

The research framework assisted on analysing the political context basedich on the three first-level variables: *state goals, political interests,* and *institutions & capacities.* The first-level variables consist of each three varying second-level variables (see figure 2 (p. 17) and table 7). Each policy level, international, national and regional, is analysed these variables.

This chapter is a summary of the complete analysis on the political dimension. The complete analysis is added in the appendices



First level variables	Innovation systems	Technology diffusion	Regimes and niches
Second level variables	- Presence and structure of technological innovation systems - Performance of innovation systems with respect to their functions (e.g. R&D activities, knowledge stock)	- Global level of relevant technologies - Location on core/periphery of technology - Possibilities for technology export	- Structure, resources, and coordination of existing regimes - Structure and resources of newcomers' niches - Niche-regime interaction incl. external support mechanisms

Table 7: First and second level variables related to the political domain of energy transitions
Source: Cherp et al. (2018)

1. Policy goals and ambitions

International energy ambitions and policies

International agreements and treaties foster international cooperation, and they set directives on the development of countries, and therefore cities. The NDCs of the Paris Accord are a clear example for this (United Nations, 2021a). According to the World Bank Group (2017) Kazakhstan increased its sustainability efforts in 2010 by putting energy efficiency and climate mitigation on the political agenda. The goals were set to decrease the energy intensity of the economy by **10% in 2015** and **25% in 2020** compared to 2008. The 2015 goal is likely met with a reduction of 15% (Our World in Data, 2020). However, the 2020 goal is arbitrary. On one side, the energy intensity increased in 2018 to a reduction of 10% compared to 2008 (Our World in Data, 2020). But on the other side, in 2019 a reduction of 21% compared to 2008 was achieved (KNOEMA, 2019).

Kazakhstan's most important international political commitment to the energy transition is signing the Paris Climate Accord (2015) in 2016, which legally binds Kazakhstan to reach an economy wide absolute **15% GHG-emissions reduction from 1990 levels by 2030.** Besides, Kazakhstan announced a motivation to increase their mitigation ambitions to 25% from 1990 levels when additional international support, finance access to international carbon markets, and low carbon technological sharing were provided (World Bank Group, 2017). However, after a downfall of carbon emissions from 1990 -1999 due to economic stagnation, emissions steadily increased since 1999 (see figure 18) (Ministry of Energy, 2015). Growing carbon emission are directly correlated to GDP growth, which is a major goal of the government. A carbon decrease with growing GDP trend has not been observed yet, and therefore, major adaptations are required to achieve the 2030 goals. (Our World in Data, 2020).

Secondly, Kazakhstan incorporated the United Nation's *'2030 agenda for sustainable development'* in two national policy documents (RWA, 2020b). The agenda includes at least four goals directly related to Almaty's energy transition. Unfortunately, clear factual commitments are not included in this agenda.

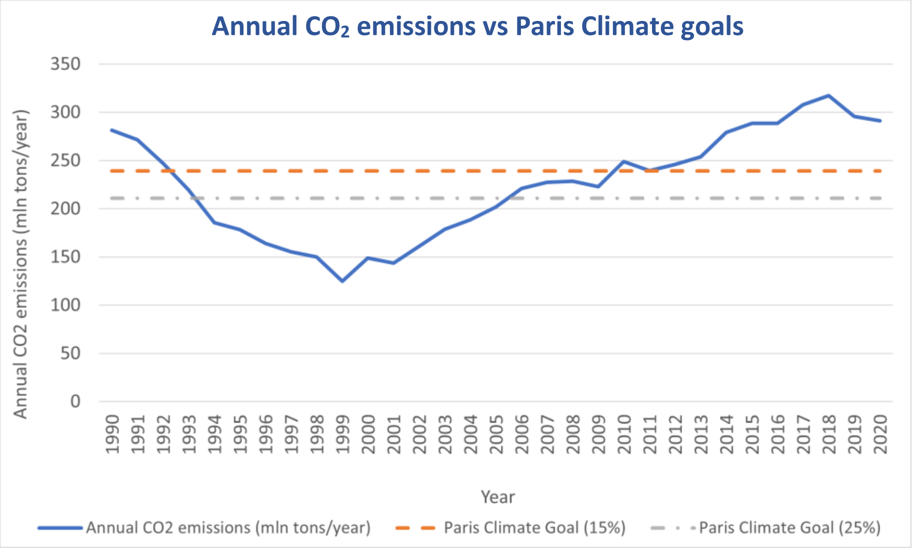


Figure 17: Carbon emission compared to the Paris Climate Goals
Source: Our World In Data, 2020

Thirdly, trading relations are implicitly and explicitly influencing national policy. The EU is Kazakhstan's most important trading partner with a significant 40% of its external trade. Currently, 80% of Kazakhstan's energy exports go to Europe, mainly petroleum (products) (European Commission, 2022). However, regarding the Clingendael Institute (2021), between 2015 - 2030 imports of coal will drop by 71-77%, oil 23-25%, and natural gas by 13 - 19%. After 2030, expectations are that imports decrease more drastically, with oil imports dropping 78-79% and natural gas 58-67% (Leonard et al., 2021). These drops are dramatic for the economic stability of Kazakhstan since their gross domestic product (GDP) relied for 21% on fossil fuels in 2020, and around 70% of all its exports (World Bank, n.d.).

Besides, the EU is also the single biggest investor in Kazakhstan, representing 48% of total (gross) foreign direct investment (FDI) flows and around 60% of total net FDI stocks in 2018 (EEAS, 2020). Policy influence via these investments is explicitly mentioned by the EBRD (EBRD, 2020, P. 1):

> *"We combine investments with policy dialogue to develop a good regulatory framework for sustainable energy, water and resource use. Through EBRD Green Cities, we support municipalities in developing Green City Action Plans to address key environmental challenges and to invest in sustainable infrastructure."*

The GCAP of Almaty is a relevant example of policy steering investments of Kazakhstan and Almaty. The EBRD has invested 1.37 billion euros in green economy developments between 2015 - 2020.

In 2015, these trading relations, were intensified with an increased (trade) collaboration between Kazakhstan and the European Union (EU): the *Enhanced Partnership and Cooperation Agreements* (EPCA). This also increases the influence of EU's policy frameworks on Kazakhstan's development directions (European External Action Service, 2021). The European Green Deal is probably the most important and related policy linked to energy transitioning since it concerns clean energy production, sustainable industries, and clean buildings. The Grean Deal likely influences Kazakhstan's policies.

National energy ambitions and policies

The 'Strategy Kazakhstan 2050' provides development goals and challenges for the coming decades. The main goal is to enter the world's top 30 most developed countries in 2050. This goal forms the centre of political decision making in which economic growth is the key performance indicator (Nazarbayev, 2012, p. 2). See appendix D (p. 108) for an elaborated reflection of the *'Strategy*

Kazakhstan 2050'. On the one hand this focus on economic growth is counter intuitive to sustainability policies and sustainable development goals as Kazakhstan's steep GDP growth was merely the outcome of exploiting exhaustive natural resources (IEA, 2021g). On the other hand, does the strategy focus on results in 2050 for which ten complex challenges are defined, that demand a reform of current economic behaviour. The strategy proclaims that developed countries heavily invest in green energy technologies, and estimates a **50% renewable energy production in 2050**. Another challenge is the exhaustion of natural resources. Due to its large amount of natural resources Kazakhstan holds a strong trading position. However, the strategy admits that, although natural resources are crucial for economic growth, they are limited, and therefore should be managed efficiently and carefully. Therefore, the ambitions is to transform natural resources into a sustainable and efficient vehicle for economic growth (Nazarbayev, 2012). Interestingly, various scholars concluded the favourable natural climate conditions of Kazakhstan for renewable energy production, especially for wind and solar power (Bogdanov et al., 2019; Karatayev & Clarke, 2016).

In 2013 the government presented the *'Concept for the Transition of Kazakhstan towards a Green Economy',* Green Economy Concept (GEC) in short. The GEC pleads for economic transformation motivated by various deficiencies in current economic standards and activities. First, billions of economic losses occur due to inefficiencies in natural resource exploitation. Second, an inadequate energy tariff pricing systems disincentivises technological development and innovation. Third, current economic (industrial) activities have severe negative environmental consequences. For example, almost one third of agricultural land is degraded or under significant threat of being so; a forecasted sustainable water sources shortage of 13-14 billion cubic meter in 2030; and sever negative health effects caused by environmental contamination and air pollution (Nazarbayev, 2013; PwC, 2021).

The GEC was adopted in 2013 and set clear goals for the water sector, energy sector, air pollution and waste recycling. These are the latest binding national goals concerning air pollution and clean energy production with the main energy goals of an share of RES in electricity production of **no less than 3% in 2020, 30% in 2030,** and **50% in 2050** (Nazarbayev, 2013). Realisation of the 2020 is probably not met, even when hydropower is included, since hydropower provide no more than 2% of annual electricity (ITA, 2021). Although, according to PwC (2021), nationally hydropower provides around 9%, while solar and wind both generate around 1%. However, probably this relates to the installed capacity instead of realised production. Locally, Almaty obtains around 4% of their electricity from hydropower (World Bank Group, 2017). However, these plants were already commissioned in 1970 (HPP Kapshagai) and 2011 (HPP Moinak). Accurate and recent data on shares of solar and wind generation are not available for Almaty.

Regional (city) energy ambitions and policies

Since 2010 various energy related policies have been active in the Almaty region. This section provides a brief overview. Appendix D provides the complete overview. The "*Law on Energy Saving and Energy Efficiency"* (2012) was introduced to obligate energy consumers that exceed 1,500 toe/year annually to report and submit energy efficiency plans (RWA, 2020b). Around 7,500 organisations exceed the limit, with 4,300 governmental organisations, 2,500 public actors and 765 private entities (World Bank Group, 2017). Besides, a State Program "*Energy Efficiency-2020"* was approved, as well as the *"Strategic Development Plan until 2020*". The municipality is responsible for planning and execution of these energy efficiency programs for the city. However, despite these laws and strategies the most clear energy goals seem to be the ones of the Paris Climate Accord (World Bank Group, 2017). The *"Law On Supporting the Use of Renewable Energy Sources"* established a feed-in-tariff policy in 2013 for the coming 15 years to support RE implementation in de area. However, according to various sources, feed-in-tariffs are not competitive with traditional energy sources (Karatayev et al., 2016; Laldjebaev et al., 2021; PwC, 2021).

Another local strategy that included energy measures as well was the *"Almaty 2020 Development Program"*. The program included energy measures to modernise and upgrade heat supply, install natural gas-based equipment in CHP-1, and installing heat pipes and boilers in neighbourhoods poorly connected to the heat system. The program also set goals to achieve a total of

4.25% renewable energy of total electricity volume and increase to gas supply by 1.2 million m^3/h in 2020 (RWA, 2020b; World Bank Group, 2017). The 4.25%-goal is probably only met when hydropower, consisting of 4% of RES, is included. However, this includes plants from 1970 and 2011, so not much is done to reach the goals. Accurate and recent shares of renewable energy are not available.

Besides, two recent policy documents are published that concern clear energy reduction measures. The **Energy Efficiency Transformation (EET)** focusses on energy consumption reduction measures, to increase the energy service proficiency of the municipality to its citizens, and to mitigate related municipal expenditures. The research mainly focussed on qualitative goals, namely reducing GHG-emissions and Primary Energy Consumption (PEC), prevent energy bills to increase when local public service provider improve their services, and create an attractive environment for private (foreign) investment for energy efficiency measures. An overview of the EET measures is provided in appendix C. The **Green City Action Plan** (GCAP) strives to systematically address (urgent) environmental and urban development challenges, while taking social concerns into deliberation. The plan focusses on seven sectors: transport, buildings, water and wastewater, solid waste, energy, industry and land use (RWA, 2020a). An important (political) motivation to be involved in the green cities program of the EBRD for local authorities is the severe air pollution Almaty experiences (RWA, 2020a). The GCAP identified sectoral challenges, of which six out of eight concern district heating and renewable energy sources with regards to the energy sector. The original plan was to present the final report in September 2021. However, due to various reason, for example the COVID-pandemic, the plan was still not finalised when conducting this research (June 2022).

2. Political dynamics of CtG-transition

The overview of the various binding and non-binding policies, treaties, partnerships and plans provide insights that relate the research framework. This section analysis the political dynamics for the CtG-transition regarding the first and second level variables of the research framework. An overview is presented in table 7 .

State goals

First, binding policies are directly related to the **type of state goals**. On every policy level the plans focus on specific type of goals. Internationally the Paris Agreement is the most important binding energy policy, directly related to the goal: climate change mitigation. Regionally, the EET mostly relates to this, as cleaner energy should decrease air pollution. Furthermore, nationally sustainable energy sources should go hand in hand with state goals as energy security and affordability. The national leading ambitions to enter the top 30 most developed countries directly relates to this. Energy affordability and reliability have clear implications for local policies. Currently, (fossil)energy prices for households are subsided for 33% to assure affordability (OECD, 2014). These subsidies negatively influence penetration of renewable sources to the market. Bolwig et al. (2019) shows that low electricity prices negatively impact the introduction of renewables to the market. However, the importance of affordable energy, and the vulnerability of political stability, became clear at the beginning of 2022, when increased LPG prices (due to lifted price controls), lead to violent protests (CNN, 2022).

There are various **factors affecting the state goals.** The major (negative) factor is the dependence on fossil fuels for internal usage and export. Currently, fossil fuels are of existential importance for Kazakhstan. Overall, Kazakhstan is the world's 9th largest coal, 9th largest crude oil, and 12th largest natural gas exporter (IEA, 2021g). However, international energy transition trends, trading agreements, foreign investments, and future demand decline are factors affecting this situation. Regionally, the investments by the EBRD and the World Bank are major factors affecting the energy goals via their investments. Besides development banks, Almaty aims to obtain an attractive financial climate for foreign investors. Because an improved investment climate can positively affect the goals by attracting foreign (private) investments, which can catalyse the energy transition, and therefore help reaching the goals.

Political interests

Second, with regard to the political interests**, special interests** are most relevant. (Inter)nationally and regionally, demand for fossil fuels is expected to be drastically declined around 2050. Therefore a new focus on economic activity is needed as the major trading partner (EU) moves away from fossil fuels relatively quickly and Kazakhstan committed itself to sustainability goals as well. Though, industrial lobbies profit from the status quo, such as pricing systems for fossil fuels. Investments in fossil fuels result in technological lock-ins, which are further discussed in the socio-technical section. Steering mechanism or adaptation in pricing systems are needed for other energy source to penetrate the market. However, political action is required to change the current energy landscape in Almaty, as the few market leaders do not favour system change due to profitability. But new income streams and (clean) energy production have to be planned carefully to anticipate on coming fossil fuel decline and EU's import standards.

Besides, energy affordability and security are important aspects for political stability. Changing current energy system is fragile, since it cause political unrest and destabilize current situation. However, somewhere in the future the change towards other income streams and clean energy need to be made. Besides, various (urban) residents profit highly by clean(er) energy because it increased the air quality and therefore public health.

Institutions and capacities

Third, the second level variables **state capacity** and **international processes** are relevant. State capacity is closely related to the political stability. The growing GDP is highly related to political stability, and to vision is to remain this growth (Feng, 1997). However, the market and pricing systems causing this growth, constrain implementation of sustainable practices Moreover, regional governments are constraint by limited economic resources. Therefore a long term plan involving attracting financial investments is required. **International processes and agreements** can help in this. The implications of this variable are explained in the second level variable *factors affecting state goals*. The interrelatedness illustrates the complexity of the situation and the involvement of various interests.

3. Energy policy goals and political influences

The political arena is important to understand the status quo, current measures, and to identify challenges when implementing new policies. The two tables below present the most important binding policy goals (table 8) and an overview of political variables of the research framework related to the CtG-transitions (table 9). Some factors impact multiple levels. Unless the impact is highly different, similar factors are mentioned a single time on the largest active level.

Agreement / treaty	Goals / commitments	2020	2030	2050
International				
Paris Climate Accord	Economy wide absolute GHG reduction (from 1990 level)		15%	
National				
Green Economy Concept	Power sector: Share of alternative sources in electricity production[1]	**No less 3%** from solar and wind	30%	50%
	Power sector: Share of gas power plants in electricity production	20%	25%	30%
	Power sector: Reduction in CO_2 emissions in electricity production (2012 levels)	2012 level	15%	40%
Local (city level)				
Air Quality Improvement for the City of Almaty	**Conversion of CHP-2 and CHP-3 from coal-to-gas generated energy**	**2025**		
Almaty 2020 Development Program	**Share of renewable energy of total electricity production**	**4.25%**		

Table 8: Overview of important binding energy policy goals for Almaty in the CtG-transition and energy neutrality ambitions

[1] Renewable sources identified as solar, wind, hydro and nuclear power (GEC, 2013)

First-level variable	Second-level variable	
International scope		
State goals	*Type of state goals*	Paris Climate Accord: binding commitment to reduce the GHG-emissions 15% compared to the 1990 level in 2030
	Factors effecting state goals	Economic dependence: fossil fuel exports highly depend on Europe and China. Current export result in economic growth, which causes political stability.
		Income dependence: major share of economic resources obtained from foreign investors (EU and China). EU responsible for 80% of energy export, 40% of all external trade, and 60% of net FDI.
		Reduced demand: drastically demand decline forces Kazakhstan to move towards other (more sustainable) trading activities. Also if it wants to maintain strong economic partnership with Europe.
Institutions and capacities	*International processes*	International agreement: (non-)binding international treaties (EPCA in specific) steer policy frameworks towards sustainable development which otherwise probable would be hard due to financial dependence on fossil fuel and *technological lock-ins.*
National scope		
State goals	*Type of state goals*	Economic diversification: creating modernised income streams from alternative resources, that are energy efficient, less air polluting, and mitigate negative climate effects.
	Factors effecting state goals	Fossil fuel dependence: export shares highly depend on fossil energy (60% of total export). But, demand will likely reduce coming decade, and thus alternative income streams are needed.
Political Interests	*Special interests*	Industrial lobbies: energy pricing systems and current energy demand makes fossil energy more profitable than (sustainable) alternatives. Therefore political steering mechanisms and other stimuli to invest in sustainable business cases are needed.
		Technological lock-ins: drastic decline of fossil fuel demand forces industrial parties to find new economic activities in the future. However, traditional activity is most profitable. Government should intervene for sustainable implementation.
Institutions and capacities	*State capacity*	Political stability: closely related to voters' preferences. Growing GDP leads to political stability. Sustainable practices cannot be drastically implemented and follows international demand and standards. However, economic reform cannot wait until fossil fuels are abandoned from the market.
Local (city) scope		
State goals	*Type of state goals*	Modernise energy infrastructure: Energy infrastructure of the city is inefficient and outdated. Heat and electricity sector experience losses up to 22% of PEC for final district heat and electricity users. Modernization and increased efficiency is needed, especially since energy demand is growing.
		Affordable energy: Increasing efficiency and modernizing the energy should not lead to increased energy costs for residents.
		Energy accessibility: only 70% of citizens is connected to DH. Municipal plans aim to increase this percentage. Besides a goal is set to increase the conversion form residential DH from coal to gas.
	Factors effecting state goals	Investment climate: Almaty aims to provide an attractive environment for foreign investors to invest in cleaner, more efficient and renewable energy sources
Political Interests	*Special interests*	Industrial lobbies: energy sector is dominated, by a few parties. Likely they are against radical change due to *technological lock-ins* and *path dependence.*
		Voter's preference: Municipalities depend on their citizens. Citizens profit from energy security and affordability, and demand this from municipality. On the other hand do current circumstances harm citizens health due to air pollution caused by power plants and traffic. This is an important political motivation and responsibility of municipality.
Institutions and capacities	*State capacity*	Economic resources: Economic resources are limited for the municipality. And although energy efficiency plans should be profitable at the long term, initial investments are substantial. Therefore, (investment) funds, development banks and private investors are attracted and involved in development projects. Involvement comes with influence in project decisions. Therefore the World Bank and the EBRD influence decisions for the EET and GCAP.
		Governmental system: It appears that governmental and municipal power is more centralized. Besides many companies with high energy consumption are state-owned or public. The municipality has more influence in the decision-making processes.
		International agreements: Due to large investments, the EBRD and the World Bank influence the decision making process. Besides, the banks invest in line with Western policy directions (e.g. climate mitigation, renewable energy production, etc.).

Table 9: Overview of relevant political variables influencing the energy landscape of Almaty, based on the research framework

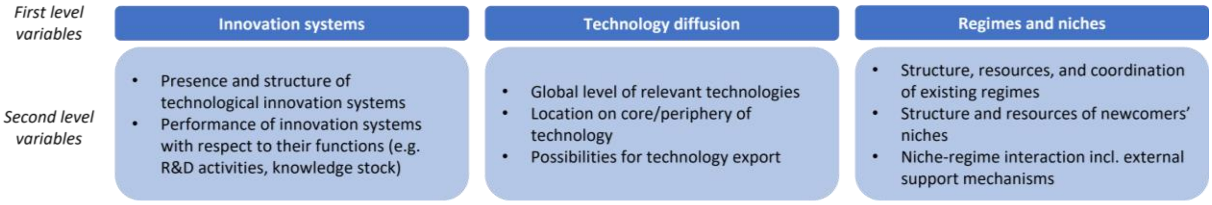
VII. Socio-technical dimension

Socio-technical aspects of Almaty's energy landscape

1. Overview of socio-technical system

Various circumstances create a situation in Almaty that favours fossil energy, and results in challenging circumstances to transform to cleaner or renewable energy infrastructure. The challenging situation is a combination of various economic, technical, political, and social aspects. Economic actors are inclined towards fossil energy because of low production costs, profitability of current processes, and expensive transformation processes. Political factors are inclined to fossil energy usage because of increased economic growth, increased GDP, and resources for development projects, which support political stability. Besides the riots of early 2022 illustrated the political and social impact of disruption in the status quo, and showcased the importance of affordable energy (LNG fuel) for citizens. All these factors explain why Almaty's is completely fossil fuel oriented. And why, despite Almaty's geographical favourable renewable energy characteristics, implementation does not emerge. All these factors result in a stable socio-technical fossil fuel oriented regime involving many factors and actors that favour the status quo and oppose radical change of current system.

This section analysis important socio-technical factors active in Almaty's CtG-transition and it's wider energy goals. The first- and second-level variables of the research framework assist in analysing socio-technical aspects (Figure 2 (p. 17) and table 10). Besides, the framework of Bolwig et al. (2019) provides insights on the dynamics of RES in socio-technical systems (see Appendix A).



First level variables	Innovation systems	Technology diffusion	Regimes and niches
Second level variables	• Presence and structure of technological innovation systems • Performance of innovation systems with respect to their functions (e.g. R&D activities, knowledge stock)	• Global level of relevant technologies • Location on core/periphery of technology • Possibilities for technology export	• Structure, resources, and coordination of existing regimes • Structure and resources of newcomers' niches • Niche-regime interaction incl. external support mechanisms

Table 10: First and second level variables related to the socio-technical domain of energy transitions
Source: Cherp et al. (2018)

2. Disrupting the existing regime

Central to socio-technical system is the current regime, the stable existing system defended and marginally developed by incumbent parties, who are heavily involved and benefit from current rules and institutions (Geels et al., 2017). Almaty's **energy regime** is heavily fossil fuel oriented. Many facets of society (e.g. politics, economics and society) are organised around the current system, which is expressed in legislation, subsides, infrastructure, behaviour, build area, industrial lobbies, heating systems, etc. Altering this status quo, so disrupting this systems, requires commitment and collaboration of multiple actors and systems. The Green Economy Concept (Nazarbayev, 2013) was a start in this process, pleading for economic transformation, a tariff system for RE to compete with fossil fuels, and reduce negative external effects. This policy is the backbone of Almaty's technical innovation system towards renewable energy. However, considering remarks on a lack of RE microgeneration processes and uncompetitive feed-in-tariffs for RE, the policy does not suffice (Karatayev et al., 2016; Laldjebaev et al., 2021; PwC, 2021).

Currently, Almaty is positioned in a crucial situation, since the obsolete and deteriorated, existing infrastructure requires financial investments and technical changes to remain active, but also to increase productivity, and efficiency of existing infrastructure. The CtG-conversion of CHP-2 is an example of such investments. However, with these infrastructural changes there will be heavily invested in fossil fuel-based infrastructure, while GHG-emissions have to be diminished and should eventually be zero in 2060.

CtG-investments are ambiguous, and should be analysed carefully. On the one hand these investments are required since they increase energy efficiency and decrease carbon emissions and air pollution. Which is significant progress for current situation of Almaty. On the other hand, investments lead to *path dependence* in the future, and should therefore be thoroughly analysed, as this inclines that decision made currently, largely shape the development and innovation path of the future. Therefore, current CtG-transition investment creates a situation in which there is no place for large scale RES in the future. The CtG-transition requires a balance within a diabolical dilemma, between improving current system without creating path dependence on fossil energy for coming decade.

Current situation of an obsolete infrastructure that demands development, can function as a **window of opportunity** to step away from fossil fuel dominated infrastructure. Vigorous policy and legislation, sufficient (infrastructural) investments focussed on long term effects, and supporting financial systems for large-scale RES (feed-in-tariffs) steer towards clean(er) energy systems. Current situation appear to be a crossroad between previous and future investments, and sunk investments seem to be manageable due delays of various infrastructural improvements.

The effects of feed-in-tariffs and other financial stimuli can for example be seen in the Netherlands. Since 2008 they had three variations of the *Stimulating Renewable Energy* (SDE) subsidy, which was more progressive than previous renewable energy stimulating measures. Due to these stimulating measures, which were introduced to fulfil energy efficiency goals, the implementation of renewable energy increased significantly (See figure 19)(CBS, 2022)

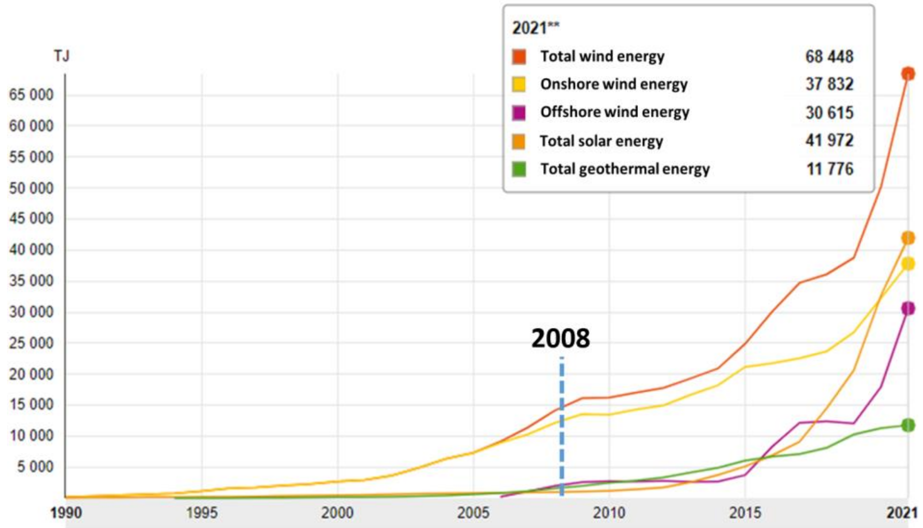


Figure 19: Implementation of renewable energy with SDE-subsidy, introduced in 2008
Source: CBS (2022)

Germany confirms the potential success of feed-in tariffs. Due to competitive pricing systems renewables were economically profitable, which lead to an tremendous upcome of renewable source. Nowadays, Germany is famous for its share of electricity from renewables since it proclaims around 30% of all electricity (Geels et al., 2017). However, important to realise is that this transition covered around 30 years since the tariff-system was implemented in 1990. This example, with a favourable outcome, highlights the importance of path dependence.

3. Financial stimulation of niche development

Many factors benefit from and favour current socio-technical energy regime, and therefore obstruct progress of upcoming niches and regime disruption, thus implementation of RES. Many of these factors involve financial incentives that maintain the status quo or are insufficient to trigger change. For example, to maintain energy accessibility for citizens, fossil fuel energy consumption is subsidised through price controls for approximately 33%, which account for a total of 3,3% of national GDP in 2014. Overall, coal consumption had an estimated subsidisation rate of around 60%. And domestic oil prices are at least two times below the export prices (OECD, 2014). The political sensitivity of this situation became clear during the riots of January 2022, when LPG prices rose as price controls were loosened and the price became market conform (CNN, 2022).

Low feed-in tariffs for RES implementation cannot compete to the subsidies of fossil energy. The two systems are similar, but change is required for RES to become competitive. The government maintains the fossil fuel subsidies to promote economic growth. The probability of this to change is low, and therefore higher feed-in tariffs are more realistic (Karatayev et al., 2016). Kazakhstan's Ex-director of the RES department also mentions that current low fossil energy prices are merely possible due to amortised power plants. However, she proclaims after required financial investments for new installations, renewable energy will be quite competitive (PwC, 2021).

So, on the one hand policy should decrease fossil fuel subsides. On the other hand, policy should stimulate and support the implementation of renewable energy. According various sources renewable energy cannot be competitive to fossil energy. Feed-in-tariffs should recalibrated for RES implementation.

4. Niche development and awareness

Lastly, behavioural change and awareness of energy consumption is a recurring theme in socio-technical transitions. This awareness is lacking in Almaty according to various experts. Firstly, overall awareness about energy consumption and external effect is lacking by citizens, and should be promoted (RWA, 2020b). Current circumstances are beneficial for increasing awareness, such as unadaptable district heating and price controls leading to very low fossil -energy prices. Second, the implementation of microgeneration projects is lacking. Additionally to contribution to the amount of renewable energy, microgeneration does also create awareness among citizens and businesses (PwC, 2021). Individuals who want to become prosumers by installing small-scale RES experience many difficulties, for example electricity restrictions supplied to the grid, lack support of authorities and bureaucratic difficulties, lack of differentiated tariffs per time of the day, monopolisation of the energy market, and lack of local small-scale renewable equipment (RWA, 2020b). So, besides various financial stimuli, there are also legislative measures that can promote small-scale generation and awareness.

5. Relevant socio-technical factors

Previous section discusses the most prominent socio-technical trends in the energy transition of Almaty. However, various more socio-technical factors can be distinguished. Table 11 (next page) presents an overview of most socio-technical aspects related to the energy transitions of Almaty.

First-level variable	Second-level variable	
Innovation systems	*Presence and structure of technological innovation system*	Current system is not encouraging innovation. Legislation and fossil subsidies are not encouraged technological or behavioural change. For example, public organisations are not rewarded for energy saving behaviour (World Bank Group, 2021).
		For specific sector this a technological innovation system is not present. For example for stimulating private RE microgeneration projects and cleaner private transport methods. However, innovation on public transport is relatively present (World Bank Group, 2021).
	Performance of innovation systems with respect to their functions (e.g. R&D, knowledge stock)	Lack of monitoring and checks results in disincentivised citizens and organisations for investing in efficiency measures or behavioural change. More data and monitoring of energy consumption should enable adequate energy audits. This will likely increase awareness for energy efficiency too.
Technology diffusion	*Global level of relevant technologies*	Suitable landscape for existing technologies that should be exploited. *Levelised cost of energy* of renewable energy already outperforms fossil-based alternatives in new projects (IRENA, 2022)
	Location on core periphery of technology	Regarding RE implementation the location of Almaty is interesting, since it is relatively close to China. Besides, various trade agreements with China and Europe encourage to share newest technologies.
Regimes and niches	*Structure, resources, and coordination of existing regimes*	Overcoming path dependence requires sufficient legislative backing and financial investment to promote large-scale RES. Despite increased legislation previous years, it seems insufficient yet. Legislation should be implemented based on implementation challenges (PwC, 2021)
	Structure and resources of newcomers' niches	Existing funds are not competitive with traditional fossil-energy system, also because large-scale infrastructural adaptations are required (World Bank Group, 2017). Moreover, current supportive tariff-system for implementation of RES does not unlock substantial implementation by RES (RWA, 2021). This is because RE can simple not compete with fossil energy within current infrastructure and legislation (PwC, 2021)
		Insufficient small scale and microgeneration projects. These projects should be promoted by providing information, legislation and traject support. This would create awareness among citizens, and could fasten large-scale uptake of market players (PwC, 2021)
	Niche regime interaction incl. external support mechanism	Tariff mechanism introduced in 2013 does not succeed in large-scale uptake of renewable sources

Table 11: First and second level socio-technical aspects related to the CtG-transition of Almaty

VIII. Techno-economic dimension

Analysis of Almaty's energy landscape

The last dimension comprises the techno-economic dimension. Relevant techno-economic aspects are current and future energy demand, the type of requested energy (e.g. electricity, heat), and current and future price(trends). These aspects are studied following the New Stepped Strategy (NSS), inspired on the Trias Energetica approach. The NSS consists of three steps (Van Den Dobbelsteen, 2008):

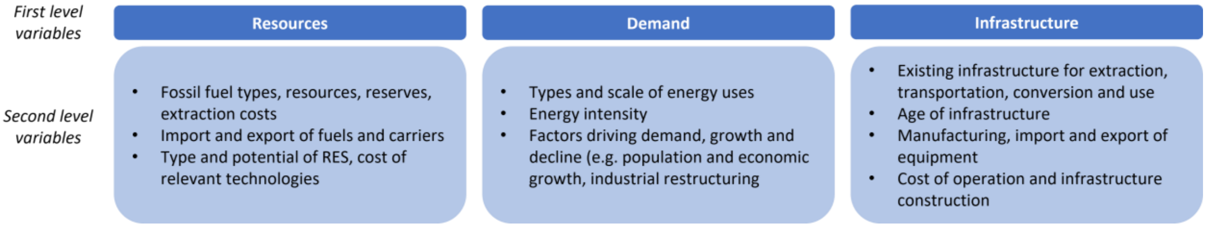
1. Reduce the demand
2. Reuse waste streams
3. Implement renewable energy sources

Regarding the CtG-transitions the first and third step are studied during this research. Reduction of demand is based on the reduction measures of the EET, which regardless of the CHP conversion, should be implemented. Potential reduction, and the measures, of the electricity and district heat sector have been discussed in chapter V. During this section it is analysed what Almaty's potential is for implementing renewable sources, when reduction and reuse have been maximised.

This section consists of two parts. Part one studies the renewable energy potential of Almaty for various energy sources, and compares them to fossil fuel options. This part focusses on natural circumstances for implementation of solar, wind, geothermal and hydro energy.

The second part consists of quantitative analysis comparing the CtG-plans of converting CHP-2 to renewable alternatives, based on four aspects; 1.) technological possibilities, 2.) carbon emission, 3.) economic feasibility, and 4.) impact on the existing network. The analysis are inspired by first- and second level variables of the research framework (see table 12). The variables are implicitly integrated in quantitative analysis and graphs, instead of tables as previously.

The sections of *renewable energy potential* and *financial trends of energy production* present the outcomes that form the starting point of the quantitative analysis. Next, the techno-economic analysis are discussed. The complete analysis is found in appendix E.



First level variables	Resources	Demand	Infrastructure
Second level variables	• Fossil fuel types, resources, reserves, extraction costs • Import and export of fuels and carriers • Type and potential of RES, cost of relevant technologies	• Types and scale of energy uses • Energy intensity • Factors driving demand, growth and decline (e.g. population and economic growth, industrial restructuring	• Existing infrastructure for extraction, transportation, conversion and use • Age of infrastructure • Manufacturing, import and export of equipment • Cost of operation and infrastructure construction

Table 12: First and second level variables related to the techno-economic domain of energy transitions
Source: Cherp et al. (2018)

1. Renewable energy potential

The energy transition towards large-scale implementation of RES in Almaty (and Kazakhstan) is divided in extremes when considering technological and economic opportunities and challenges.

Opportunities

First, various natural characteristics result in a favourable climate, and thus technological potential, for production of renewable energy (Bogdanov et al., 2019; Karatayev et al., 2016; MacGregor, 2017; PwC, 2021). Solar and wind energy contain the most potential in nearby Almaty.

First, for **solar energy**, regions nearby Almaty belong to the areas with the highest potential for solar PV production of Kazakhstan, based on *direct normal irradiation* (NDI)*,* with averages around 1,500 - 1,600 kWh/m^2. The north of Kazakhstan has irradiations rates around 1,100 kWh/m^2, and for example the Netherlands 900 - 1000 kWh/m^2 NDI (World Bank Group). Spaces with high irradiation rates appear to be suitable for solar PV installation, since the terrain is open, flat, not densely populated. Besides, nearby potential areas existing grid connection is available (220kV, 500kV and 1150kV) (see figure 20).

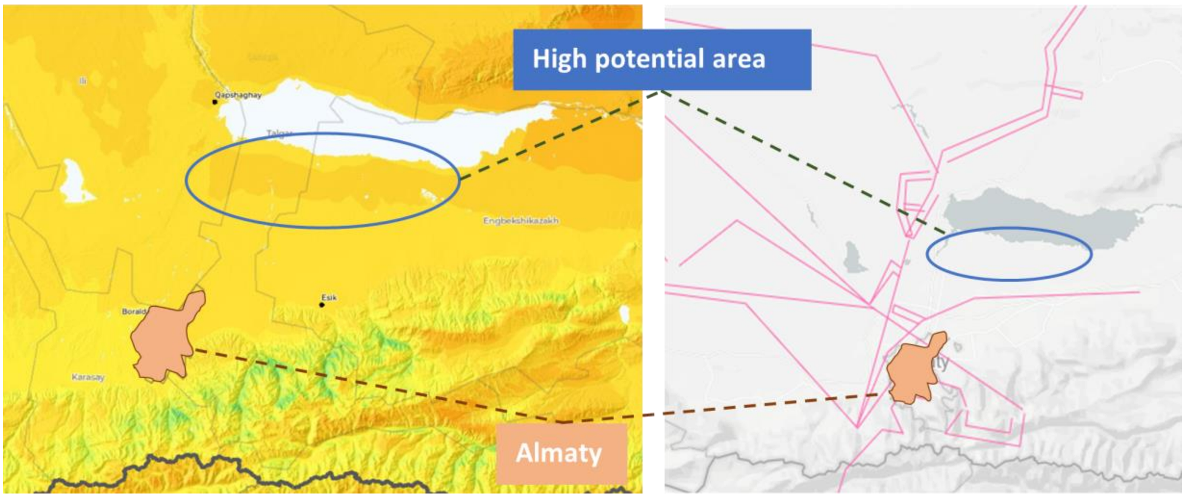


Figure 20: Solar PV potential nearby Almaty (left) and nearby grid connection to potential PV areas (right)
Source: SolarGIS (2022), Energydata.info (2018)

The situation for **wind energy** is similar to that of solar energy (see table 21). The steppes climate and wind streams create suitable circumstances for wind power generation nearby Almaty. However, conditions in the Middle- South and South-West of Kazakhstan are favourable. The Almaty region experiences wind speeds of around 6.4 m/s with energy potential of 425 W/m^2, compared to 600 W/m^2 Turkestan (Middle-South), 450 W/m^2 Atyrau (South-West), and 300 W/m^2 for Amsterdam (World Bank Group, ESMAP, Vortex, et al., 2022).

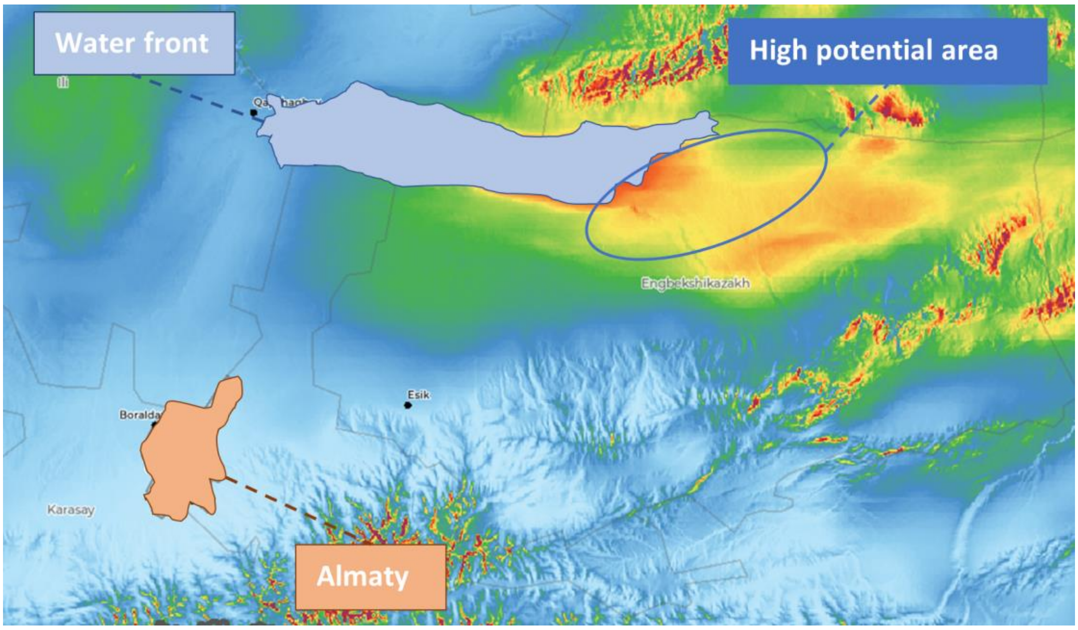


Figure 21: Wind energy potential nearby Almaty
Source: Global Wind Atlas (2022)

Third, regarding **geothermal energy,** potential around Almaty limited data is available. Various sources exclude geothermal energy from their studies (Bogdanov et al., 2019; Karatayev et al., 2016, 2016; PwC, 2021), and only few include it (Boguslavsky et al., 1999; World Bank Group & ESMAP, 2019). The exclusion of geothermal potential could be prescribed to the zeitgeist of last decades, since geothermal was not popular and our society is mainly designed on fossil based energy. However, due to lacking data on geothermal energy and the popularity of other sources (e.g. solar and wind), geothermal energy is excluded from the quantitative analysis. Though, further research and renewed popularity of geothermal energy could introduce it in future scenarios.

Last, **hydropower** already accounts for around 13% of the total energy generating capacity if Kazakhstan. Nearby Almaty two large scale hydro power plants (> 50 MW) generate energy for Almaty, the HPP Moynak (300 MW) and HPP Kapchagay (364 MW). Besides, MacGregor (2017) states that 8 small HPPs are operational in the Almaty region, with a total generating capacity of 72,1 MW. Five more hydro power plants are planned for the Almaty region with capacities of 34,8 MW, 42 MW, 24,9 MW, 15 MW, and 12 MW (total of c. 130 MW) (Eshchanov et al., 2019). Next to these planned hydro energy plants there is limited data on future potential in the Almaty region. Therefore, during this research hydropower, as new implemented technology, is not included in the quantitative analysis. However, the main purpose of HPP plants nearby Almaty is to cover peak loads in the region (Samruk Energy, 2017).

For this research the focus of a RES alternative for CHP-2 will consist of solar and wind energy, in which hydro energy can play a role for balancing the network. Solar and wind energy dominate in literature for renewable energy, for example in policy reports (Nazarbayev, 2013; World Bank Group, 2017), institutional reports (PwC, 2021; World Bank Group, 2018) and academic papers (Bogdanov et al., 2019; Karatayev et al., 2016; MacGregor, 2017; PwC, 2021). Other sources of renewable energy therefore excluded for the analysis.

Challenges

Besides the favourable aspects, various challenging characteristics for large-scale implementation of RES can be identified. First, the harsh continental climate results in very cold, long winters and high-temperature summers (Karatayev et al., 2016). As mentioned previously, district heating is one of the main energy consuming services of the city. This is partly due to system inefficiencies and poor insulation, but also due to long winters resulting in high seasonal demand. Second, as previously discussed, an abundance of fossil fuels and current pricing systems lead to fossil fuel production low costs. These low costs compete with the implementation of RES (Bogdanov et al., 2019). Lastly, the economy is very energy intensive, which makes it hard to generate sufficient energy with the right characteristics (e.g. electricity, district heat, high temperature energy) (Bogdanov et al., 2019).

2. Financial trends of energy production

LCOE ranges

This section provides an overview of current cost levels and future cost trends various renewable and fossil fuel energy sources. For renewable sources the focus is on solar and wind energy, as these are considered to be favourable for Almaty. The costs (trends) are based on the LCOE, which is a relatively simple measure for analysing (expected) energy costs per kWh. Overall, the LCOE is a comprehensive measure, that includes most essential cost aspects, the total installed costs, M&O costs, and costs of capital. The motivation and limitations for this method is elaborated on in the methodology section. Moreover, as specified in the methodology section, when Kazakh specific number were not available, assumption are made on the average of China and Europe.

Table 13 presents an overview of current and expected cost level ranges of Europe and China, as Kazakhstan was not available. These ranges are used to analyse the CtG-conversion of CHP-2 and potential renewable sources. (World Bank Group, 2017). LCOE averages of hydropower are hard to predict since the costs highly vary per case, due to natural circumstances, technological requirements, and case specificities (EIA, 2022). However, as mentioned before, is new hydropower potential not included in the quantitative analysis of the CtG-transition.

Interestingly, the LCOE of new coal projects is 1.5 times higher than for solar projects. New gas projects are around 1.7 times more expensive per kWh. IEA (2020) takes into account capital costs, operations and maintenance (O&M), thermal fuel (fuel), electricity costs (fuel), price per tonnes emitted carbon (carbon), and CHP heat revenues. A more elaborated analysis of current LCOE measures is presented in the financial analysis of appendix E.

Energy source electricity generation	LCOE 2021 ($/kWh)	LCOE 2030 ($/kWh)	LCOE 2050 ($/kWh)
Coal + gas (CHP KZ)	0.042[1] (0.056 excl. subsidies)	-	-
Coal (CHP)	0.060 - 0.170[2]	0.080- 0.185[2]	0.095-0.200[2]
Gas (CHP)	0.100 - 0.110[2]	0.120-0.140[2]	0.130- 0.170[2]
Solar (utility scale)	0.035 - 0.048[3]	0.020 - 0.040[2]	0.015 - 0.030[2]
Wind (on shore)	0.028 - 0.042[3]	0.045[2]	0.040 - 0.045[2]
Hydropower (river)	0.048	0.048 - 0.082[4]	0.048 - 0.082[4]

Table 13: Overview LCOE per energy source

[1] Source: globalpetrolprices.com (December 2021), comparable (World Bank Group, 2017a p. 44, 2017b, p. 23)

[2] Source: IEA (2021b) specification of LCOE per energy source in 2020, 2030 and 2050 per region (China and Europe)

[3] Source: IRENA (2022): realised LCOE measures for the year 2021

[4] Source: EIA (2022) specification of LCOE of hydropower in 2040, so accounted these numbers to 2030 and 2050 (global)

Renewable energy cost trends

The LCOE of **Solar energy** has been declining majorly because of technological improvements and increased competition. First, the levelised cost of electricity (LCOE) declined from 0,417 ($/kWh) in 2010 to 0,048 ($/kWh) in 2021. Second, the total installed cost decreased from 4,808 $/kW in 2010 to 857 $/kW in 2021. Last, the capacity factor (production efficiency) has significantly increased as well, from 2,37 - 2,69 ha/MW in 2010 to 1,89 - 1,94 ha/MW in 2021, with the top 5th percentile at 0,93 ha/MW (IRENA, 2022).

Onshore wind energy experienced a similar development, with a global average LCOE decrease from 0,102 $/kWh (2010) to 0,033 $/kWh (2021). Total installed cost decreased 35% between 2010 and 2021, from 2,042 $/kW to 1,325 $/kW. Wind turbines are more efficient in energy generation as well. The *capacity factor* increased from 27% (2010) to 39% (2021) as global average.

Hydropower has been implemented in Almaty's energy grid for decades. Hydropower is the only technique that experienced increased LCOE between 2010 and 2021, from 0.039 $/kWh in 2010 to 0.48 $/kWh in 2021. However, still 85% of newly commissioned hydropower plants has cheaper LCOE than new fossil fuel-fired alternatives. The increase in cost is due to challenging locations and therefore higher install costs. The total installed costs were 2135 $/kWh in 2021 and 1315 $/kWh in 2010.

For quantitative analysis and calculations the average LCOE and total installed costs of China and (countries in) Europe was leading. These values can vary from global averages. Figure 22 showcases the cost trends of global average cost decrease of solar, wind and hydropower.

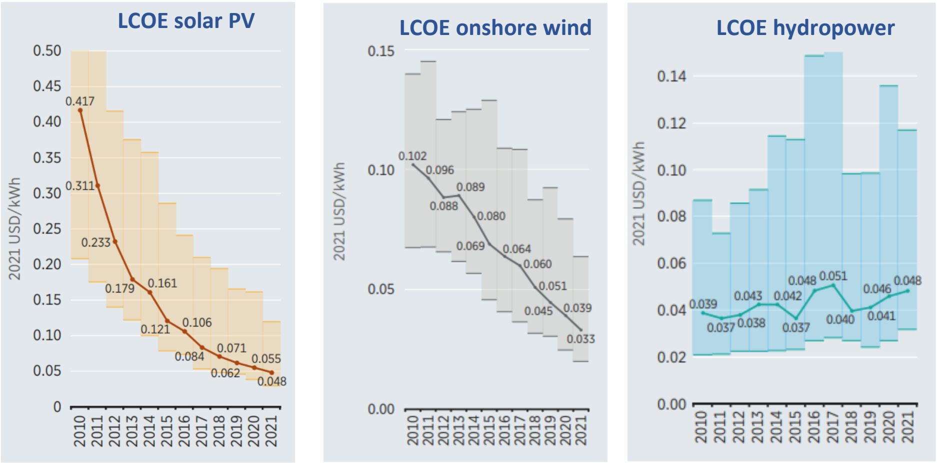


Figure 22: Development of LCOE's of solar PV, onshore wind, and hydropower
Source: IRENA (2021)

3. Quantitative analysis: RES alternative for the CtG-transition

This section presented results of comparing the conversion of CHP-2 to the RES alternative of solar and wind. The analysis departed from four various starting points: 1.) financial resources, 2.) spatial impact of the RES scenario, 3.) avoided carbon emissions, 4.) network reliability and stability including to two fundamental aspects, the baseload capacity and peak demand generation. Motivations and limitations of the quantitative analysis methods is elaborated on in the methodology section.

In order to conduct quantitative analysis, the exact context in which they are executed need to be defined. Compensating CHP-2 by the RES alternative energy contains implications varying per energy source due to their characteristics (e.g. LCOE, capacity factor, spatial requirements, etc). Therefore, prior to the analysis, the ratio of wind and solar energy and the amount of energy required to compensate CHP-2 had to be determined.

Wind and solar energy ratio

Various challenges must be overcome in order to implement large shares of RES, and even more to achieve energy neutrality, such as stabilising the electricity network, electrification of current sources, and storing energy. For this analysis a preferred ratio of 50% solar and 50% wind energy was determined for compensating the yearly CHP-2 energy production. This ratio was selected because of favourable natural circumstances, the complementary characteristics of solar and wind, and thermal energy saving potential during cold periods. Besides, it is assumed that this ratio suffices during the beginning of the energy transition (and for this study), as various traditional energy sources are still active, for example CHP-1, CHP-3, two HPP's and imported energy from KEGOC. This is elaborated on in *'starting point four'*. See appendix E for the complete analysis

This conclusion lead to an equal share of energy generated from wind and solar to compensate CHP-2 (6,267 GWh/year). However this amount is without energy losses and required electrification steps. The final energy demand by wind and solar is explained in the next section.

Energy demand to compensate CHP-2

In order to compensate the energy production of CHP-2 by renewable sources, various aspects have to be taken into account. First, CHP-2 generates heat and electricity, in which heat is for a significant amount a by-product in this process. However, solar and wind energy solely produce electricity. Therefore, compensating CHP-2 requires electric energy to be converted to heat. Power-to-heat can be converted with an efficiency of nearly 100% with electrical boilers (Beyond Zero Emissions, 2018; IRENA, 2019c; Schoeneberger et al., 2022). Therefore, for calculations an efficiency rate of 99% was taken.

Second Almaty experiences considerable network losses due to the obsolete infrastructure. Current transmission and distribution losses had to be included. Especially heat losses are significant due to obsolete infrastructure system (World Bank Group, 2017). An overview of the CHP production, power-to-heat conversion and current energy losses is presented in figure 23 .

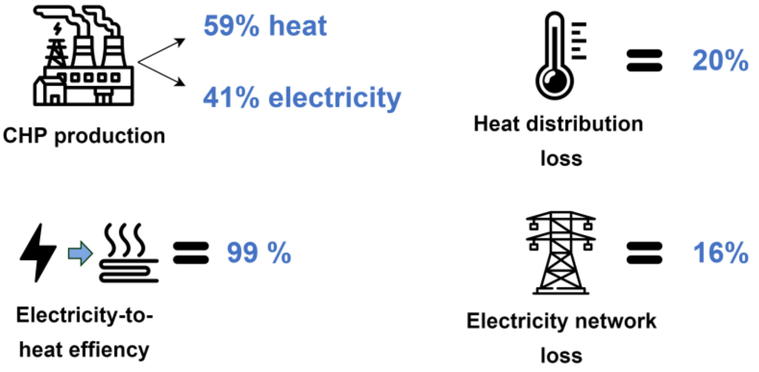


Figure 23: Specifics of current energy production and losses
Source: The Word Bank, 2017

However, these loss rates do not include the energy efficiency improvements planned to be implemented in Almaty before 2030 (World Bank Group, 2017). Reducing energy demand before increasing generating capacity is conform the *Trias Energetica* principle. Therefore, it is assumed that these improvements are realised. The EET reduction measures (appendix C) are taken into account, which leads to heat and electricity loss rates presented in table 14.

Overall, table 15. Includes a breakdown of the required generated amount of energy by RES for heat and electricity, taken into account the various consequences for compensating CHP-2 with renewable sources.

Energy reduction sector	Current energy loss (%)	Energy savings per sector (%)	2030 energy loss (%)
District heating	20%	34%	**13%**
Electricity network	16%	41%	**9%**

Table 14: Almaty's energy losses and reduction in percentages based on the EET

Type of energy	Specification	Amount (GWh)
Electricity	CHP-2 net production for final usage	2,546
Heat	CHP-2 net production for final usage	3,721
	Heat distribution losses (13%)	491
	Loss power-to-heat (1%)	42
Subtotal	***Heat + electricity demand (excl. electricity network losses)***	***6,800***
	Electricity network losses (9%)	642
Total	**Heat + electricity demand (incl. losses)**	**7,442**

Table 15: Breakdown of required generated energy by RES for heat and electricity

Starting point 1: project finances

Financial investments are a decisive factor for project realisation, and a frequently mentioned threshold for RES implementation in Almaty (PwC, 2021; RWA, 2020b). The LCOE of renewables was proven to already outcompeted traditional sources in general (e.g. coal and gas) with differences only expected to increase in 2030 and 2050 (see table 13) (IEA, 2021d). Besides, since the financial investments to convert CHP-2 are considerable it was interesting to compare the required investments for the CHP-2 conversion with the RES alternative. These calculations are based on the LCOE, for which an elaborated argumentation is provided in the methodology.

First, this section analysed the total investments costs of the RES alternative for compensating CHP-2. Second, it was analysed how much solar and wind energy potential could be installed from the total project costs of the CHP-2 conversion. See table 18 for current LCOE's for Almaty. The total project costs contain c. 680 mln USD.

Financial investment RES scenario

The lower and further decreasing LCOE of solar and wind energy compared to gas-based energy should function as clear long term financial incentive to implement RES. Although, current prices of coal-based electricity in Almaty are equal or slightly higher than the to the LCOE of RES alternatives, in 2030 prices of solar and wind are assumed to be at minimum 2.5 to 3 times lower than new gas-based energy, and 3 to 4 times at minimum in 2050. Besides, substantial increase of RES implementation is required for working towards energy goals stated by the government. Nonetheless, the upfront capital investments, and creating an attractive investment climate, form a major barrier for implementation of RES (Karatayev, 2016). Therefore, the required capital investments for RES are compared to the investments for CHP-2.

In order to calculate the required capital investments the total installed costs per kWh are determined. The total installed costs are an element of the LCOE. Therefore for this calculation the averages for China and (a country in) Europe are assumed to represent the costs for Almaty. Table 16 contains the variables required to calculate the investments costs, based on IRENA (2022). Calculations on the required amount of megawatts is presented in appendix F (p. 127-128)

Type of energy source	Installed capacity (MW)	Installed costs ($/kW)	Total installed costs (bln USD)
Solar	2,573	700	**1.8**
Wind	2,315	1390	**3.2**

Table 16: Overview of the required total investment costs for the RES scenario

The required amount of installed capacity represents 50% of the energy production of CHP-2. The sum of the investments of solar and wind represents the capital investments required to compensate the yearly energy production of CHP-2. The total capital investment for the RES scenario results in circa 5 bln USD. Which is around 7 times the investments for the CHP-2 conversion.

Since this calculation was based on assumptions, some validation with existing RES project was valuable. Table 17 presents realised or being implemented projects in (or nearby) the Almaty region, and the converted price per MW for the RES scenario to compensate CHP-2 (AstanaTimes, 2019, 2022; Eurasianet, 2020). The calculations from the IRENA (2022) data are therefore considered to be realistic, if not slightly conservative.

Type of energy source	Installed capacity (MW)	Total investment (mln USD)	Equivalent price for RES scenarios (bln USD)
Solar park Karaganda	100	65	1.7
Solar park Kapshagai	150	71	1.2
Wind farm Almaty	60	79	3.0

Table 17: Reference project nearby Almaty region converted to investment requirements for RES scenario

These high capital investments confirm the statements of high upfront costs for RES compared to existing power plants, as the assumed investment costs for the RES scenario are seven times higher than the 680 mln require to convert CHP-2 into a gas-based power plant. However, as previously explained, the costs for producing the energy after implementation is substantially higher for fossil fuel energy than for RES, due to fuel costs, carbon permits and higher maintenance costs. The high upfront investment costs still form a barrier, but the LCOE better represent costs of energy of the lifetime of the power plant. For example, according to the LCOE calculator of IEA (2022), although investment costs of new gas-based energy is around 6.5 times less expensive than solar energy, the LCOE for gas (with decreased gas prices) still remains higher than for solar energy.

However, as Karatayev (2016) states, the capital investments itself are not always the major barrier, but also the environment institutional framework to acquire investments. For example, the capacities to acquire foreign investments and the institutional framework to process construction permits. These aspects are related to political dynamics as well, such as the corruption rate (Karatayev et al., 2016).

Renewable energy potential of CHP-2 conversion investment

Besides the LCOE and capital investments, eventually Almaty's goal is to remain carbon neutral. Therefore, the investments for converting CHP-2 could also be interpreted as lost investment capital for the energy transition as fossil energy should eventually be phased out. This section analysed the amount of energy that could be generated by the financial investments of the CHP-2 conversion.

During this calculation current LCOE was leading, since the CtG-conversion should start early 2023. However, according to the prognoses, the LCOE of fossil energy increases in 2030 and 2050, while the LCOE of solar and wind energy decreases even further. This is mainly caused by technological improvements, increased fuel costs and carbon prices.

Type of energy source	Fossil (CHP)	Solar	Wind
LCOE Almaty 2021 ($/kWh)	0.042[1] (0,056 excl. subsidies)	0.0415	0.035

Table 18: Overview of current (assumed) LCOE's of Almaty (based on averages of Europe and China)
Sources: IRENA (2022)
[1] Source: globalpetrolprices.com (December 2021), comparable (World Bank Group, 2017a p. 44, 2017b, p. 23)

For calculating the energy that could be produced with the total investment costs of the CtG-conversion (680 mln USD), the investment costs were divided by the LCOE of solar/wind energy, resulting in circa:

16,400 GWh of solar PV energy
&
19,450 GWh of wind energy

These productions were based on costs of investments with an assumed lifetime of 30 years. Therefore the results cannot be interpretated as an absolute energy production. However, the equivalent of annual energy production of CHP-2 was analysed. The energy production of CHP-2 remains the same after conversion. Therefore, it was compared how much energy could be generated by RES compared to CHP-2, if investment costs were used to install solar and wind energy. In total 7,400 GWh/year of electricity is required to compensate CHP-2 yearly levels of energy production, including network and efficiency losses (World Bank Group, 2017). The investments costs of the CHP-conversion equalled to:

2.2 years equivalent of CHP-2 energy for solar
&
2.6 years equivalent of CHP-2 energy for wind

The results were interpretated as: if all investments costs of CHP-2 conversion were invested in solar or wind energy, this results in an equivalent of 2.2 (solar) and 2.6 (wind) years of energy normally produced by CHP-2 in a year. Moreover, in the future, wind energy is expected to be a factor 3-4 times cheaper than gas in 2050, and solar energy even 4-8 times, mainly due to rising costs of fossil fuels, carbon permits, and maintenance and M&O for fossil energy (IEA, 2021e) .

Even when an uncertainty margin of 10% is taken into account for the LCOE, so a 10% increase of the costs per kWh, the equivalent years of energy for solar would be 2.0 years and for wind would be 2.4 years.

To conclude, when considered that the LCOE is leading, long term investments in renewable energy would be rational, as long term production of renewable energy is cheaper per kWh than new fossil energy projects (See table 14). However, large upfront investments form a major barrier for large scale RES implementation. Nonetheless, when it is assumed that energy neutrality in 2060 is Almaty's goal, it would be reasonable to start implementing large scale RES since lost investments in fossil-fuel energy could be prevented.

Starting point 2: spatial analysis to compensate for CHP-2 energy production

The second starting point was the amount of energy CHP-2 annually generated. This section concluded with a spatial analysis of requirements to generate an equal amount of energy to compensate the annual generating capacity of CHP-2.

Solar energy production to compensate CHP-2

In order to calculate spatial requirements for the RES scenario some variables for wind and solar had to be clarified. Table 19 provides the variables for calculating the land areal in a 50/50 solar-wind ratio for the RES scenario.

Specifications for solar PV	Amount
Annual required GWh (50% of CHP-2)	3,721 GWh
Realistic annual production solar PV Almaty[1]	1.446 GWh/year/MW
Space usage of solar PV per hectare[2]	1.94 ha/MW

Table 19: Overview of specifications of Solar PV for calculating the required land areal
[1] SolarGIS (2022)
[2] IRENA (2022)

These variables result in an total area of 50 km^2 (5,000 ha) is required to compensate for 50% of CHP-2 annual energy production including transmission and electrification losses. This a substantial area that in various densely populated areas would form a major barrier. However, Kazakhstan consists of the top 15 of least densely populated countries, so available space is assumed not to be a limiting factor.

Around 50 km^2 (5,000 ha) needed for required installed capacity

Wind energy production to compensate CHP-2

The second half of renewable energy for compensating the CHP-2 input relies on wind energy. Similar to solar energy, various sources promote the implementation of wind energy because of the favourable weather conditions.

Various variables are required to calculate the needed land areal to compensate 50% of CHP-2, such as the installed peak generation, (World Bank Group, ESMAP, Vortex, et al., 2022), the actual average output per installed MW (IRENA, 2016, 2021b; World Bank Group, ESMAP, Vortex, et al., 2022), and the average land use per installed MW (IRENA, 2019c; Miller & Ketih, 2018). These variables are collected for Almaty in order to calculate the required amount of wind turbines and land areal to compensate CHP-2. Table 20 provides the values.

Specifications for wind energy	Amount
Annual required GWh (50% of CHP-2)	3,721 GWh
Peak capacity of wind turbines[1]	1.75
Annual energy production of wind turbine[2]	2.8 GWh/year
Space usage of solar PV per square kilometre[3]	3 MW/km^2

Table 20: Overview of specifications of wind energy for calculating the required land areal
[1] Global Wind Atlas, 2022
[2] IRENA, 2021a &
[3] IRENA, 2019b & Miller & Keith, 2018

The values result in an amount of 1,325 wind turbines, which requires a land areal of 770 square kilometres to compensate for CHP-2

Around 1,325 wind turbines needed for required installed capacity

Around 770 km^2 needed for required installed capacity

Spatial representation for solar and wind energy production

Figure 24 presents a spatial representation of the required land for solar and wind energy. The representation is based on the potential location for solar and wind energy, but also on perceived suitable land since the area contains a low utilisation rate and has a relatively equal surface. The solar energy area is 50 km^2 and the wind farm consists km^2.

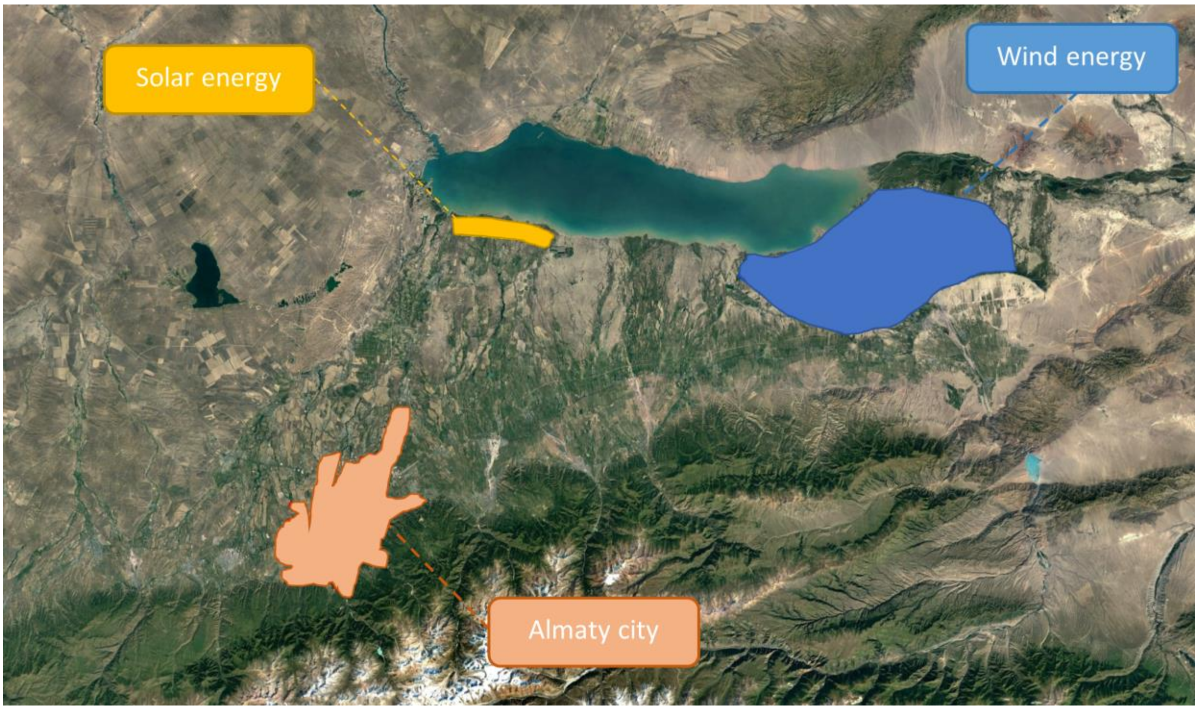


Figure 24: Impression of land requirements for compensating CHP-2 energy production by solar and wind energy

Starting point 3: CO_2 emissions reduction per energy scenario

Installation rate of scenarios

The most urgent motivation for Almaty's CtG-conversion were to improve the city's air quality, with the priority to abandon particulate matter (NO_x) and reduce CO_2 emissions. These arguments formed the starting point of this analysis, in which CO_2 emissions of the three energy production scenarios were compared; traditional coal based production, post-conversion gas based production, and the RES alternative based on solar and wind. The calculating method is explained in the methodology section.

The variables for the conventional CHP-2 scenario and for the CHP-2 conversion to gas are provided by the plans of Samruk Energy and EBRD (see table 21) (EBRD, 2022). The CO_2 emissions analysis uses a relatively simple method, and therefore experiences several limitations. Motivations and limitations for this method is explained in the methodology section.

Scenario		Amount	Unit
CHP-2 Coal	CO2 emission per year	6.5	mln tons/year
	Installation period	0	years
CHP-2 Gas	CO2 emission per year (after conversion)	3.5	mln tons/year
	Installation time phase 1 (200 MWe)	4	years
	Installation time phase 2 (370 MWe)	2	years
RES	Preparation of policy procedures	2	years
	Installation of renewable energy sources	4	years

Table 21: Overview of carbon emission reduction and planning of three energy scenarios for Almaty
Sources: EBRD (2022)

The installation rates for solar PV and wind turbines depend on various factors, such as policy procedures, availability and number of installers and technicians, availability and transport time of materials, efficiency of installation, etc. These numbers vary per project, which makes it impossible to specify the exact planning for the RES scenario. However, assumption can be made based on empiric data of other countries.

In the Netherlands the total amount of installed capacity solar PV grew with nearly 3.5 GW in 2020 (RVO, 2021). They have a similar populations size and active labour force as Kazakhstan (Ceicdata, 2017; Statista, 2022). Although, in the Netherlands policy structures and institutions are highly developed for increased implementation of solar PV, it is assumed that Kazakhstan could increase its solar PV also considerably, since the design of policy and supportive institution action majorly influence the uptake of RES. For example, China and the United States increased their installed capacity of solar PV with stunning amounts of respectively 48 GW and 19 GW, due to policies favouring RES and expiration dates renewables energy subsides. Growth of solar energy uptake grew with 60% in China and 45% in United States due to favourable policy and supporting mechanisms (IEA, 2021b, 2021c).

According to IRENA (2021a) total installed capacity of solar PV increased in Kazakhstan with around 600 MW in 2020. Therefore, it is assumed that Almaty is able to install the total amount of solar PV (2,500 MW) during the six year that were planned for the CHP-2 conversion. Policy frameworks and institutions should stimulate, structure and fasten procedural requirements for solar energy implementation, and the industry should be able to install the capacities. It is assumed that it requires two years for designing supportive policies and legal structures for large scale solar PV, and that the total implementations requires 4 years of installation. In total the installation phase takes an equal amount of time as the CtG-conversion.

The case for onshore wind energy uptake is highly similar. Reference case, the Netherlands, installed around 1,100 MW capacity in 2021. However, the implementation bottleneck is mainly policy-oriented. Besides, factors as delayed material deliveries and rising material costs decreased production rates as well (RVO, 2022). So, the bottlenecks are policy or market oriented rather than technical. Although Kazakhstan's wind energy increased with 200 MW installed capacity in 2020 (IRENA, 2021b), the main limiting factor probably was economic feasibility due to lacking RES stimulating policies. For example in South-Africa and Turkey, total installed capacity of wind energy increased in 2020 with respectively 600 and 1,300 MW. Therefore it is assumed that it should be feasible to install around 2,300 MW in around 4 years when supportive circumstances are created.

CO_2 emissions per scenarios

All parameters to calculate the CO_2 emissions for the three scenarios are now available. As mentioned the installation rates are assumed to be equally divided over the planned years, and therefore the percentages of emissions are too.

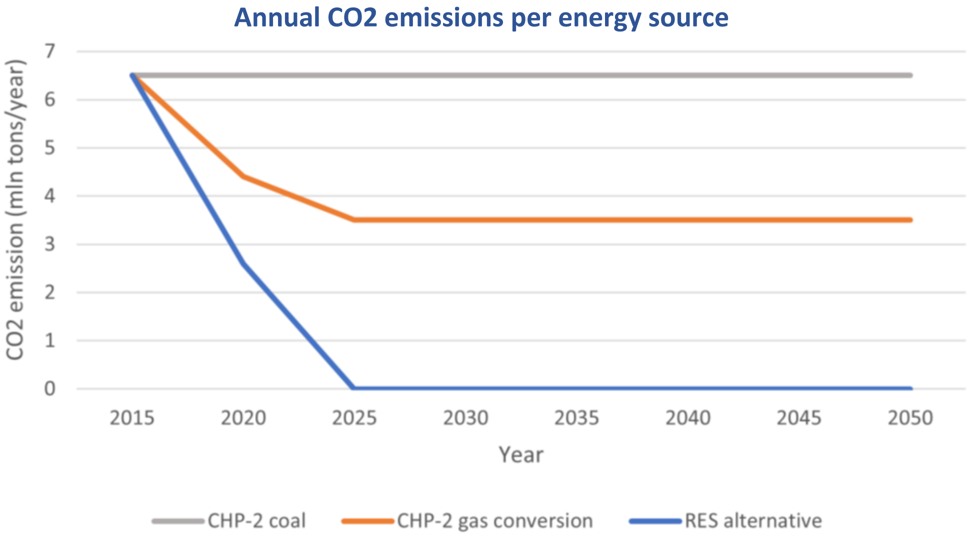


Figure 25: Annual CO2 emissions per energy scenario

Figure 25 illustrates the annual tons of CO_2 emissions produced in the three different scenarios. Scenario 1 'CHP-2 coal' represents the current scenario, and shows a yearly 6.5 mln ton CO_2 emissions if current circumstances proceed. Scenario 2 'CHP-2 gas conversion' showcases the CO_2 emissions when the conversion is being realised. EBRD (2022) describes two phases in which the coal-based systems are being decoupled to gas-based systems. During these years the emissions gradually decrease, and stabilise at 3.5 mln tons CO_2 emissions annually after the conversion is finished. Scenario 3 depicts the transition towards the RES scenario. The implementation of solar and wind energy happens within the same timeframe of the CtG-conversion, during which the CHP still emits CO_2. After all hectares of solar PV and the wind turbines are realised, CO_2 emissions end.

However, since the CO_2 emissions are yearly, it is highly interesting to see how much CO_2 is cumulatively emitted during the years of energy production with an assumed life time of 30 years. Figure 26 illustrates these estimations in which the coal-based emissions in total sum up to 188 mln tons of CO_2, the gas-conversion scenario results in around 115 tons of CO_2, which is a reduction of c. 39% in 2050 compared to the coal-based scenario. The renewable scenario results in a cumulative emission of 33 mln tons CO_2 in 2050, since after realising the solar and wind potential, CO_2 emissions fully ends. The coal-based scenario emits more than **seven times** the amount of CO_2 and the gas-based scenario more than **four times** (figure 26). So, overall, when improving air quality and reducing CO_2 emissions are the desired result, the renewable energy scenario does tremendously better than the other scenarios.

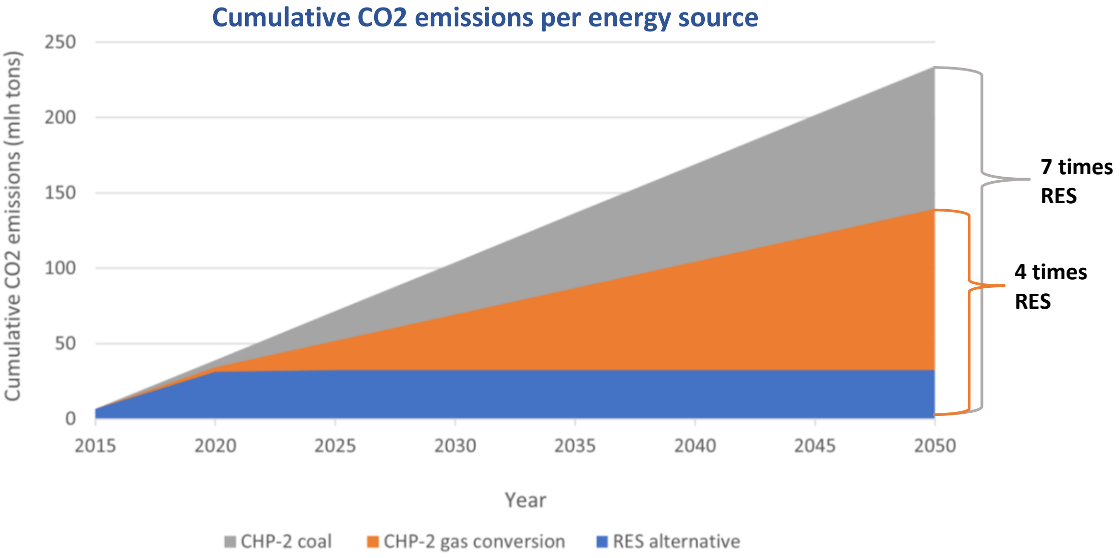


Figure 26: Cumulative CO2 emissions per energy scenario

Starting point 4: reliable and constant energy network

Base load and peak capacity

Constant and reliable availability of energy (electricity and heat) supply is a prerequisite for developed (urban) areas nowadays. The World Bank Group (2017) mentions that electricity or heat shortages have occurred so far, but that increased electricity demand foreseeably pressures the system in the future. Integrating renewable energy sources, and decoupling fossil-based generators (CHP-2), increases the systems variability, and is therefore important for guaranteeing reliable energy supply.

Electricity supply

Baseload electricity production in RES scenario

Originally CHP-2 forms a cornerstone of the energy network of Almaty, producing around 38% of all electricity and 48% of the cities heat demand. Decoupling CHP-2 from the electricity network therefore heavily impacts energy supply. An important requirement to replace CHP-2 for RES is that the baseload electricity demand is still produced reliably by other sources. This is explained in the methodology. Based on the methodology, a baseload of around 60% of the annual electricity demand is assumed. Figure 27 shows the electricity baseload of 2015 (orange line) of 3,456 GWh/year. This baseload can be fully covered by current available electricity generators excluding CHP-2, so CHP-1 (gas), CHP-3 (gas), HPP Moinak, HPP Kapshagai and imported electricity of KEGOC (grey area).

Though, future electricity demand is expected to grow with around 700 MW (assumably for 2040), which results in an average demand increase of 2.8% per year. This increase is between the growth of developed countries (1.6%) and developing countries (5.4%), what appears to be reasonable for a relatively developed city like Almaty (IEA, 2020d). Besides, various and energy reduction measures are being implemented till 2030 (World Bank Group, 2017). Efficiency measures affecting electricity and build area sectors are included for electricity demand, and resulted in demand reduction of 41% on network losses and 27% for energy consumption of the build area. The assumed future baseload, based on these numbers, is prognosed with the blue line. The production plants (excluding CHP-2) appear to be capable to deliver the baseload demand until 2044. Though the margins are small with current production rates.

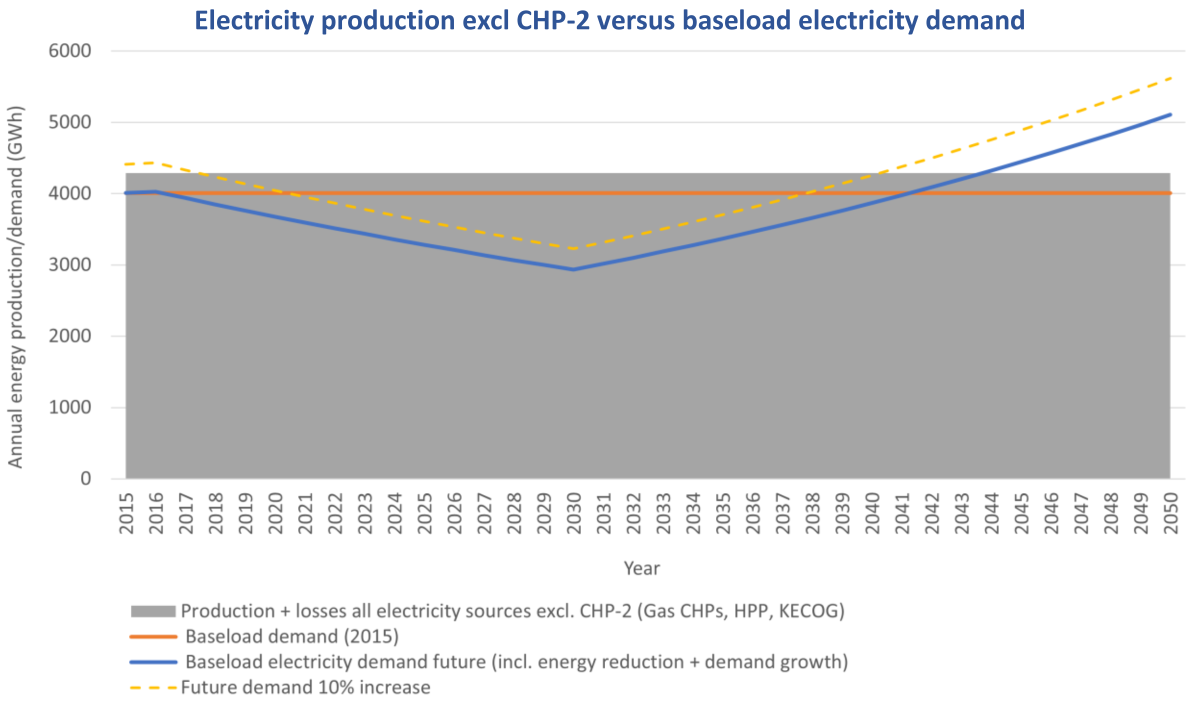


Figure 27: Electricity production (excl. CHP-2) versus baseload electricity demand

Although, 60% of baseload demand is probably a high baseload demand, an uncertainty of 10% for this demand has been analysed as well (yellow dotted line). This increased baseload demand causes problems, as current production rates of power plants are insufficient to generate the baseload demand. However, CHP-2 was producing the largest energy shares in Almaty, because it had the lowest production costs since the energy was coal-based. Consequently, other plants are not operating at an optimal energy production rate for when CHP-2 would be excluded. Besides, more electricity could be imported form KEGOC as well. And thus, most probably the baseload can be increased.

Second, various projects are planned to increase generating capacity. For baseload production the renovation of CHP-3, increasing its generating capacity from 173 to 450 MW, is most relevant. This renovation results in substantial increase of constant reliable gas-based electricity.

Lastly, solar and wind energy complement each other and therefore a certain baseload can be expected from these sources as well. Future energy system with major shares of renewable sources should also provide a baseload production IRENA (2015). Wind and solar can provide this for a certain amount, because of their complementary characteristics. Figure 28 presents the outcomes of a stable baseload production of solar and wind in Germany. Though, for Almaty RES production could experience higher variability since the RES production are probably positioned within limited distance.

To conclude, although with current generation rates the margin of baseload electricity production seems small, there are various factors to increase the production. Moreover, solar and wind generate some baseload production as well collectively. However, most important, this analysis should be conducted with reliable, specific local data, as baseload production capacity is a fundamental aspect of energy security.

Average monthly power from wind and solar PV in Germany

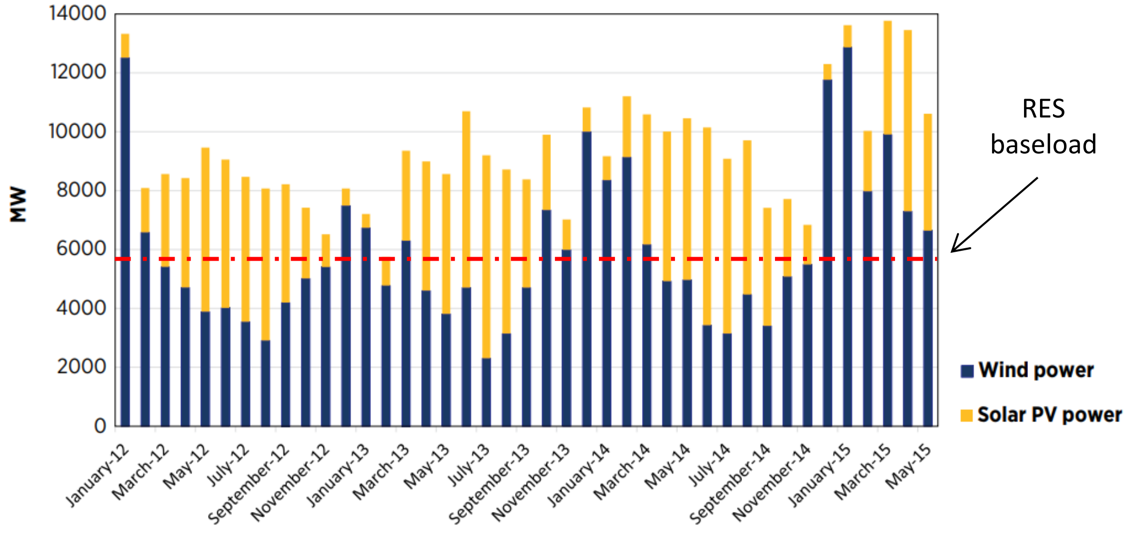


Figure 28: Baseload generated by solar and wind between 2012 and 2015 in Germany
Source: IRENA (2015)

Peak production in RES scenario

Secondly, it was analysed whether sufficient electricity can be produced during peak demand since Almaty often experiences hot summers, electricity peaks can be substantial due to cooling systems.

As mentioned in the methodology, it is assumed for Almaty that peak demand consists of around two times the baseload, so an increase of 100%. Figure 29 illustrates that peak production capacity of CHP-1, CHP-2, KEGOC and the HPP's combined suffices to produce peak demand in the 2015 situation. Besides, gas fire plants, which CHP-1 and CHP-3 are, and hydro energy are specifically sufficiency for short power increasing since production can be increased instantly. However, when the same energy reduction measures and expected growth are implemented as for the baseload, current installed peak capacity falls slightly short to cover peak demand in 2050.

Peak production capacity (excl. CHP-2) and peak demand

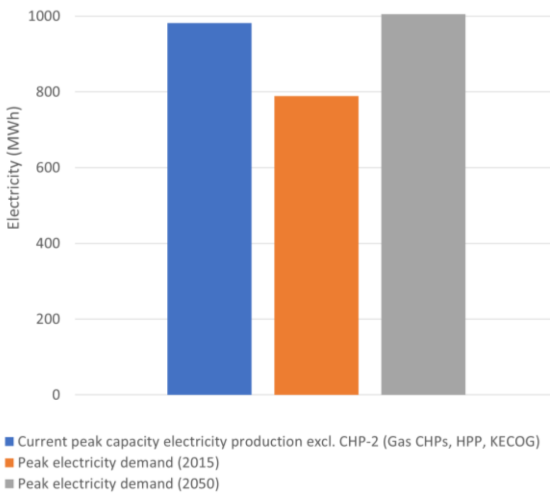


Figure 29: Current peak production capacity (excl. CHP-2) and peak demand in Almaty

Although, peak capacity demand seems sufficient for the coming years, with current installed capacity (excl. CHP-2), the margin are thin, since installed peak production capacity only has a 20% margin with peak demand currently and this margin is only around 10% in 2050. However, within this analysis it is excluded that solar and wind also produce a certain load of base energy, and therefore it can be assumed that the peaks do not completely rely on the traditional sources. Lastly, various projects are planned to increase peak capacity, such as the previously discussed CHP-3 renovation. And additionally increasement plans for HPP Kapshagai from 80-150 MW, and a minor increase of HPP Moinak by 11 WM (100 GWh/year) (Samruk Energy, 2022d). Collectively renovation projects result in an additional installed peak capacity of around 360 MW. However, similar as to the baseload demand, reliable local data should be obtained to validate these analysis.

District heat supply

CHP-2 obtained a dominant position in Almaty's energy sector since besides the 38% of electricity generation, CHP-2 also produced 48% percent of the city's annual heat production. Compensating CHP-2 by a RES alternative thus impacts the heat production sector. Therefore, analysing this sector was important. The more since heat is a dominant type of energy in Almaty because of the harsh climate. For example, district heat (DH) comprised 65% of all energy for municipal buildings and 38% percent of residential buildings (World Bank Group, 2017). Although heat could be generated by electric boilers powered by RES, the situation without RES was analysed because of variable energy generation and the timely process of realising infrastructural changes to electrify the DH system.

Despite the dominant role of CHP-2 in Almaty's DH sector, various sources contain sufficient capacity to generate heat. Figure 30 shows the installed generation capacity of heat generating sources. District heat peak generation is based on the assumption that all heat is produced in 180 days for 10 hours a day (World Bank Group, 2017). However, precise reliability of this assumption is not significant, since the shares of installed capacity and the division of production loads over the various plants concludes on the production capacities. These installed capacities and share of production loads are assumed to be reliable, as they originate from the World Bank (2017) report.

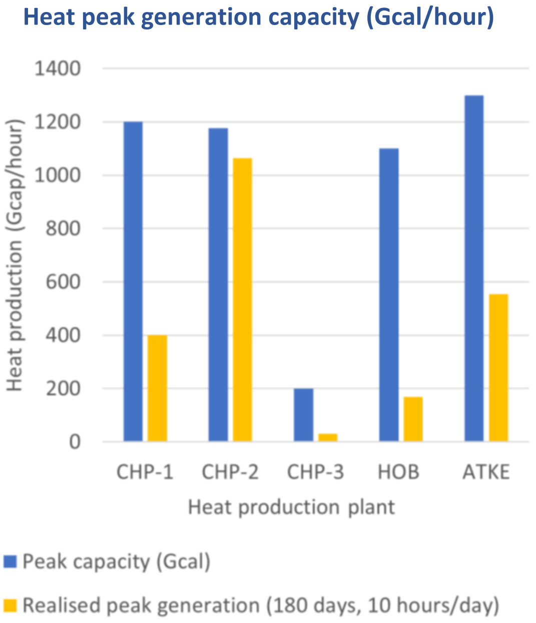


Figure 30: installed peak capacity versus realised peak production (assumed all heat was produced in 90 days for 5 hours pe days)
Source: The World Bank, 2017

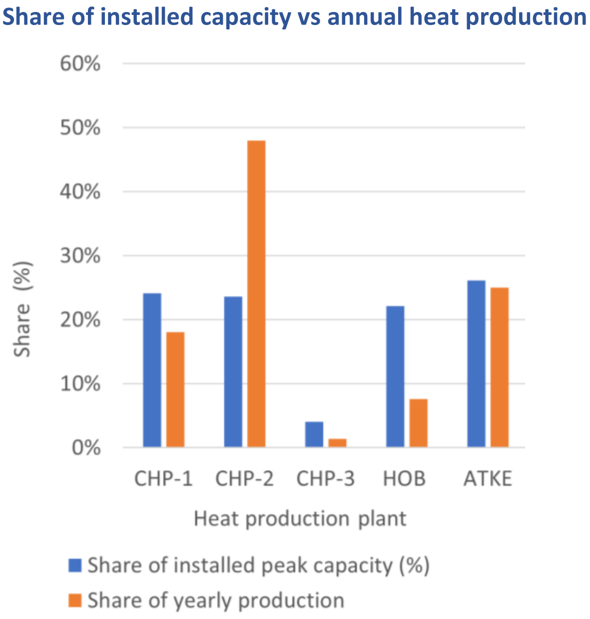


Figure 31: share of installed capacity of power plants versus actual share of annually produced heat per plant
Source: The World Bank, 2017

Most important, depicted by figure 31, is the division of DH production compared to the installed generation capacity. Although, CHP-2 produces 48% of Almaty's district heat, the installed capacity only determines 24% of total installed generation capacity. Various DH sources contain similar generating capacities, such as CHP-1 (24%), HOB (22%) and ATKE (26%). However, they generate substantial lower shares of total DH, CHP-1 (18%), HOB (7.5%) and ATKE (25%). CHP-2 produces majority of the DH, because of the fact coal-generated heat creates a financial incentive to maximise the generating capacity (World Bank Group, 2017). Figure … showcases that alternative DH production sources are able to compensate DH generated by CHP-2. For now, it is assumed that total generated heat for DH is the most important factor to determine the required installed capacity for all heating functions. Total installed capacity excluding CHP-2 requires 60% of its installed capacity to generate all DH currently being used during cold periods. Total DH contains 4 mln Gcal while installed capacity of CHP-1, CHP-3. HOB, and ATKE have a generating potential of 6.8 mln Gcal.

Besides, the financial incentive to maximize CHP-2's DH production disappears after the renovation from coal-to-gas based energy. Therefore, there is no direct financial incentive to oppose against the RES alternative from a heating perspective, as DH generation is still secured and the CtG-conversion eliminates the financial advantages of CHP2. However, these conclusions should be validated by local data because technological characteristics could results in specific local difficulties.

Second, the planned modernisation of CHP-3 increases the generating capacity (173 to 450 MW) and suitability for DH generation (Samruk Energy, 2022a). This modernisation increases the total generation capacity significantly, as the contribution of CHP-3 on DH production is marginal. Assumably, Almaty's total DH capacity remains equal if CHP-3 is renovated and CHP-2 is phased out.

Last, as previously discussed, energy demand reduction and reuse of existing source should be optimised prior to increasing installed capacity, in accordance with the Trias Energetica. The World Bank (2017) concludes on a energy saving potential of 27% on the build area, which results in significant reduced heat demand as vast amount of energy in the build area concern DH (65% of municipal buildings and 38% of residential buildings). Potential for local reuse of heat waste (e.g. industrial activities and waste processing) and opportunities for renewable heat production (e.g. geothermal energy) should be explored for future heat supply instead of adding new capacity. Especially since current installed capacity suffices total heat demand. The energy saving potential and excessive installed capacity of current DH production sources is confirmed by various local anecdotes concluding that windows were wide open during colder period as excessive DH was produced, and internal temperature could not be managed. This is conform the outcome of sufficient, maybe even excessive, heat generation capacity.

The main limitation that should be validated by local sources is the interchangeability of DH across sources in Almaty. It is uncertain whether all DH is interchangeable in the city, and therefore some production plants may not be connected to each other. However, the probability that this limitation forms a serious risk for phasing out CHP-2 seems minor. First, CHP-2 and HOB are already connected according to The World Bank report (2017). HOB is the production plant mostly performing under its capacities, with only generating 7.5% of total heat, while comprising 22% of total installed generating capacity. Second, The World Bank report (2017) includes plans to connect CHP-2 and CHP-1 as DH production sources. Therefore, connection to interchange the heat from CHP-1 in the area of CHP-2 appears already to be planned. Lastly, various infrastructural changes are required due to obsolete piping of the DH system. This major operation could probably also include connection certain district heat systems with decreased cost implications due to the planned operational activities.

IX. Discussion

In previous sections, the position of the CHP-2 CtG-conversion within Almaty's wider energy goals from the three individual dimensions is studied. This discussion section is used to combine and interpret the results and interrelatedness of the dimensions within the broader scope of Almaty's energy transition. The intention is to provide in-depth insights for policy-makers and urban planners on the assessment framework of CHP-2's CtG-conversion, its role within the wider energy goals of Almaty, and (long-term) consequences. First, the aim is to relate the dimensions, present nuances and provide additional insights. Second, additional limitations, validity, and suggestions for further research are discussed.

Overall, the CtG-transition of Almaty is a very complex process, including various actors, interests, and dynamics, that are interrelated and collectively sustain current dynamics. The best way to describe Almaty's energy situation is by referring to Geels (2014) *'carbon lock-in'* which entails the self-maintaining process of a fossil fuel based energy system because of significant interests of various societal aspects (e.g. political, economic, technical, social). The incentives of various dimension are interconnected and together maintain the system. The carbon lock-in is positioned on a split between short term and long term thinking. Short term thinking is identified by current fossil energy system that is maintained by the governmental actors to sustain economic growth in order to maintain political stability. Due to current pricing systems, subsidies and investments in fossil infrastructure, energy suppliers and industrial actors maintain their fossil fuel based activities as they are profitable and low-risk. The profitability and current market dynamics prevent new technologies and RES alternatives to penetrate the market (see figure 32).

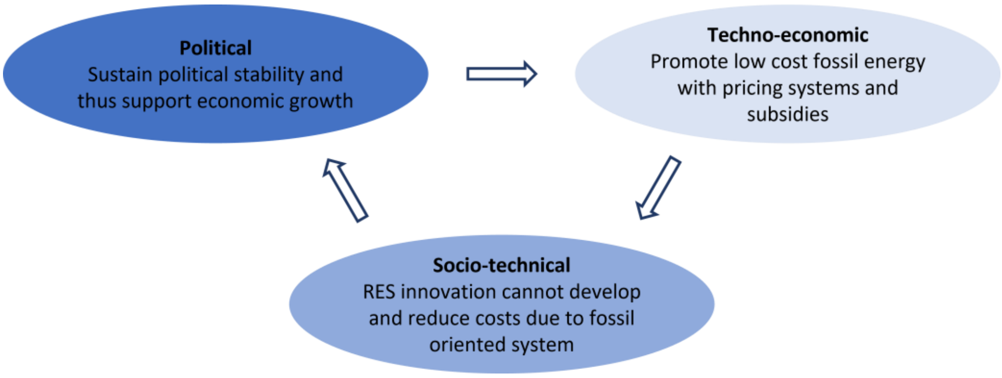


Figure 32: Illustration of carbon lock-in with self-maintaining system per dimension

This short term vision is dominated by temporary economic growth and political stability. However, it neglects a long term approach, characterised by genuine climate goal efforts, changing dynamics of the energy market, path dependence, economic diversification, and high future infrastructural costs. The CHP-2 CtG-conversion plays a crucial role within this carbon lock-in, as it obtains an important role in Almaty's energy network and the investments steer Almaty's energy development (path dependence) since investments are for a minimum of 30 years. The impact of the CHP-2 conversion and the resulting carbon lock-in is briefly interpreted per dimension, integrated, and recommendations and insights are provided.

1. Interpretation and integration

The **techno-economic dimension** is typified by unexploited potential for RES implementation. The techno-economic analysis concluded that implementation of renewable energy is suitable from various starting points This study focussed on exploiting potential of solar and wind energy because of Almaty's suitable natural circumstances, complementary characteristics, and cost competitiveness (Bogdanov et al., 2019; IRENA, 2022; Karatayev et al., 2016; Karatayev & Clarke, 2016).

First, current electricity network appears robust enough to start implementing renewable sources and phasing out CHP-2. The baseload production suffices the demand when considering that existing power plants (gas and HPP) can increase their constant production and necessary shortages can be imported from KEGOC. Besides, RES provides a certain baseload and capacity increasement of existing power plants is planned. However, with current electricity generation margins are thin, so increased grid capacity must be assured. Peak load demand from existing sources appear to be sufficient in the 2015 sources, even with a 10% uncertainty margin. Besides, baseload production from RES and imported energy from KECOG are not included. For future scenarios the peak generation capacity probably requires increased capacity. Though, various planned developments should secure future peak demand. Besides, sufficient time is available to adapt the energy infrastructure for 2050.

Second, implementation of renewable energy is favourable over fossil sources from an (long term) economic perspective. Especially, since normally high capital investments prevent RES implementation, as these investments are already fulfilled for existing fossil based plants, and sometimes even amortised. Although, capital investments for the CHP-2 conversion are lower than the RES alternative, they are still substantial and reduce the entrance barrier for RES implementation. Even more because RES will be increasingly important in the future due to rising fuel prices and carbon permits for fossil energy.

Third, a RES scenario is preferred with regard to air pollution reduction and climate ambitions. The CHP-2 CtG-conversion reduces carbon emissions cumulatively with 40% in 2050 compared to current coal-based situation. The RES alternative achieves 85% reduction, assuming that CHP-2 emissions stop after RES implementation. Considering that the city council aims to fulfil their (binding) energy ambitions, serious efforts to reduce fossil energy dependency and increase RES capacity are a necessity. However, current installed capacity of RES, should produce around 4% of total electricity supply (AstanaTimes, 2022). Therefore, they have to increase their RE production by 7.5 times before 2030 in order to reach the 30% renewable electricity goal (Nazarbayev, 2012).

The most important limitation for the techno-economic dimension is that results are deduced from relatively high-over quantitative analysis based on various averages and assumptions. Therefore, validation with local data essential. However, still the analysis present a calculated estimation of the opportunities for RES implementation, and the benefits compared to gas-based energy. Specific limitations of the techno-economic dimension within this study, besides the aspects explained in the methodology, consist of oversimplification of reality and a limited scope of technological and economic implications. These limitations are a direct result of limited data and a lack of local specificities.

First, oversimplification is experienced in the potential sites for solar and wind energy. These analysis are mainly based on data from the World Bank Group (2022), height maps and geographical images. However, site specific characteristics are not included. Second, energy variables such as LCOE, MW/ha and capacity factor consist of averages from other data. This leads to an oversimplification of the results as costs for total installation, maintenance and operation, fuel, and carbon permits will vary from the average of Europe and China. However, as previously discussed, some of these assumption (e.g. total installed costs) are realistic based on reference projects in the region.

Second, since three dimensions and their interactions are studied, time constraints limited the depth of analysis. For example, the implementation of RES entails various infrastructural and technical implications (e.g. baseload production, peak capacity, electrification of network). These elements are essential for large scale RES implementation and therefore elaborated in-depth research is required. For example, according to The World Bank Group (2017), measures are planned to replace 32 ATKE boiler houses and 100 small boiler houses. The RES scenario may imply that these boilers are (partially) replaced by electric boiler houses. In-depth financial and technical consequences for such implications were beyond the scope of this research.

The **socio-technical dimension** of Almaty's CtG-transitions finds itself on a crucial and unique crossroad in its energy system history. Many powerplants and infrastructural elements are obsolete and need repair or replacement, meaning that financial investments are required in the near future. The situation is an opportunity to focus on increased RES implementation, as large upfront investments are often a big hurdle for RES implementation. Existing power plants, despite their high M&O and fuel costs, are financially more beneficiary than new RES project because of uncompetitive pricing systems.

However, IRENA (2022) concludes that new fossil energy projects contain higher LCOE's than RES projects. And although, RES capital investments are substantially higher (7 times) than the CHP-2 conversion, it provides a crucial opportunity for Almaty to avoid renewed *fossil energy path dependence* and to breach the *carbon lock-in*.

Currently Almaty (and Kazakhstan) is situated in a carbon lock-in. Many economic, social, technological, and political factors favour short term focus on fossil energy. Politicians aim to foster growing GDP in order to maintain political stability. Current pricing systems, implemented to encourage GDP growth, stimulate industrial actors to maintain current activities. Therefore, industrial actors oppose to change, as they made fossil energy oriented investments, and current activities are profitable within the economic playing field. Due to this fossil energy oriented economy, technological improvements focuses on marginal improvements within current system, instead of radical shifts towards RES (Geels et al., 2017). Investments in CHP-2 and improved infrastructure around it, implies maintaining the carbon lock-in, and creating renewed path dependence towards fossil energy.

Path dependence is created when investments of the past, determine current/future developments. Investing in the conversion of CHP-2 and infrastructure, instead of RES, implicitly means a dominant focus on fossil fuel energy and al the political, economic, technological and social aspects it entails. Since the investments are for at least 25-30 years, this means that the infrastructure has to be improved and maintained for fossil based energy till 2050. However, some coal-based elements of current system are already active since 1970. Meyer (2004) and Pahle (2010) proved that previous transitions took decades, and are still going on. So, investing in CHP-2, without large investments in RES, entails decreased urgency and financial resources for realising carbon neutrality in 2060.

Avoiding fossil fuel path dependence and breaching with the carbon lock-in entails creating a socio-technical system that supports RES implementation. Supporting RES does require phasing out policies for the fossil fuel system. Actively managing phase outs includes: 1.) regulations that reduce emissions from fossil fuels; 2) changing market rules for decarbonization (e.g. carbon tax); 3) reduced support (such as tax breaks or subsidies) for high-carbon technologies; and 4.) policies to encourage social discussion and debate, such as the creation of new committees or networks (Geels et al., 2017; Köhler et al., 2019).

These measures are supported by the reinforcement loops of Bolwig et al. (2019) as regulation that reduce fossil fuel emissions lead to increased electricity costs, which lead to increased eagerness to invest and develop RES technologies. Technological developments lead to reduced production costs, and these costs reductions leads finally to decreased electricity prices. Encouragement of niche developments and technological improvements eventually result in the emergence of RES in the energy system regime. This emerge to the regime level should be supported by nudging actors to slowly break with fossil fuel dependency, to eventually break with the carbon lock-in, without disbalancing the political stability (see figure 33).

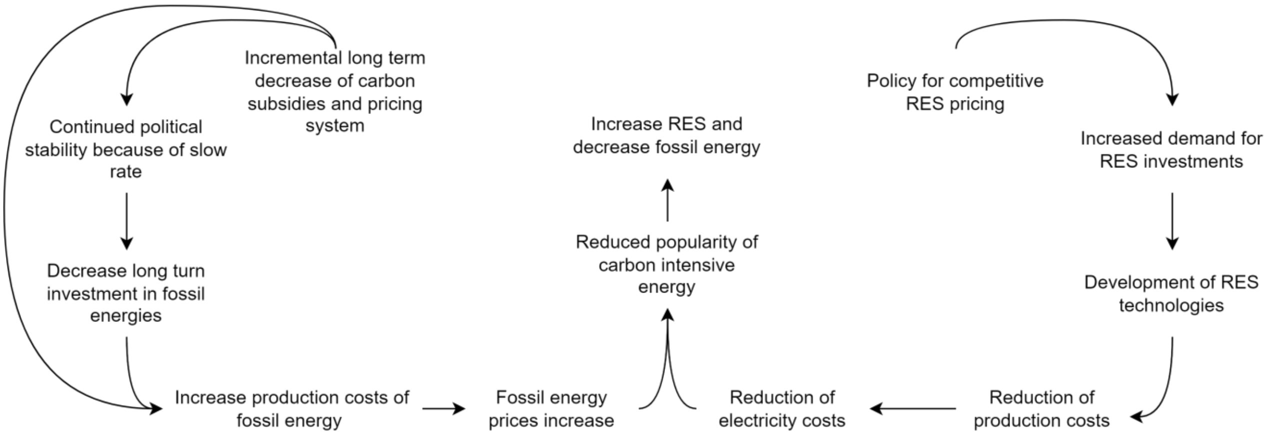


Figure 33: Two simultaneous feedback systems for breaching with carbon lock-in. Left: phasing out fossil energy; Right: stimulating RES implementation

The outcomes of the socio-technical analysis do contain some specific limitations. For example, the balance between gradually phasing out fossil fuel promoting policies and maintaining political stability is vague and unspecified in this study. Theoretically the phase out is a clear requirement for large scale implementation of RES and for conformation of honest effort to achieve stated energy goals. However, the precarity and fragility of Almaty's (and Kazakhstan's) energy situation was confirmed during the political unrest of early 2022. Determining specific policies or levels of policy phase outs is beyond the scope of this research, while determining the strategy for a phase out is extremely important for the success. However, most important is that governmental actors show commitment to (long term) energy goals by creating long term strategies, inform involved actors, and invest in the future (e.g. grid capacity increasement). These commitments are important to convince economic, societal and technological actors that the movement towards RES is genuine.

Second, landscape shocks are often needed to introduce radical emergence of new energy generation methods. For example, the Fukushima accident was such a landscape shock, and resulted in the reintroduction of Germany's nuclear phase out and large scale implementation of RES (Geels et al., 2017). However, in Almaty, such a radical event, that functions as a window of opportunity has not occurred. The obsolete infrastructure and required financial investments for the fossil energy system presents a good moment to actively start phasing out fossil energy, but it cannot be interpreted as a landscape shock. Contrary, the plans of converting CHP-2 prove the determination to make additional investments in current energy system, without radically investing in renewable energy. Therefore, it can be questioned whether the rational arguments for phasing out fossil energy are convincing enough to slowly disrupt current energy system. The analysis of this decision making process within the city council was beyond the scope of this research, and therefore remains a limitation.

The socio-technical dimension of Almaty is highly related to the political dimension, as policies and revisited pricing systems should steer the socio-technical systems towards change. This is in line with Cherp et al (2018) which states that (national) policy is central to niche development and thus regime shifts, which are fundamental factors for the fossil fuel phase out.

Almaty's CtG-transition assessment framework slowly boils down to the **political dimension.** Energy transitions have proven to take decades. Extended path dependence towards fossil energy and a maintained carbon lock-in must be prevented. Governmental bodies have to carefully, but steadily, manage the phase out of fossil fuel energy by creating competitive circumstances for RES implementation, support and protection of niche development, and discourage fossil energy production and investments. Various energy pricing systems have been proven to work in other countries (e.g. Germany, The Netherlands, Denmark), although it is always a slow paced and long term effort. The main goal is to find a balance between stimulating economic growth and maintaining political stability, but also phasing out fossil energy. Continuously supporting and subsidizing fossil industries, is short term acting, and maintaining the system artificially. Various reasons encourage to start phasing out fossil energy, and invest intensively in RES.

First, if binding international, self-announced climate goals, and local severe air pollution are taken seriously, a tremendous increase of effort is required to preserve the possibility of success. Especially since the location of CHP-2 and its emissions is proven to severely impact citizen's health (EBRD, 2022). Although NO_x emissions are eliminated, carbon emissions still negatively impact public health (Dong et al., 2021). These intentions of governmental actors are openly debated since aspirations are not in line with political decisions (Poberezhskaya & Bychkova, 2021). Various examples have proven that energy transitions take decades to execute. So, obsolete infrastructure and required investments could be stimuli for long term planning in accordance with intended ambitions.

Second, current economy benefits from fossil fuel supportive measures on the short term, but it should be adapted for long term profit and sustainability, as major trade partners are actively moving away from fossil fuels. For example, after 2030, oil imports by Europe are expected to decrease by circa 78% and natural gas imports by 58-67%, while 80% of Kazakhstan's energy exported is directed to Europe (Clingendael, 2021). Trading agreements help stabilising (alternative) income stream, but also result in increased policy influence by neighbouring countries. Especially Europe's product standards focus on reduced carbon emissions, energy efficiency and sustainable product sourcing. Therefore, trade agreements and dependence on neighbouring countries, should stimulate Almaty to actively start implementing RES and alternative economic income streams. Long term adaptations towards a fossil free economy must start, as future drastic change of the energy system harms the economy, political stability and is probably not realistic.

Third, long term sustained economic growth lies in maintaining heterogeneous income streams that do not solely rely on natural resources. Stimulating RES creates market opportunities for alternative businesses and increase the variety of income streams. And countries that invest most in RES technologies, such as China, Denmark and Germany, obtain currently most competitive RES prices. Major trade partners are moving faster away from fossil fuels. So, Kazakhstan has to increase its pace and utilise fundamental decisions moments, such as the CHP-2 conversion.

Last, Almaty contains high economic potential for RES implementation. Stimulating multiple energy production sources increases competition, which result in cost reduction, and thus lower energy prices for consumers. However, currently competitive technologies cannot emerge due to price systems for fossil energy.

In short, the political dimension has a fundamental role to find a balance between remaining political stability, but simultaneously preventing renewed path dependence and a sustained carbon lock-in. This should be achieved by the stimulation of RES niche development implementation, and discourage unequal pricing systems and fossil fuel subsides, to stimulate the emergence of RES in the regime of Almaty's energy system.

The main limitation regarding the political dimension is that this study does not elaborately include potential solutions to resolve the tension between long-term sustainability and short-term political interests. However, short-term political gains regularly exclude long-term and integrated action, and policy implementation (Laes et al., 2014). For Almaty, the short-term benefits are highly important since economic growth provides various opportunities for societal development, GDP growth and political stability. Although, the tension between short-term politics and long-term sustainability measures are stipulated in this study, elaborated and in-depth analysis are not provided.. Though, this tension and how to cope with the dilemma is extremely important for progression towards the announced energy goals. Heinrich and Biermann (2016) argue for systematic institutionalisation of sustainability politics as a prerequisite of assuring long-term progression and prevention for short-term political action. However, the design of this institutionalisation is beyond the scope of this research, although it is an essential element for sustainable success. The reduction of severe air pollution, causing large scale damage to public health, could function as a strong political motivation for short-term investments in large-scale RES implementation (World Bank Group, 2017).

Overall, Almaty's CtG-transition with the conversion of CHP-2 is mainly a dilemma between long term or short term planning, and political prioritisation and decision making. Techno-economically and socio-technically increased implementation of RES is feasible and favourable as it reduces carbon emissions, improves public health, seriously adds to achieving climate ambitions, promotes energy cost reduction, is economically favourable in the future, and helps maintaining trading relations with neighbouring countries. First, politically a balance between realistically promoting RES and maintaining economic growth is required to slowly but steadily move towards increased RE implementation, without causing immediate political unrest. Financial support of RES and incremental decrease of fossil fuel pricing systems and subsidies are essential. Figure 34 presents the Almaty case implemented in the framework of Cherp et al. (2018). The original diagram of Cherp et al. (2018) comprehensively illustrates multidisciplinary dynamics of energy transitions. Figure 34 presents the multidisciplinary dynamics that are dominant in Almaty energy transition. The fundamentals are similar to the framework, however specific characteristics for Almaty are implemented and minor adaptations are implemented to create a case specific framework.

Second, renewed path dependence towards fossil fuels and a maintained carbon lock-in should be prevented. The CtG-conversion of CHP-2 is an opportunity to distance from a complete fossil based energy system, without disrupting the energy system immediately since reliable backing mechanisms are available, energy security is not endangered in the near future, infrastructural costs are expected to be manageable, and implementing RES happens gradually while phasing out CHP-2.

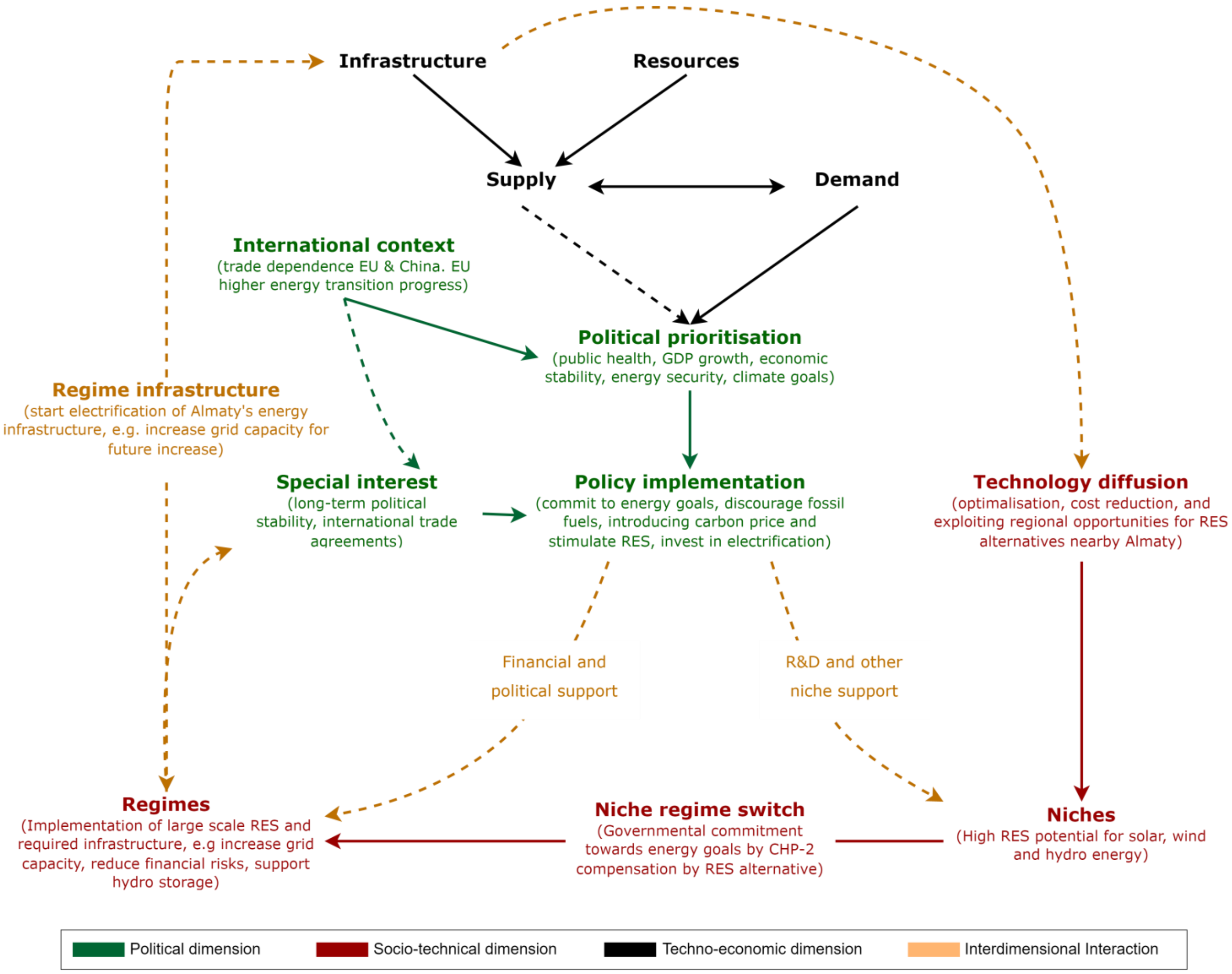


Figure 34: Socio-technical, techno-economic, and political interaction, based on the Cherp et al. (2018), but specified and adapted for Almaty CtG-transitions
Source: Cherp et al. (2018)

The leading role of the political dimension is confirmed and stipulated by various sources (Baktymbet et al., 2020; Karatayev et al., 2016; World Bank Group, 2018). Decisions and policies implemented by political actors catalyse development in the energy transitions in the techno-economic and socio-technical dimensions. Political actors should promote analysis of energy transition challenges and opportunities, together with local experts, industrial parties and NGO's. Subsequently, sufficient funding for introducing and implementation of renewable technologies to the market should be provided. Last, financial resources should be available to cover the unprofitable top compared to existing fossil based costs. These supports should be maintained at least until the techniques have passed the 'learning curve' whereupon they result in the least cost alternative transition pathways.

2. Alternative pathways

The energy transition is a long term process, entailing different actions, within different local characteristics, during specific times. Because of the complexity and multidisciplinary of the process a single quick-fix solution is non-existent (Köhler et al., 2019). These characteristics are applicable on Almaty's energy transition as well. Therefore, focus areas had to be selected in this study, resulting in excluding certain aspects (e.g. energy sources, technical implications).

The current situation, consisting of an outdated system that requires investments for CHP-2 and infrastructure, results in a major opportunity to start the phase-out of current fossil fuel system. Although the phase-out should be carefully managed, it should foremostly get started in the first place. The importance of starting the phase-out, because of its impact on sustainability transitions, is stipulated by various sources and casus (Geels et al., 2017; Geels & Turnheim, 2022; Köhler et al., 2019; Pahle, 2010). Analysing opportunities to start phasing out current fossil energy system was one of the main priorities. This resulted in analysing possibilities that were relatively well studied in the region of Almaty, for which sufficient data was available, and provided opportunities to catalyse the phase-out on a relatively short term. Eventually, this resulted in the focus on mostly solar and wind energy. This section reflects on the motivation, consequences and limitations for focussing on solar and wind, and thus leaving out alternative sources Almaty.

Motivation to focus on solar and wind

This study mainly focussed on unexploited potential for solar and wind energy because of Almaty's suitable natural circumstances, their complementary characteristics, and cost competitiveness (Bogdanov et al., 2019; IRENA, 2022; Karatayev et al., 2016; Karatayev & Clarke, 2016). Other clean(er) energy techniques, such as geothermal, hydro, nuclear energy, are excluded for varying reasons.

First, additional to the existing 664 MW installed hydropower capacity, the potential for increased hydropower capacity near Almaty is limited. Additional planned small hydropower adds up to 130 MW installed capacity (Eshchanov et al., 2019; Samruk Energy, 2017). Although this capacity is valuable for stabilising the network, especially due to the variable generation characteristics of solar and wind, additional potential is marginal and therefore not included within this study.

Second, geothermal energy is excluded from this research as the majority of existing studies concluded on limited potential or excluded it entirely (Bogdanov et al., 2019; Karatayev et al., 2016, 2016; PwC, 2021). To our knowledge, only Boguslavsky et al. (1999) concluded on substantial potential for geothermal energy in the Almaty region. Studies that mention geothermal energy potential refer to this study (Laldjebaev et al., 2021; World Bank Group & ESMAP, 2019). Furthermore, data to explore geothermal energy potential near Almaty is limited as well, and it is not acknowledged in geothermal modelling tools, such as ThinkGeothermal. Although, geothermal energy has not received much attention yet, further research on potential sources is highly interesting as geothermal energy could be a valuable addition to the variable electricity generation of solar and wind (IRENA, 2021a). Especially since district heating forms a major share of the final energy consumption in Almaty during cold periods, which forms a challenge for large shares RES in the future. However, currently this data is not available, and therefore beyond the scope of this research.

Last, nuclear power is not included in this research for three reasons. First, Almaty's specific energy goals focus mainly on increasing the share of solar and wind energy (RWA, 2020b). Second, the LCOE of new nuclear power plants are not competitive with solar and wind energy (IEA, 2019a). Newly commissioned nuclear energy plants are more than three times as expensive than onshore wind and two times more than solar energy, based on global averages (IEA, 2019a; IRENA, 2022). Lastly, the construction time for building a nuclear power plant contains 11-12 years, which is far more than solar or wind energy (Shykinov et al., 2016). Within current assessment framework, the relatively simple and short term implementation of solar and wind energy is expected to be favourable. Especially, within the short term goals that Almaty has for increasing renewable/clean energy shares (i.e. 30% RE in 2030). However, with the abundance uranium resources, nuclear energy could play a valuable part for Kazakhstan's national energy provision (World Bank Group, 2018).

Although this research presents various arguments for favouring the RES alternative over the CHP-2 conversion, the two options are not necessarily mutually exclusive. This study concludes that compensation of current energy demand by RES is feasible with a buffer for future energy growth. However, these conclusions are based on assumption and contain uncertainties. Therefore outcomes should be validated by local data and experts..

Consequences of varying outcomes, based on local data, should be taken into consideration. For example, as previously mentioned, Almaty imports electricity from KEGOC. This electricity is 1.5 times more pollutant than ALES energy. KEGOC energy is mainly coal-based, so gas-based energy would be preferred considering the carbon emissions. So, when RES implementation eventually leads to substantially more import of coal-based energy from KEGOC, the result is still unfavourable. Therefore, the gas-transition could be identified as "the best second option".

Once more, it is mostly a matter of prioritization in accordance with the *Trias Energetica.* First, the (EET) reduction measures are planned and will be implemented in coming years. The second step is to reuse (local) waste streams within the system, which is not included in this study. The third step, however, is producing energy from renewable sources as much as possible. This study concluded that current energy system should be able to assure energy security in the near future when CHP-2 is phased out. Therefore, the focus should mostly be on implementing RES, analyse and develop reliability by combining sources (e.g. solar, wind, hydropower, geothermal), develop storage techniques (e.g. hydropower pumps, thermal energy storage), and adapting infrastructural needs for a RES oriented system. Lastly, during the transitions phase towards a renewable energy system, energy supply should be secured by fossil fuel sources that are as clean as possible. However, when appears that energy security cannot be secured after implementation of RES, long term KECOG energy import should be avoided, and then increased gas-based energy, could be the "second best option".

As mentioned, this is all about prioritisation since according to the analysis there is no direct need to heavily invest in extra fossil fuel capacity. RES investments should be prioritised since additional fossil investments results in path dependence and an extended carbon lock-in.

Finally, another often recurring discussion in energy transitions is the potential and future implementation of *Carbon Capture Utilisation and Storage (CCUS).* CCUS refers to the process of directly capturing CO_2 from the production source (e.g. fossil fuels), and where this CO_2 is used for secondary processes (e.g. synthetic fuels, chemicals, materials) or stored for longer periods of time (IRENA, 2021d). An important remark is that CCUS reduce adding additional CO_2 to the atmosphere, and thus does not fully eliminate carbon emissions (IRENA, 2021d).

CCUS is not included in the analysis for this study for several reasons. First, the Trias Energetica prioritises production of renewable energy over clean and efficient usage of fossil energy. Furthermore, step 4 'generate energy clean and efficient with fossil resources' has been removed from the Trias Energetica steps in later versions because these sources are preferably prevented (Van Den Dobbelsteen & Tillie, 2011). Current CCUS techniques are still carbon emission reducing methods instead of being renewable. Therefore, in accordance with the Trias Energetica, this study prioritises renewable energy production over efficient usage of CCUS. Second, this study aims to provide realistic and reasonable insights and recommendations for Almaty's CtG-transition. Various political, institutional and academic sources confirmed technological opportunities and stimulated implementation of renewable energy sources (Bogdanov et al., 2019; Karatayev et al., 2016; MacGregor, 2017; Nazarbayev, 2013; World Bank Group, 2018). CCUS, on the contrary, was not mentioned in any of these sources between 2016 and 2021. Lastly, the LCOE of CCUS is not expected to be financially competitive in the near future (IEA, 2020a). IRENA (2022) ranges the LCOE of CCS (gas) for 2021-2025 between 0.145 - 0.185 \$/kWh, compared to 0.060 \$/kWh and 0.042 \$/kWh for solar and wind (global averages). Only when carbon prices raise substantially, to around 50 \$/tCO_2 for coal and 100 \$/tCO_2 for gas, CCUS can be a viable option compared to existing fossil energy plants (IEA, 2020a). However, these ranges are still not competitive with solar and wind energy.

To conclude, RES alternatives are prioritised over CCUS in this study. However, this does not entail they are mutually exclusive in the coming future. However, due to the aforementioned characteristics of CCUS and the challenges of breaching the carbon lock-in and renewed path dependence RES alternatives are preferred and therefore extensively studied.

Consequences of focus on solar and wind

Although, a focus on solar and wind energy was necessary and the argumentation may be valid, exclusion of other techniques has implications on the research outcomes. In the long term a dominant focus on solar and wind energy may comprise complications. For example with regard to lacking diversity of renewable production sources, suboptimal heat generation methods, and required large scale energy storage. This section discusses these implications and reflects on them in the context of Almaty's energy situation.

First, the selection of solar and wind energy narrows down investigation towards various other potential energy generating sources. General consensus agrees that future energy system requires a diverse mix of various renewable (or cleaner) energy generation sources (IRENA, 2019a). This is due to the often variable generation due to dependence on sun hours, water (reservoir) levels, and wind speeds. And secondly because of varying types of energy from renewable sources. For example solar and wind are most suitable for electricity generation, geothermal for thermal energy, and biogas as fuel for vehicles and machinery. This study focusses on solar and wind since it is most potential to start phasing out fossil energy, breach the carbon lock-in and prevent renewed path dependence. However, in this study this contained generating electricity from solar and wind to convert into heat for district heating, when analysing the compensation of CHP-2. Although electricity can be converted relatively efficiently to heat, on the long term other sources are more suitable. Heat production based on solar and wind requires vast amounts of electricity, that is produced variably. In the future, this method requires substantial network capacity increasements and (thermal) energy storage to supply large scale district heating. Therefore in the future alternative sources should be analysed for heat generation, for example waste energy from (heavy) industry or geothermal energy. However, currently solar and wind energy fulfil their role as a first step towards phasing out fossil energy, while traditional plants remain operational to secure baseload demand and peak generation capacity.

Second, the focus on solar and wind will heavily impact the requirements for future electricity network. The process of electrifying various sectors such as transport and industry, require substantial increasements of the electricity network. However, the impact of compensating CHP-2 by solar and wind is manageable, especially since various traditional sources are still operating. Although some investments in the electricity network might be required, they are expected to be limited in this stage.

As mentioned before, the focus on solar and wind should function as a start of the energy transition of Almaty. Future energy systems design and dynamics remain uncertain yet. Future developments should be designed according the Trias Energetica principle. Therefore, energy efficiency should firstly be increased. Current energy efficiency measures already plan to reduce electricity network losses by 42%, heat distribution losses by 34% and electricity and heat for the build area by 27% (World Bank Group, 2017). These measures are planned to be implemented before 2030 and therefore reduce the impact of compensating CHP-2 by solar and wind energy. On the long term the Trias Energetica will determine how much energy can be reduced, what energy streams are reusable (e.g. heat waste from the industry), and lastly what energy sources are preferred to design a stable energy system. Therefore it is possible that various other generation sources, such as geothermal energy, CCUS and nuclear energy, should be added to the future energy system.

3. Internal and external validity

Internal validity has long been unsure during conducting this research. Normally, local specific data and various interviews with local actors should guarantee the internal validity. However, due to the pandemic and political unrest, it was not an option to visit the case site for a longer period of time, to create connections, set up meetings, and collect data. Many hours were invested in getting in touch with experts, which eventually lead to an exploratory online interview. However, various efforts to set up connections, and collecting data, with other relevant actors (e.g. EBRD, ALES, city council) were unsuccessful. Difficulty of connecting to people online have definitely impacted the outcomes.

However, the aim was to assure internal validity by obtaining as much local data as possible within the possibilities, by first focussing on local specifics, than national data, and otherwise selected averages of similar cases. When feasible the data was validated by reference cases.

Although, **limitations** of (local) data collection have been discussed in the methodology, it is important to reflect on it post-research conduction. Secondary data has been collected, structured and analysed, mainly from 2015. This data is extensive and recent, however additional (local) data collected from local reports and experts would be preferable, for example more specific data on the electricity network and power plants (e.g. peak- and baseload demand/capacity, network capacity, local gas/RES electricity costs) and current political challenges. Additional local data could validate current outcomes, which is an essential step as energy projects are highly local specific. This validation would also be important for assuring internal validity.

External validity is guaranteed by the extensive multidisciplinary research framework, as the research can be extended to other cases. The study structure, with the multidisciplinary research framework and analysis per dimension, is applicable to other case studies. The wide starting point of the study is especially suitable for energy transition, as these transition are case specific and depend on various techno-economic, socio-technical and political characteristics. Based on this study, challenges could be prioritised and specific bottlenecks for the energy transitions can be identified.

It would be especially interesting to apply the research framework to similar cases in where cities heavily rely on coal as well. Although outcomes will differ, it is interesting to compare the dynamics and especially to analyse how political, socio-technical and techno-economic dimensions vary and what solutions are suitable. Considering the coal dependency of Almaty, this specific study is most relevant for countries/cities experiencing similar challenges, for example Western European and Mid-Asian countries.

4. Further research

Further research can be divided in two directions; local research focussing on the energy transition of Almaty, and studies on the multidisciplinary dynamics of energy transitions focussing on urban areas in general.

Additional research for Almaty can be divided in four aspects, namely research on local specifics of the three individual dimensions discussed this study, and their interrelatedness.

First, additional research on the political dimension within Almaty could focus on connecting short and long term strategies. So, how to balance current economic growth and political stability, with long term sustainable urban planning and development with its beneficiary financial, technical and political consequences. This is directly related to the long term strategy for the fossil phase-out. What decisive moments and opportunities occur in the future that can function as a momentum for RES implementation and breaching with the carbon lock-in?

Second, local dynamics, data, and expert insights can provide in-depth solutions for local socio-technical challenges. First, setting up a competitive pricing system for RES implementation is important. Studying this would go hand-in-hand with four previously mentioned aspects; 1.) implementation of sufficient carbon reduction regulation per sector, 2.) abandoning existing fossil energy supporting measures, 3.) redesigning market rules to catalyse decarbonisation, and 4.) implement policies to include and motivate actors to take part in the debate and create awareness.

Second, reduction of investment risks for local and international parties could be studied. For example how to show governmental commitment that sustainability is the long term goal (e.g. investing in increased grid capacity, energy storage), and creating favourable financial incentives (e.g. reduce currency risks, lending conditions). Third, further research could provide insights on how governmental investment maximise the impact of RES emergence in the energy regime. If the local government stimulate this emergence (e.g. invest in infrastructure, niche protection measures) technological development increases, production costs reduces, and therefore breaching with conventional fossil energy system is stimulated. Last, spatial consequences can be studied by local partners. For example, local data can determine the optimal combination of spatial preference and electricity production of solar and wind energy. Or further study can analyse spatial consequences of (partial) power-to-heat infrastructural changes.

Third, additional research with local data and experts can provide insights on techno-economic matter. First, local infrastructural and technological specifics could be validated, such as the electricity backing capacity of existing sources, district heat generating capacity and infrastructural connection, grid capacity for RES generation, and primary steps for electrifying the build area. Second, local in-depth analysis of financial criteria could be obtained. For example, quantifying the local LCOE for solar and wind on this scale and structuring additional infrastructural costs if they are required.

Last, local characteristics on the individual dimensions can support additional research on Almaty's future energy scenarios. Energy modelling tools can assist in designing future energy scenarios, including various additional RES besides solar and wind. For example, research on the individual dimensions can clarify long term strategies and potential for reuse of local energy waste streams, geothermal energy sources, nuclear energy or CCUS. The energy scenarios should be designed based on the Trias Energetica principle that include local insights on saving potential, reuse opportunities and various renewable energy generation capacities.

To conclude, further research can take the outcomes of this study to the next level by specifying current opportunities and bottlenecks for starting the phase-out of CHP-2, and researching long term strategies and preferred design for a sustainable energy system that breaks with current carbon lock-in and helps achieving Almaty's energy ambitions.

Next, it would be highly interesting if further research extrapolates the research method of this study, concerning the multidisciplinary dynamics of energy transitions, on various other urban areas. This setup could generate additional insights on the dynamics of energy transition in heterogeneous urban areas. This would be interesting for a variety of reasons.

On the one hand, such studies could be conducted on similar coal-dependent urban cases to analyse similarities and differences with the Almaty case. When multiple cases are studied, some best practices can be obtained for coal-based energy systems, and what solutions and designs are preferred for specific challenges.

On the other hand, the research framework can be extrapolated to various heterogeneous cases to analyse the three dimensions and their interrelatedness. Urban areas with different political, socio-technical and techno-economic dynamics will conclude on different solutions. For example, it could be that technological potential for RES is the major barrier, or that a lacking socio-technical system for RES innovation and implementation is the main challenge

Both types of further research can contribute valuable insights on the energy transition within the urban realm. The challenges are numerous, substantial, and heterogeneous. So different studies add to various strategies to tackle this challenges.

X. Conclusion

Almaty finds itself positioned on a crossroad of the energy transition concerning the CHP-2 CtG-transition. The three dimensions of the research framework (i.e. socio-technical, techno-economic and political) are highly involved in the project, and by analysing the dimensions and their interrelatedness, conclusions on CtG-transitions within the wider energy ambitions of Almaty can be identified. The analysis provide an extensive assessment framework and recommendations for local governments, policy makers and urban planners of Almaty. The study provides insights on opportunities and challenges of the CHP-2 CtG-conversion within the various dimensions, which provide long and short term consequences and a RES alternative. Besides, the study and research design provide valuable information to conduct similar research on other urban areas confronted with energy transition challenges. Insights resulted from answering the sub-questions, eventually enabled to answer the research that was stated as:

> ***How does Almaty's CtG-transition of CHP-2 fit in the wider energy goal to become carbon neutral in 2060 from a multidisciplinary - techno-economic, socio-technical and political - perspective? And what are alternative energy transition pathways?***

In short, analysis of the political, socio-technical and techno-economic dimension of Almaty's energy system and their desired ambitions, concluded that the conversion of CHP-2 from coal-to-gas should preferably be prevented. Based on analysis, this is assumed to be technically feasible and economically favoured on the long term. Current circumstances of obsolete energy infrastructure and required capital investments create a unique momentum to greatly improve the city's progress towards renewable energy, actively start the fossil energy phase-out, and make progress towards their energy goals. Large investments in CHP-2, without prioritising RES implementation, result in renewed path dependence towards fossil energy in the future, and majorly complicate the circumstances to achieve their climate goals of 30% RES in 2030 and carbon neutrality in 2060.

This study concludes that an alternative pathway based on solar and wind energy is feasible within Almaty's existing energy infrastructure. The RES alternative is technically feasible, with current backing mechanisms, and economically preferable for the future. The RES alternative is a significant step in creating a sustainable energy system, and additional renewable/clean energy potential could be added to create an optimal sustainable energy infrastructure for Almaty in the future.

Six sub-question (SQ) were set up to structure the analysis and obtain insights for the research question. In the remainder of this conclusion the outcomes of the study are elaborated, based on these sub-questions.

> SQ1: What is the current state of literature on the role of a multi-disciplinary approach techno-economic, socio-technical, political - of energy transitions?

From the literature study it was concluded that established studies on energy transitions stipulate the importance of integrating multiple dimensions in energy transitions through system thinking because of its complex and interdisciplinary nature. Leading in this debate is the fact that many energy transition analysis predominantly focus on techno-economic elements, but that interdisciplinary approaches that include, social, economic, technical, political and cultural aspects are required to better represent reality. Besides, multidisciplinary analysis should be incorporated in assessment frameworks for energy transitions. For example in projects as the CtG-transition of Almaty.

Therefore a research framework was implemented that focussed on three main dimensions of multidisciplinary analysis (e.g. socio-technical, techno-economic and political) and their interrelations within energy transitions, supported by first- and second level variables per dimension.

SQ2: What is the current energy situation of Almaty?
SQ3: What are specifics of the coal-to-gas transition?

Almaty's energy system is characterised by energy-intensive infrastructure and build area, and highly obsolete infrastructure and power generation plants, which results in inefficient energy usage. This study focussed on the energy production and distribution sector, and the build area sector, as these sectors are major consumers of electricity and district heat, and are therefore deeply connected to the CtG-transition and the CHP-2 conversion. The build area (i.e. residential, public, commercial and industrial buildings) consume around 80% electricity and district heat. The electricity network endures distribution losses around 16%, and district heat endures distribution losses of 20%. Various actors are active in Almaty's electricity and district heating sector, such as ALES, KECOG, and ATKE. For ALES three CHP's and two HPP plants are most important for electricity and heat production.

The project of conversing CHP-2 from coal-to-gas based energy functioned as the starting point of this research. The project entails converting Almaty's biggest power plant (510 MW) from coal-to-gas based energy in order to reduce carbon emissions, and thus air pollution in the city. CHP-2 produces c. 37% of Almaty's electricity and 48% of its heat supply, with annual CO_2 emissions of c. 6.5 mln tonnes. The primary goal of the CtG conversion is to reduce the city's carbon emissions, and to completely eliminate NO_x emissions. Total project expenditures are 680 million USD.

The three dimensions of the research framework are studied separately to identify the energy landscape of the CtG-transition. The various dimensions are all related to the energy goals of Almaty and their interrelatedness is eventually decisive on the impact on the energy goals.

SQ4: How do techno-economic characteristics of the CtG-conversion relate to a renewable alternatives for Almaty?
SQ5: What are characteristics of the socio-technical dimension for Almaty's CtG-transition? And how does this comply with their wider energy goals?
SQ6: What are Almaty's energy policy (goals) and political dynamics regarding the CtG transition and its wider energy ambitions?

The **techno-economic dimension** is characterised by unexploited potential of renewable energy in the Almaty region. Various analysis concluded that a RES alternative based on solar and wind energy is favourable from a financial, technical and carbon emission point of view.

Financially, current LCOE for onshore wind energy is already competitive with current fossil electricity in Almaty, and the LCOE for solar PV is nearly competitive. Besides, the LCOE for coal and gas will increase in the future due to high M&O costs, and rising fuel and carbon prices. This conclusion does entail that Almaty's fuels prices and carbon price increase according to global expectations. Although long term financial predictions present beneficial LCOE for renewable energy, the substantial upfront capital investments to compensate CHP-2 by RES, in combination with investment risks, form a major barrier for realisation. But the required investments in obsolete infrastructure and renovation of CHP-2 create suitable circumstances, that lower the investment barrier in RES.

Technically the implementation of solar and wind energy to compensate CHP-2 in Almaty is feasible as well. The analysis concluded that existing power plants contain sufficient baseload and peak electricity and heat generation capacity to support relatively variable RES energy production. Especially, when planned reduction measures are taken into account. Though, reliable data collection form a limitations, thus local data analysis is required to validate the outcomes. Besides to sufficient generation capacity, existing electricity infrastructure is available nearby potential RES area, and therefore infrastructural costs are expected to be relatively small. Last, the Almaty region contains perfect conditions for wide implementation of solar and wind energy due to it scarcely populated and unplanned open areas. Therefore, direct spatial implications form no direct limitation to RES implementation. However, long term infrastructural implications due to large scale electrification towards carbon neutrality remain unsure. These developments should be planned, although there is no immediate urgency because of existing infrastructure. However, grid capacity increasement should be stimulated since the near future will depend more on electrical energy rather than fossil fuels if the government commits to set energy goals.

Considering the carbon emissions, the RES alternative remains the most attractive alternative. Converting CHP-2 eventually results in a cumulative carbon emission reduction of c. 40% in 2050. Though, air pollution remains a damaging factor for public health. Contrarily, the RES alternative, completely eliminates carbon pollution after the implementation is completed, which results in a cumulative carbon reduction of 85% in 2050. Conclusively, since the city council proclaims that reducing air pollution and protecting public health are the most urgent factors for the CtG-transition and conversion of CHP-2, implementing the RES alternative is the reasonable and impactful strategy.

The **socio-technical dimension** of Almaty's existing fossil fuel dominated energy system is characterised by being stuck in a carbon lock-in. However, current obsolete infrastructure and need for financial investments provide a window of opportunity to breach this lock-in and avoid renewed path dependence towards fossil energy, as investments in the energy system are indispensable which lowers the entrance barrier for renewable alternatives.

First, in order to start breaching the carbon lock-in, various collectively implemented steps are required to make RES become competitive with fossil energy. First, implementation of sufficient carbon reduction regulations. Second, abandoning existing fossil supporting measures (e.g. tax breaks, subsidies). Third, adaptation of market rules to catalyse decarbonisation (e.g. competitive pricing, rising fuel prices, carbon tax). Last, create policies that include actors in the debate, create awareness, and encourage social discussion (e.g. creating social committees, working groups, surveys).

Second, stimulating RES alternatives and eliminating fossil promoting measures creates a playing field in which various techniques can compete for implementation. Due to this 'level' playing field the emergence of technological development is promoted, which leads to better RES techniques and cost reduction, and therefore increases the attractiveness of renewable alternatives. Preventing renewed path dependence and breaching the carbon lock-in enables niche developments to emerge on regime level, which results in wider implementation.

Action in the **political dimension** is required to catalyse the energy transitions, promote RES implementation, to breach with the carbon lock-in and to prevent renewed path dependence on fossil energy. Various (political) arguments favour RES stimulation for Almaty on the long term, such as decreasing fossil fuel dependency, increasing citizen's health, (inter)national climate ambitions, ambitious energy transition activities of major trade partners, and a chance to diversify economic activity. Political actors have to decide between short term economic growth and political stability, or long term planning towards a sustainable and diversified energy system. Two policy cycles have to be adapted. First, regulations of fossil fuel energies have to gradually be phased out. A gradual, but steady, phase-out is required since economic growth and political stability are major (short term) political drivers that should be maintained. Second, stimulating policy for RES development and implementation are required since currently RES cannot compete sufficiently with fossil fuel alternatives, and therefore cannot penetrate the heavily fossil oriented market.

Almaty's existing energy systems contains many barriers that oppose to reaching set climate goals. Most important is to breach the dependence on fossil energy from an economic, technical, and political point of view. This dependency is identified as a carbon lock-in, and additional investments in Almaty's gas-based energy infrastructure lead to renewed path dependence on fossil fuels, and a remained carbon lock-in. Implementing solar and wind energy as RES alternative for the CHP-2 conversion is an important step towards breaching the carbon-lock in and stimulating renewable energy increase. Therefore the city council should consider large investments in the implementation of renewable alternatives, and start phasing out CHP-2 instead of renovating it, in order to achieve significant progress towards climate ambitions, and prevent another carbon lock-in.

This study leads to the following recommendations for the city council, policy makers and urban planners in Almaty, with regard to the CtG-transition and the wider energy ambition of the city to be carbon neutral in 2060.

Recommendations for Almaty

1.

Prioritise RES implementation for compensating CHP-2 over the conversion from coal-to-gas since this is preferable for long-term political, socio-technical and techno-economic aspects.

2.

The urge for the CHP-2 renovation and infrastructural investments provide unique opportunities to start the fossil energy phase-out, prevent new carbon lock-in and renewed path dependence. High infrastructural investment often form a major barrier, which is decreased by current situation. This unique situation should be a call for action. Start acting today, prevents drastic and unrealistic investments towards a renewable energy system in the future. Phasing-out CHP-2 is a first and moderate step to gradually convert current energy system towards a renewable oriented system.

3.

Progressive (political) action for phasing-out CHP-2 should start because the long term strategy towards renewable energy is supported by various long term rewards:

- Drastically reduces carbon emissions
- Maximises improved public health
- Major achievement towards energy goals
- Promotes energy cost reduction and technological improvement of energy generation, distribution and usage
- Preferred with long term financial scope
- Stimulates economic diversification
- Helps maintain long term trade relations by heterogeneous income sources and increase of energy standards

4.

Proactive local political action by the city council, policy makers and urban planners is required to breach the impasse of the carbon lock-in and catalyse the implementation of renewable energy. Actions that could be politically organised are:

- Create a long term political strategy that ensures political stability and economic growth, but simultaneously guarantees the fossil phase-out to breach the carbon lock-in and path dependence.
- Show commitment to energy goals by public investments in long term energy system of the future (e.g. increased grid capacity, balancing capacity, research RES and storage potential), and support of niche development (e.g. competitive RE tariffs, subsidies). This reduces investment risks for international and industrial actors, and therefore decreases investments barriers. Phasing-out CHP-2 would be a convincing start.
- Increase political support for the CHP-2 phase out by creating awareness and promoting that public health and long term economic stability are the most important stimuli.
- Public awareness and available information should also stimulate RE microgeneration.
- Exploit Almaty's position as large and well-developed city to be Kazakhstan's market leader of the energy transition, adapt national policy, and set up pilots to learn and share lessons.

5.

Despite the various in-depth analysis and some local comparisons, the outcomes of this study should be validated by local specific data and experts. Local validation resolves local issues and result in case specific plans, especially regarding the technological, spatial and economic feasibility.

The Almaty case is representative for various coal-dependent urban areas, for example in Western Europe, post-Soviet states and (Middle-) Asia. The major conclusion is that multidisciplinary analysis provide clarity on the challenges and opportunities per dimension, which result in specific clear bottlenecks needed to overcome to catalyse the transition. Multidisciplinary analysis help to identify decisive moments by analysing the individual dimensions and their interrelatedness, which creates structure in the complexity of the energy transition. Eventually the multidisciplinary framework results in focus areas that help prioritise action that catalyse the energy transition.

This study concludes on three broader recommendation, as lessons for other urban areas to analyse their energy transitions, whether this is coal-dependent or not. The recommendations include insights on the implementations and usefulness of a multidisciplinary framework.

Recommendations for other urban areas

1. Multidisciplinary analysis for (urban) energy transitions are valuable since they generate a complete impression of opportunities and challenges and where the bottlenecks for energy transitions are. This study can be an example for specific areas where the coal-to-gas transition in combination with long term renewable energy ambitions are active.
2. Analysing the three dimensions expose their individual challenges and opportunities and how these can specifically be tackled. However, integrating and relating the three dimensions is an essential step to comprehend the complete challenge and to prioritise solutions.
3. It is recommended to conduct similar research in collaboration with local partners and experts, supported by locally obtained data. This limits the need for assumptions and results in most reliable and case specific solutions, which is especially relevant for energy transitions as energy systems are unique and require case specific designs.

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XII. Appendices

Appendix A: Literature review on multi-dimensional dynamics in energy transitions

Current state of literature of energy transitions

In order to study the energy transition of Almaty and their CtG-transition, various academic literature on modelling and analysing energy transitions has been studied. Recurring themes were the technical feasibility versus practical implementation in society (Gielen et al., 2019), a need for drastic system change - radical shifts - and the challenges that it brings (Geels et al., 2017; Köhler et al., 2019), and various visions and analysis on how to comprehensively and accurately model sustainability transitions (Bolwig et al., 2019; Cherp et al., 2018; Li et al., 2015).

Drastic progression in sustainable energy systems to avoid climate change and simultaneously improving energy accessibility, increasing energy security, and decreasing air pollution, is assumed to be technically feasible regarding various analysis (Gielen et al., 2019). However, increasing our renewable energy generation from about 10% today to at least 60% in 2050 requires a drastic system change, or paradigm shift, in the power sector. Gielen et al. (2019) states that such a drastic change can only be mobilised through a systemic approach that includes and mobilises various types of innovations. Cities are crucial in realizing energy transitions because of their inherent relation to energy. Cities are political arena through which change is invented, implemented and experienced in always unique ways (Rutherford & Coutard, 2014). In order to realise energy transition ambitions (e.g. sustainability, security, affordability, etc.) a deeper understanding of socio-technical change is required, that relates to context-specific conditions, inertias, barriers, pitfalls, and the stakes of winners and losers (Rutherford & Coutard, 2014)

A literature study concluded the vast majority of established research on sustainability and energy transitions promote for a system thinking approach integrating multiple disciplines (Gielen et al., 2019; Köhler et al., 2019; Turnheim et al., 2015). Leading in this debate is the fact that various energy transition analysis mainly focus on techno-economic elements, but that an interdisciplinary approach, which includes, social, economic, technical, political and cultural aspects is needed to come to required results and carbon reduction (Geels et al., 2017). One prominent and often discussed question within energy transition analysis is how to include various interdisciplinary aspects in energy modelling, as this currently focus on quantitative data from an techno-economic approach (Gielen et al., 2019; Li et al., 2015)

Energy system modelling is relevant for this research since the aim is to analyse the impact of the CtG-transition of Almaty within its current energy ambitions. Therefore it is interesting to study how an interdisciplinary approach can be integrated in energy system modelling. Li et al. (2015) evaluated various modelling tools that aim to integrate techno-economic, socio-technical and political elements to quantitatively analyse energy transitions. Secondly, Cherp et al. (2018) identifies the three main perspectives of energy transition - socio-technical, techno-economic, and political - and combines them in a persistent meta-theoretical framework that can be used in analysis. Geels et al. (2017) reasons in line with this and also discusses the three perspectives within energy transitions. They argue that the socio-technical and political dimension should be intensively included in the debate, and suggest lessons to consider in future low-carbon analysis. Lastly, Bolwig et al. (2019) designed a framework that includes the dynamics between the three perspectives, that function as a recommendations for implementing the perspectives in quantitative models.

Dynamics of energy transitions

Dimensions on energy transitions

Studies towards energy transitions have been conducted from distinctive theoretical perspectives. Energy transitions are presumed as a coevolution of three differing systems, namely (Bolwig et al., 2019):

4. **Techno-economic systems** characterised by flows of energy, such as energy conversion, production and consumption directed by the energy market,

5. **Socio-technical systems** identified by socio-technical dynamics that influence the emergence and embeddedness of technological innovations
6. **The system of political actions** shaping the formulation and implementation of energy related policies

Important for understanding the complex energy transitions dynamics is a basic understanding of the three varying perspectives since they differ highly in concepts, variables and their theoretical origins of systems change and continuity (Cherp et al., 2018).

1. The techno-economic perspective

The techno-economic perspective approaches socio-technical systems, thus energy systems, as an entity of energy flows of energy inputs that deliver services. Energy inputs (e.g. natural gas, coal, nuclear, biomass) enable conversion devices and processes (e.g. engines, burners, CHPs) to supply heat or electricity to activate passive systems (e.g. buildings, machines, computers, vehicles) to deliver services for end-users (e.g. transportation, (thermal) comfort, assistance). Moreover, it includes material consumption and many technical aspects, such as transmission and distribution systems, road infrastructure, railway signalling systems, gas and pipelines, etc. The techno-economic dimension consists of material goods, factories, infrastructures, and input and output flows of supply chains (Geels & Turnheim, 2022). Due to its material and financial character techno-economic systems are relatively easy to quantify e.g. Sankey diagrams), and therefore economic norms can be applied to these services. Therefore techno-economic models and theories can be applied to energy processes and flows, as the physical energy flows and conversion processes are traded in markets and can be considered as production and consumption goods. However, due to this economic nature, subject to supply and demand dynamics, it is also prone to economic lock-in mechanisms, such as sunk investments, economic competition standards, and economies of scale, since it is likely that large and powerful industries will protect their vested interests and when their position is pressured (Köhler et al., 2019). Above circumstances and current systems makes it challenging to catalyse change and implement new technologies and standards in existing stabilised markets (Geels & Turnheim, 2022).

A limitation for the techno-economic perspective is that various dimensions and societal aspects are excluded. First, techno-economic (quantitative) approaches have sophisticated instruments to explore decision-making processes and policy targets. However, it limitedly considers challenges regarding social and institutional inertia, and the interplay between interests and politics in a real-world context (Turnheim et al., 2015). Policy is encountered as a fixed number of measures with clear outcomes, but reality is non-linear and capricious. Second, challenging phenomena as inertia, path dependence, and technological innovation cannot be overcome from a techno-economic perspective. Inertia and path dependence occur due to powerful economic, political and social interests, embedded in current systems (Turnheim et al., 2015). The techno-economic perspective tends to neglect intangible factors of transitions, for example institutional and cultural aspects of socio-technical development, political power and willingness, and the non-rationality (irregularity) of real-word processes (Turnheim et al., 2015). Thus in order to comprehend energy transitions are mere techno-economic perspective does not suffice, due to its limited thinking and exclusion of political and socio-technical factors.

2. The socio-technical perspective

Socio-technical systems

The socio-technical perspective tends to depict are more holistic and integrated look that analyses multiple dimensions of change, which include a wide variety of technological, economic, political, and socio-cultural aspects at different levels (Turnheim et al., 2015). Socio-technical systems provide societal functions that consist of co-evolving and interdependent interactions of technologies, supply chains, markets, infrastructure, user practices, cultural meanings, regulations, and policies. Examples of urban socio-technical systems are building, heating, mobility, and food systems. Since many societal actors are included in socio-technical systems, their development is a long term process which stretches over decades (Geels et al., 2017).

The socio-technical perspective is closely related to socio-technical transitions, and research on these systems and transition are motivated by the recognition that many environmental problems (fossil fuel depletion, decreasing biodiversity, global warming) are caused by unsustainable socio-technical systems. These systems elicit unsustainable consumption and production patterns that cannot be solved by merely technological fixes, but require radical societal shifts towards new sustainable socio-technical systems. These transitions are called sustainability transitions, and the energy transitions plays an major role in it (Köhler et al., 2019).

Sustainability transitions

Four major theoretical framework have gained significant acknowledgement within the field of socio-technical transitions, namely *transition management* (TM), *strategic niche management* (SNM), *multi-level perspective* (MLP), and *technological innovation system* (TIS).

The *multi-level perspective* (MLP) explains technological transitions through the interaction between three different levels: niches, regimes and landscape. In general the theory concludes that landscape dynamics might pressure existing regimes and create windows of opportunities for niche innovations, that might find their way into the hard-to-disrupt regime. The niche break through can contribute to shifts and fundamental change at the regime level. The niche-regime-landscape interaction highly depends on different dynamics, characteristics and timing. *Strategic niche management* (SNM) is considered as the process to deliberately influence and start the motion of regime shifts through the creation and promotion of niches and their innovation. *Transition management* (TM) combines information on the complex systems theory, governance approaches and the work on technological transitions. Transition management concerns influencing ongoing transition towards more sustainable direction through conceptualizing existing sectors as complex, adaptive societal systems and considering management to be an evolutionary and reflexive governance process. Relevant topics of TM concern problem structuring and envisioning multi-stakeholder processes, implementing (new) agenda in experiments and evaluating and monitoring processes. Lastly, *Technical innovation systems* (TIS) focus on the emergence of new technologies and the organisational change and institutional implementation required to integrate them in existing systems. The analytical interest of TIS has switched form the contribution of niche innovations to national economic growth to the introduction of new technologies as catalysator for fundamental socio-technical transitions (Markard et al., 2012).

The multi-level perspective (MLP)

The MLP is probably mostly related to energy transitions, and this theoretical framework is also mentioned by various scholar involved in energy transitions, e.g. Bolwig et al. (2019), Turnheim et al. (2015) and Geels et al. (2016). Due to its wide announcement and fitting characteristics within the Almaty case the MLP is a bit more elaborated on. The MLP states that socio-technical transitions involve the three interconnected levels: the landscape, regime and niche level.

The *niche level* is rapidly developing, but does not often prevail. They focus on radical social or technical innovations that highly differ from the existing socio-technical system and regime. However sometimes, with particular applications or with help from policy instruments for example, these innovations can prevail in the existing regime. Niches are fundamental in the emergence of novel technologies, which can occur in protected environments (e.g. market regulation, subsidies, etc.) where radical innovation can develop without being pressured by prevailing regimes and existing market competition. Windows of opportunities - momentum of disruption in existing regimes - provide possibilities for niches to compete with existing technologies and to eventually stabilise in new regimes (Markard et al., 2012).

The *socio-technical regime* is a fundamental concepts within socio-technical systems, and sustainability transitions in general. The core concept of the regime consists of logical and incremental changes in the socio-technical system along predictable pathways of development (Markard et al., 2012). Socio-technical regimes can be defined as societal systems where incumbent actors are guided by deeply entrenched rules, regulations and institutions (Geels et al., 2017). For example, various actors are active in the car industry (manufactures, dealers, policy makers, engineers, users) and together they form a strong balance with rules (policy), infrastructure (roads, factories), economic interests (retailers, dealers, garages) and socio-cultural aspects (user behaviour, transportation standards). Regimes are resilient and stable in order to overcome external pressures, internal breakdowns and disruptions. The role of the regime is to ensure that systems can fulfil their important social function. The main interest of various scholar is the idea of *regime shifts* (transitions) and factors forcing destabilisation of current regimes and the emergence of new regimes. Sustainability transition has been a central idea within the concept of regime changes from the beginning (Markard et al., 2012).

The socio-technical landscape level refers to wider societal contextual developments that impact the regime level and over which regime actors have little or no influence. Landscape level developments involve both slow changing movements (e.g. ideology, geopolitics, demographics, etc.) and exogenous shocks (e.g. financial crises, large scale accidents, wars, political unrest, etc.). The MLP describes the occurrence of transitions through the alignment of processes between the interdependent three levels (Geels, 2002).

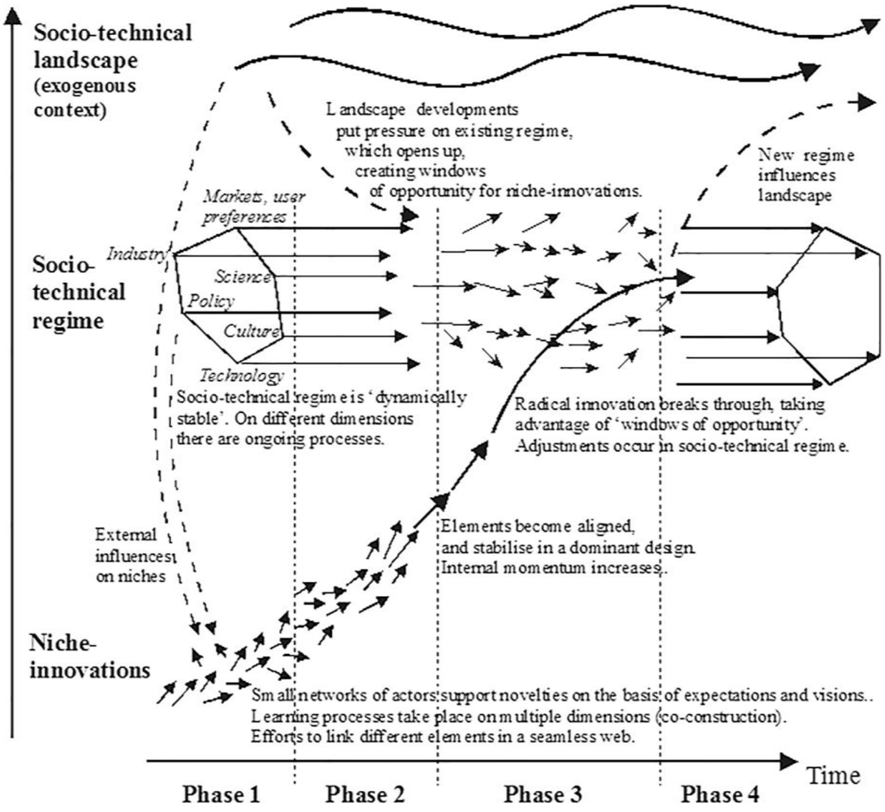


Figure A: Illustration of the multi-level perspective on socio-technical transitions
Source: Geels et al. (2017)

Figure A illustrates the interrelatedness of the three levels. On the niche level various radical innovations develop. They try to integrate within the regime level, however of many niche innovation only few succeed, due to various circumstances. They succeed when the windows of opportunities occur within the stable regime level due to (radical) changes in the landscape level (e.g. war, crisis, food scarcity). When new technologies integrate with the regime level a new stability occur that influences the landscape level. The three levels together form wat Geels (2002) calls the socio-technical landscape and are an interplay of changes and innovations within the individual levels that form new balances.

A comprehensive example provided by Geels et al. (2017) is the car-oriented transportation system, which is heavily embedded in most Western countries and account for 80-85% of all passenger distances. The system contains many incumbent actors and is sustained by various formal and informal institution, as preferred car users, dependents on car based economy (manufactures, technicians, suppliers, sales man), infrastructure engineers, politicians maintaining Their support base, cultural associations in favour of car usage, etc. The example powerfully depicts how deeply rooted and embedded a car-based system is in our society. See figure B.

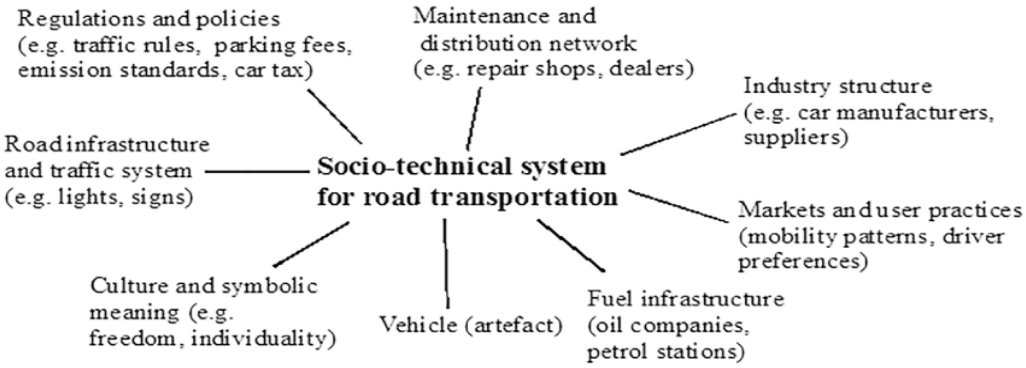


Figure B: Illustration of the embeddedness of a car oriented system in our society linked to various formal and informal institutions.
Source: Geels et al. (2017)

Innovations might be beneficial for regimes to survive or expand, for example the uptake of renewable energy to become less dependent on fossil fuels. However, penetrating or changing socio-technical regimes (e.g. current fossil fuel energy system) is difficult since new innovations that threat the regime's stability may be blocked (e.g. market parties with vested interest). The robustness of socio-technical regimes results in two dominant phenomenon that complicate and oppose adoption of changes, new market players and innovation, namely *lock-ins* and *path dependence.* Lock-ins refer to mechanism that seduce actor to rather promote incremental change than radical change. They oppose actors to change their activities due to vest interests, and thus stabilise existing systems and thus negatively influence change. Various forms of lock-ins exist, such as techno-economic lock-ins (e.g. sunk investment costs, low costs, material obduracy), social and cognitive lock-ins (e.g. behavioural routines, habits, mindsets), political lock-ins (e.g. existing regulations, standardisation of existing system, rules creating unequal playing field for innovations) (Geels & Turnheim, 2022). The *carbon lock-in* refers to a positive feedback loop towards stabilising the existing fossil fuel system. It refers to economic, political and institutional lock-ins that reinforce current fossil fuel system (Geels, 2014). Mahoney (2000) identifies path dependence as *"that has happened at an earlier point in time will affect the possible outcomes of a sequence of events occurring at a later point in time."*. So, political, technical or economic decision previously made are influencing todays energy system, and decision made today are influencing future energy systems. Since societal transitions often take decades, these are important factor to take into account for the Almaty case study.

Socio-technical regimes are sensitive for both path dependence and technological lock-ins. These two phenomena are important since socio-technical analysis is specifically interested in innovation that can overcome these issues. Innovations that are able to overcome technological lock ins, happen outside existing regimes in systems that are call *niches.* Niches are described as socio-technical systems which are unstable, have fluid boundaries, and are therefore capable of letting radical innovation occur. Smart novelties can mature and become competitive in these (protected) niche systems, which they cannot in existing regimes due to high costs, complexity or misfits with existing infrastructure. The importance to support and facilitate these technological innovation in protected niche systems is specifically stipulated in the *Strategic Niche Management* (SNM) approach (Cherp et al., 2018).

A major influential framework on socio-technical transitions is the *multi-level perspective* (MLP). This framework highlights that the robustness of regimes prevent technological niche innovations from easily changing regime systems, even when they become more effective in a social system. Destabilization or disruption is needed for niches to replace an existing resilient regime. This happens for examples due large scale external events that pressure the existing regime. This large scale embedded level is called, landscape. Pathways that lead to regime destabilization occur mostly rapidly with a non-linear pattern (Cherp et al., 2018).

3. The political perspective

Within many socio-technical transition studies the political dimension is included, since it seeks to analyse multiple dimensions. The political part is therefore often regarded as an integrated part of the socio-technical perspective in transition studies instead of a separate perspective. However, Turnheim et al. (2015) concludes that these socio-technical analysis have limited forward orientation on political goals. Moreover Meadowcroft argues that the political dimension deserves a more prominent role in sustainability transitions. He argues that political aspects in sustainability transitions contains more than just the interrelatedness of economic interests, technological feasibility and policy on which the economic and socio-technological dimension react. The political arena in which transitions take plays includes more than policies and holds great potential in sustainability transitions (defining the landscape, (de)stabilising regimes, protecting or exposing niches), and should therefore be a separate dimension to attain explicit attention. Besides he concludes that without crucial political power certain decisions and transitions directions would not have been possible (e.g. CCS projects in the Netherlands) (Meadowcroft, 2009, 2011).

The study of policy change is conducted in various domains of political science with varying epistemological practices and ontological assumptions (Cherp et al., 2018). The political perspective within energy transitions focusses on how policy adaptations and implementations affect energy systems. For energy transitions the policy perspective regularly focusses on the national level, as the majority of energy policies are implemented by the government who act in interest of the state (Cherp et al., 2018). Regional governmental bodies mostly have to design and implement policy regulations for policy goals set by the national government. For example, the Kazakhstani government signed the Paris Climate Agreement, obtained *Nationally Determined Contribution* (NDCs), which are mostly translated into detailed and specific plans by regional governments (IEA, 2020c). This central role of the state distinct the political perspective from the techno-economic and socio-technical perspectives, where the state usually functions as a normal economic actor, an element of the external landscape, or a steering factor for normative guidelines (Cherp et al., 2018). Within political perspective the motivation of political parties and a lack of political will can influence the pace and realisation of transitions (Geels et al., 2017).

Of interest for the energy transitions is the debate about the autonomy of the state and the manner to which policy decisions reflect preferences of public officials and other actors. Cherp et al. (2018) refers to Hall's typologies who identifies two dimensions to discuss varying positions of the state, namely *state-centric* and *state-structural.* Regarding energy transitions, the state-centric approach assumes that energy policy goals are imposed by national interest. The national interest for example enables the state to dictate policy measures for secure supply demand balance of energy. Contrary, the state-structural approach concerns what scholars phrase at 'the politics of energy policy'. This approach suggests that the policies implemented by the state merely reflects competing interests of various actors, such as voting residents, lobby groups, NGOs/social movements, and political parties. Governmental bodies may therefore be steered in decisions to implement certain energy transitions directions (e.g. gas, nuclear, RES) in order to maximise their political support, and therefore votes. Geels et al. (2017) reflects on this dynamic of political influence in transitions within the energy landscape of Germany, where renewable energy technologies came up rapidly, but where low-carbon transitions also have been delayed and blocked with the influence of political interference. Cherp et al. (2018) also argues that state energy policies could also be influenced by *special interests.* This reasoning suggests that interests of powerful actors in the energy field may influence the debate and decision making process of energy policies. This often depicts the political struggle between various powerful actors, such as industrial lobby groups, social (anti-)movements, and such. Geels (2014) states, within this strand of reasoning, that incumbent industrial parties use their power to prevent transitions from happening. Regarding this study, fossil fuel companies and actors highly involved in the regime play a fundamental role in the energy transition, which with their role in society, power and competing interests results in a socio-political struggle. The political landscape of Kazakhstan with various influencing factors internally but also internationally, with predominantly China, Russia and the European Union, makes that this dimension is important to take into consideration.

Dynamics of the three perspectives in sustainability transitions

Although the three perspectives discussed are semi-autonomous and have different boundaries, their changes are mutually interdependent and they evolve collectively. Currently, the techno-economic perspective predominant in analysing the implementation of sustainable energy sources. This entails quantitative analysis that focus on energy flows, conversion of energy, and market dynamics that influence energy consumption. The techno-economic perspective essentially analyses the energy transitions from theoretical economic, engineering, and earth science perspectives (Cherp et al., 2018). However, to fully comprehend the dynamics of energy transitions one should address all three systems since various studies concluded that the transition is not merely a technical matter, but is influenced as well by the values, strategies and behaviour of individual actors, and on policies, regulation and markets (Bolwig et al., 2019; Li et al., 2015). Despite the value of techno-economic analysis, it has limitations since it does not comprehensively consider the unpredictability of innovation, behavioural aspects of actors, policy steering mechanisms, and the spatial dimension of energy transitions (Cherp et al., 2018). In their paper, Cherp et al. (2018) comprehensively illustrate the interactions between the three perspectives (see figure C).

Studies of Cherp et al. (2018) and Bolwig et al. (2019) discuss how energy transitions analysis, frameworks and models can be more realistic by integrating the fundamental techno-economic, socio-technical and socio-political dimensions. Their theories and frameworks are central in this research since they comprehensively studied the dynamics, are conducted recently, are acknowledged by many scholars, and they appear to relate to the Almaty case study.

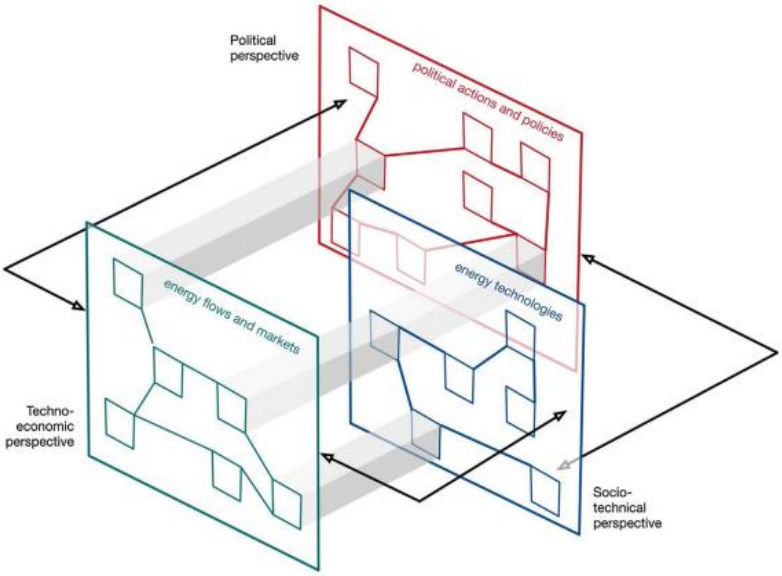


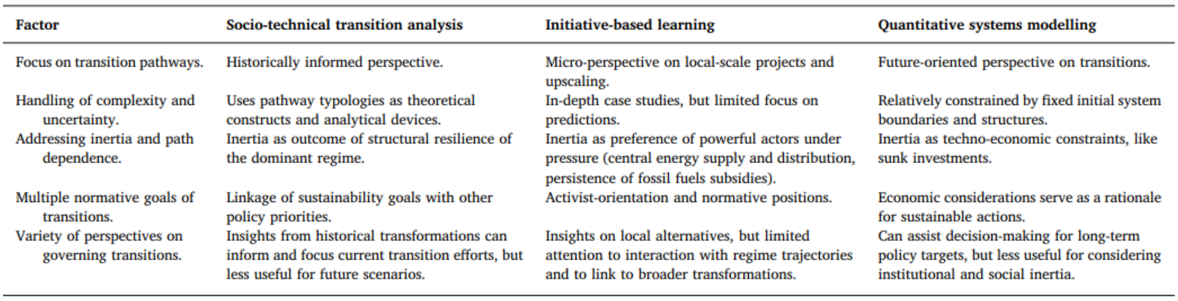
Figure C: Illustrated interactions of the three perspectives within the same real-life example (for example power plant)
Source: Cherp et al. (2018)

Despite the acknowledged interrelations and co-evolving nature of the systems, most existing energy transitions models lack inclusion of socio-technical and political factors. They frequently focus on quantitative techno-economic inputs, and lack inclusion of political aspects, involvement of societal actors, and poorly represent the co-evolving dynamics between technology and society (Li et al., 2015). Therefore, current models analyse energy transition oversimplistic and inaccurately. Besides, Gielen et al. (2019) state that even within existing quantitative models, widespread implementation of innovative technological solutions for generating renewable energy are often not feasible or commercially profitable yet. And if the technological solution exist, scale up frameworks are often needed for deployment. So, although a techno-economic approach certainly is valuable, it has various limitations and uncertainties, and is therefore incomplete. However, this does not conclude that there are no technological solutions, but merely that parallel developments should be encouraged, and the focus should not merely be on techno-economic solutions (Bolwig et al., 2019; Geels et al., 2017). Technological innovation and implementation could be steered for example through technology specific policies and complementary roles of social and organizational innovations (Sorrell, 2015).

In order to understand dynamics of energy transitions, it is important to briefly discuss the sustainability transitions concept. Turnheim et al. (2015) distinguish five *analytical challenges* to research sustainability transitions, which they obtained from analysing three theoretical sustainability approaches: quantitative system modelling, socio-technical transitions analysis, and initiative based-learning. These are:

1. Processes of transformation occur at various socio-spatial scales and over a long-term time horizon. Therefore, a thorough understanding of the history, present and future is needed for a sufficient understanding of transition pathways, but these time related approaches have different assumption for studying transitions pathways.
2. It is hard and complex to forecast innovation dynamics. However, policy measures should include innovation dynamics in their policy-making process, and include aspects of timing and potential changes in their policy measures.
3. Path dependency and innovation inertia have to be overcome in sustainability transitions. Though, the different perspectives - socio-technical, techno-economic, and socio-political - approaches capture path dependency and inertia differently.
4. Sustainability transitions must balance normative objectives with other goals, such as human health, economic competition, security, etc.
5. Integrated perspectives are required to govern sustainability transitions due to the variety of perspectives.

An overview of the analytical challenges is presented in table A.



Factor	Socio-technical transition analysis	Initiative-based learning	Quantitative systems modelling
Focus on transition pathways.	Historically informed perspective.	Micro-perspective on local-scale projects and upscaling.	Future-oriented perspective on transitions.
Handling of complexity and uncertainty.	Uses pathway typologies as theoretical constructs and analytical devices.	In-depth case studies, but limited focus on predictions.	Relatively constrained by fixed initial system boundaries and structures.
Addressing inertia and path dependence.	Inertia as outcome of structural resilience of the dominant regime.	Inertia as preference of powerful actors under pressure (central energy supply and distribution, persistence of fossil fuels subsidies).	Inertia as techno-economic constraints, like sunk investments.
Multiple normative goals of transitions.	Linkage of sustainability goals with other policy priorities.	Activist-orientation and normative positions.	Economic considerations serve as a rationale for sustainable actions.
Variety of perspectives on governing transitions.	Insights from historical transformations can inform and focus current transition efforts, but less useful for future scenarios.	Insights on local alternatives, but limited attention to interaction with regime trajectories and to link to broader transformations.	Can assist decision-making for long-term policy targets, but less useful for considering institutional and social inertia.

Table A: The five analytical challenges for researching sustainability transition.
Source: Retrieved from Bolwig et al. (2019) adapted from Turnheim et al. (2015)

In conclusion, various scholars promote for an integrated and multi-disciplinary framework/model to study energy transitions. However, combining the socio-technical and political perspectives, which are more social in nature, into the more quantitative techno-economic perspective is difficult, due to various differences, such as included actors, decisive variables, type of data.

Integrated energy transition analysis

This research integrates the techno-economic, socio-technical and political perspectives in order to comprehensively analyse the CtG-transition of Almaty in a more holistic and interdisciplinary manner, which is needed following the outcomes of the literature study. The theories and frameworks of Bolwig er al. (2019) and Cherp et al. (2018) are central to this analysis, assisted by additional literature previously discussed. Bolwig et al. (2019) and Cherp et al. (2018) both studied techniques to analyse energy transitions in an interdisciplinary manner. Their outcomes are resulted in recommendations and frameworks. Cherp et al. (2018) discuss literature central to the techno-economic, socio-technical, and political dimensions to eventually come to a meta-theoretical framework to study energy transitions. This literature is discussed in the sections above. Eventually Cherp et al. (2018) come with an interrelated framework (figure D) that includes essential elements of each individual dimension provided with a table (table B). These primary and secondary variables will be used to analyse the CtG-transition of Almaty.

Bolwig et al. (2019) provides a theoretical framework that should enable quantitative, non-linear modelling that includes socio-technical and political insights to design more realistic energy transition models. The framework comprehensively shows the effects - and complexity - of behavioural changes, policy and governmental influences, infrastructural development and other socio-technical and political variables. In the framework, the interaction of the variables and their effects are shown through feedback loops. The figure consists of variables that positively (+) or negatively (-) influence the next variable. Together these variables create feedback loops that are either reinforcing (R) or balancing (B). For example, B1 one is a stabilizing feedback loop in which the variables stabilise the household electricity consumption from the grid. When electricity costs rise, the cost/income ration of electricity increases for households, therefore they will seek for way to minimise their usage and reduce consumption, which leads and decrease of household electricity consumption, which eventually leads to decreasing electricity costs, and therefore stabilises this pattern. Various of such reinforcing and stabilizing patterns are analysed for energy transitions, and combined in a framework. See figure E.

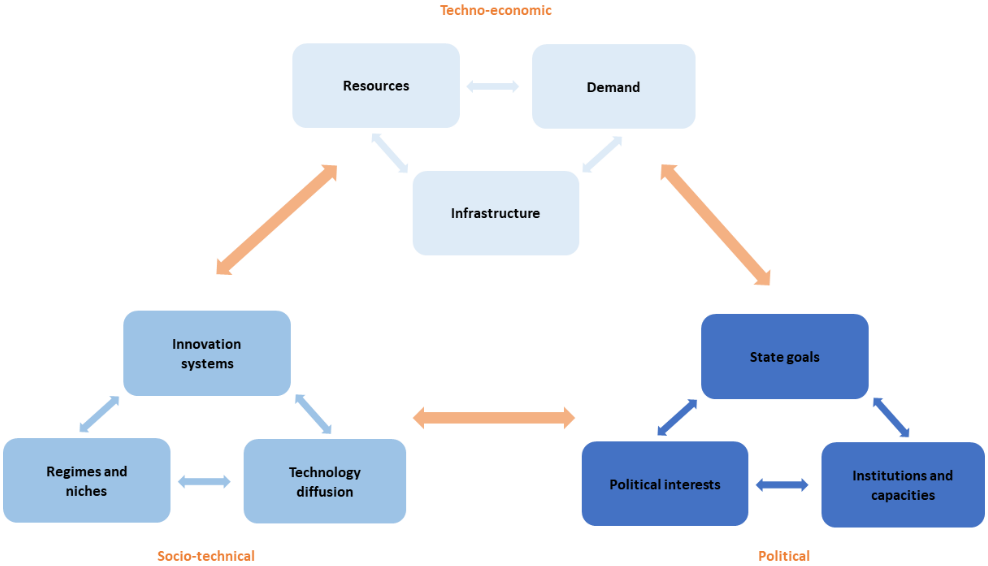
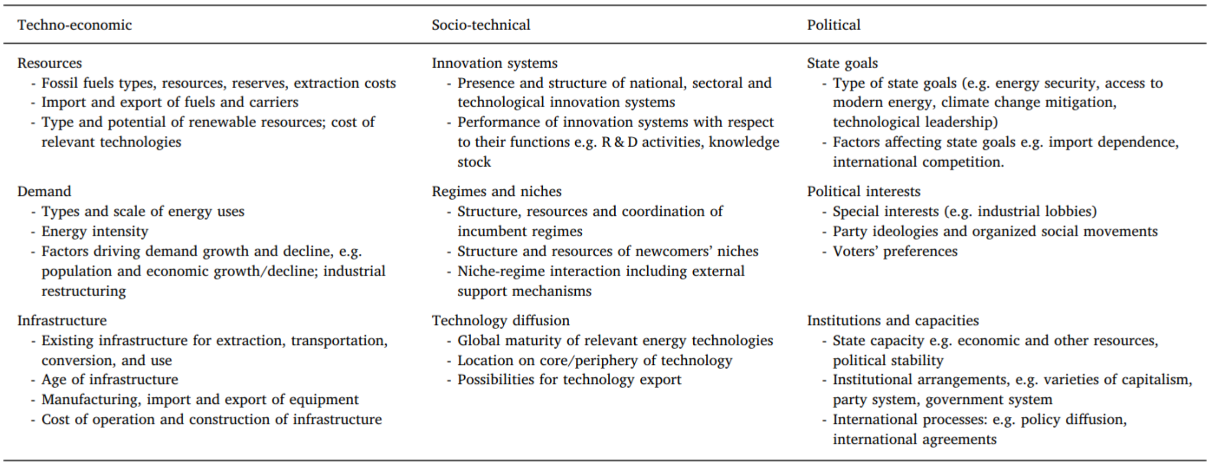


Figure D: Primary variables associated with the three dimensions of energy transition analysis.
Source: Retrieved and adapted from Cherp et al. (2018)



Techno-economic	Socio-technical	Political
Resources - Fossil fuels types, resources, reserves, extraction costs - Import and export of fuels and carriers - Type and potential of renewable resources; cost of relevant technologies	Innovation systems - Presence and structure of national, sectoral and technological innovation systems - Performance of innovation systems with respect to their functions e.g. R & D activities, knowledge stock	State goals - Type of state goals (e.g. energy security, access to modern energy, climate change mitigation, technological leadership) - Factors affecting state goals e.g. import dependence, international competition.
Demand - Types and scale of energy uses - Energy intensity - Factors driving demand growth and decline, e.g. population and economic growth/decline; industrial restructuring	Regimes and niches - Structure, resources and coordination of incumbent regimes - Structure and resources of newcomers' niches - Niche-regime interaction including external support mechanisms	Political interests - Special interests (e.g. industrial lobbies) - Party ideologies and organized social movements - Voters' preferences
Infrastructure - Existing infrastructure for extraction, transportation, conversion, and use - Age of infrastructure - Manufacturing, import and export of equipment - Cost of operation and construction of infrastructure	Technology diffusion - Global maturity of relevant energy technologies - Location on core/periphery of technology - Possibilities for technology export	Institutions and capacities - State capacity e.g. economic and other resources, political stability - Institutional arrangements, e.g. varieties of capitalism, party system, government system - International processes: e.g. policy diffusion, international agreements

Table B: Primary variables and secondary variables in Cherp et al.'s three perspective framework
Source: Cherp et al. (2018)

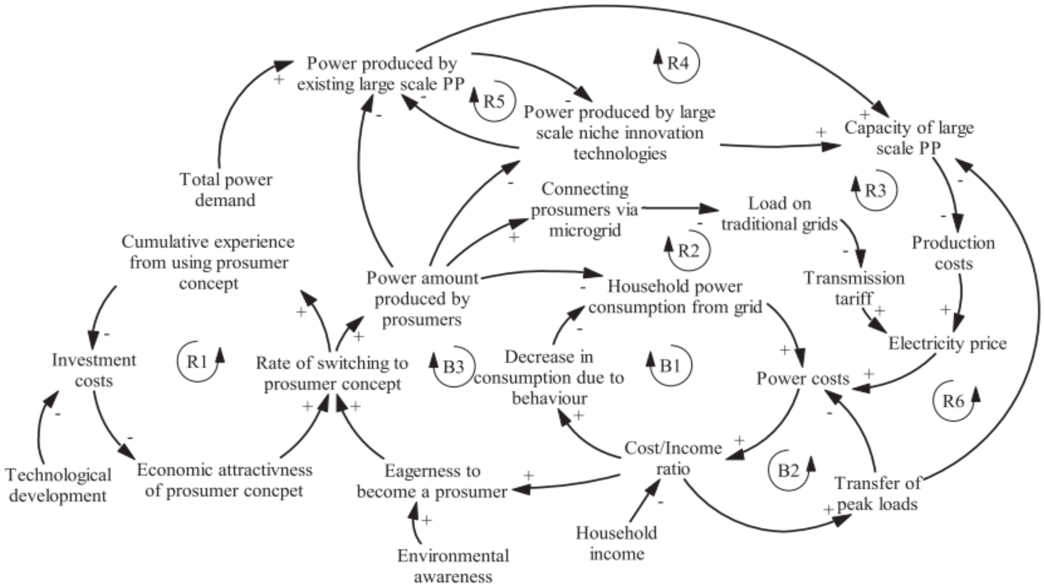


Figure E: Dynamic model of interaction between centralized and decentralized actors in the power system
Source: Bolwig et al. (2019)

Besides the importance of integrating the three interrelated dimensions in energy transition analysis, the two theories do contain limitations as well that have to be taken into consideration. First, the most important limitation is that the theoretical frameworks are descriptive frameworks yet. Socio-technical and political factors are not measured qualitatively yet. Cherp et al (2018) concludes with a framework that highlights the variables and interactions of the dimensions, but merely in a descriptive way. Bolwig et al. (2019) is working towards a quantifications of social-technical and political variables. However, the research concludes with suggestions and leaves the implementation to further research. Integrating the three dimensions into quantitative analysis however, is final ambition eventually. Second, within the socio-technical dimension exogenous shocks mark starting points for radical shifts. However, these shocks are very hard to predict and the include in any form of framework. So, the difficulty of integrating this in frameworks that create useful conclusions is high.
Despite these limitation, the insights and recommendations of these studies provide a solid starting point for an multi-perspective analysis of the CtG-transition of Almaty including techno-economic, socio-technical, and political elements.

Phase one of the analysis consists of a quantitative exploration of CtG-transitions conform existing plans. A quantitative energy model - *The Energy Transition Model* (ETM) - is used to calculate the effects of the CtG-transition based on quantitative data on for example energy production, reduction, and consumption, and avoided amount of GHG-emissions. During second phase socio-technical and political aspects are inventoried and studied based on the frameworks of Cherp et al. (2018) and Bolwig et al. (2019). This results is an overview of impacting variables from the three perspectives on the CtG-transition within the wider energy transition dynamics of Almaty. Thirdly, a quantitative exploration is conducted with the ETM to estimated and illustrate potential effects of socio-technical and political variables within the CtG-transition. This method enables comparisons of the multi-perspective analysis with the quantitative, techno-economic analysis. All-together, the three phases result in a thorough multi-perspective analysis of the CtG-transitions including quantitative and qualitative dimensions that support making recommendations on the CtG-transitions within the energy transitions of Almaty. This method can help in creating energy transition pathways and therefore help policymakers in their decision making process.

The next session elaborates on the concept of energy transitions pathways and energy models to provide additional information on the theoretical background of this study.

Energy transition pathways and models

Current energy transition from replacing fossil fuels to low-carbon alternatives plays an important and urgent role in the Paris Climate Accord for limiting average global surface temperature rise below 2 degrees Celsius. Low-carbon solutions will be key, as CO_2 emissions represent two-thirds of all GHG-emissions (Gielen et al., 2019). Increasing our energy efficiency, for example by electrification of the build area, mobility and industrial sectors, and energy saving by highly efficient renewable energy technologies will be crucial in achieving this transition (Gielen et al., 2019).

However, when talking about energy transition or sustainable energy transition it is important to specify specific characteristics of the transition, since various specificities within energy transitions exist. For Almaty as a city the goal is to eventually become carbon neutral in 2060 (UN, 2021). This means that the transition focusses on energy production without net carbon emissions. Within this research however, the focus is on the coal-to-gas transition. This could be seen as a transition within the transition. Since Almaty still heavily relies on coal based energy and heat generation, their current energy system emits many polluting GHG-emissions. The coal-to-gas transition is about converting coal-based combined heat power pants (CHPs) to generate electricity and heat on gas. This transitions can be presented as a transition phase towards carbon neutrality, since gas-based electricity still emits GHG, although significantly fewer than coal-based electricity. According to the GCAP (RWA, 2021) the conversion should reduce GHG-emission by 70-90%. In this research the energy transition refers to the ambition of Almaty to become carbon neutral by 2060, and the CtG-transition refers to the conversion form coal-based electricity and heat by the CHPs to gas-based.

The cross-sectional and complex nature of this transition that covers a variety of disciplines - technology, politics, economics, social aspects - results in an inter-sectoral challenge that needs collaboration (Chen et al., 2019). An open multi-disciplinary approach is required where information and data is shared by civil society organisations, the industry, governments and academia (Tronchin et al., 2018). According to Chen (2019), the broad scope and possibilities of the transition to low-carbon energy systems results in various options for creating more sustainable energy systems. These options are often presented as energy transition pathways (ETPs), as scenarios for the energy transition. In their paper, Chen et al. (2019) present a variety of approaches for ETPs, for example energy economics and management, renewable energy generation and consumption, environmental impacts of energy systems, and electric vehicle and energy storage. ETPs are valuable for multiple parties, such as policy makers, commercial parties and NGOs, in structuring their activities (Child et al., 2018). Often, ETPs are presented through broad quantitative analysis of possible energy alternatives that assist and inform policy- and decision makers about potential pathways and their effects (Naegler et al., 2021). Besides, ETPs are valuable for various organisations. For example governments can adapt their policies, NGOs can design alternative strategies or criticise existing policy, and industrial parties can base their commercial strategy and investment risks based on the designed pathways. Frequently, ETPs are used by countries and regions to research potential scenarios on which the aforementioned organisations can base their activities (Bogdanov & Breyer, 2016). However, it is important to mention that ETPs always contain subjective elements and are therefore prejudiced since developers make certain assumption and select parameters that influence the outcome. Decision makers must be aware of possible interests and position of pathway developers. Nevertheless, ETPs are a valuable way of visualizing and creating clearance for the energy transition (Child et al., 2018).

ETPs, supported by energy models, are of great help to explore and identify renewable energy opportunities and challenges. However, energy models are frequently criticised due to their lack of the interaction between the various disciplines (Crespo del Granado et al., 2018). For example, models often have a techno-economic nature in which economic and technical feasibility is leading. Geels et al. (2017) state that the models provide valuable insight, but entail several crucial limitation as well. Firstly he argues that that the models often represent a limited range of the actors involved, and the process of how they make decisions. Second, transitions cannot be conceptualised as tame processes, consisting of a steady implementation of low-carbon technologies represented in fluid graphs, as is often the case. These aspects relate to the MLP framework with radical nice innovations and disruptive exogenous landscape events. Third, techno-economic models often put emphasis on one specific actor. This characteristic potentially lead to controversial outcomes with the optimal outcome for the intended actor but with socially unfavourable outcomes, negative complications for non-included but related actors, or by means of technological solutions that are not feasible yet (Geels et al., 2017). Other limitations from lacking interaction of disciplines often occur due to collaborations of experts with homogeneous backgrounds, and poor interdisciplinary knowledge transference due to a lack of documentation and transparency (Crespo del Granado et al., 2018). Specific relations between dimensions are often unknown or cannot be estimated and modelled precisely yet. The awareness of the interplay between dimensions is increasing and techniques to analyse the nexus between them is stimulated (Chen et al., 2019; Crespo del Granado et al., 2018). Köhler et al. (2019) stipulate the fact that transitions are a multi-actor processes, which makes them very complicated and unsuitable to be approached by single disciplines or theories.

Transition decisions should therefore not be approached solely from a techno-economic perspective, but completed with the socio-technical dimension to present more realistic understandings and transition specific dynamics. First, Geels et al. (2017) promotes for including a wider range of actors to include their beliefs, competing interests, unique knowledge and complex relations in the cost-benefit perspective. For example groups like residents, the media, advisory bodies and city authorities should be included. Second, a socio-technical approach includes changes in user practices, political challenges and cultural discrepancies, that are essential to include next to innovative low-carbon technological considerations. Third, societal transition, like the energy transitions, are essentially about trade-offs between multiple objectives and pressures. Meaning that discussions occur for example about cost-effectiveness, inclusivity, social acceptance, political feasibility, and equity. Lastly, due to its public nature, the energy transition presents limited incentive for private parties to act. Resulting in free-riders problems and prisoner's dilemma's. Public policy is therefore crucial in changing the playing field of economic conditions and the emergence of low-carbon innovations.

To analyse the position of the CtG-transition within the wider energy transitions of Almaty, additional information is needed. Sub-questions are developed to provide the additional knowledge to eventually answer the research question. The methodology section elaborates on the sub-questions and techniques to answers them. The conceptual framework (figures F & G) is created to visualise the intention of the research and how the sub-questions and intermediary results assist in finally answering the research question, which assist in analysing the CtG-transition from a multi-disciplinary perspective.

The top section of figure F schematically represents the structure and fundamental concepts for this research. The framework highlights the role of the theories of Bolwig et al. (2019) and Cherp et al. (2018). Their theories and frameworks in combination with a quantitative analysis, by use of the ETM, should provide information for recommendations on the CtG-transition within the energy transition. The recommendation for the CtG-transition of Almaty functions as empirical data for urban energy transition in general and specifically for regions that rely on coal-based energy. This is illustrated in the bottom section of figure F.

Figure G is a schematic representation of how the case study is conducted and what research methods are used. The figure distincts independent variables (light green) and dependent variables (dark green) related to the sub-questions, and intermediary results (grey). The icons present whether literature review, qualitative interviews or quantitative research is conducted for the results.

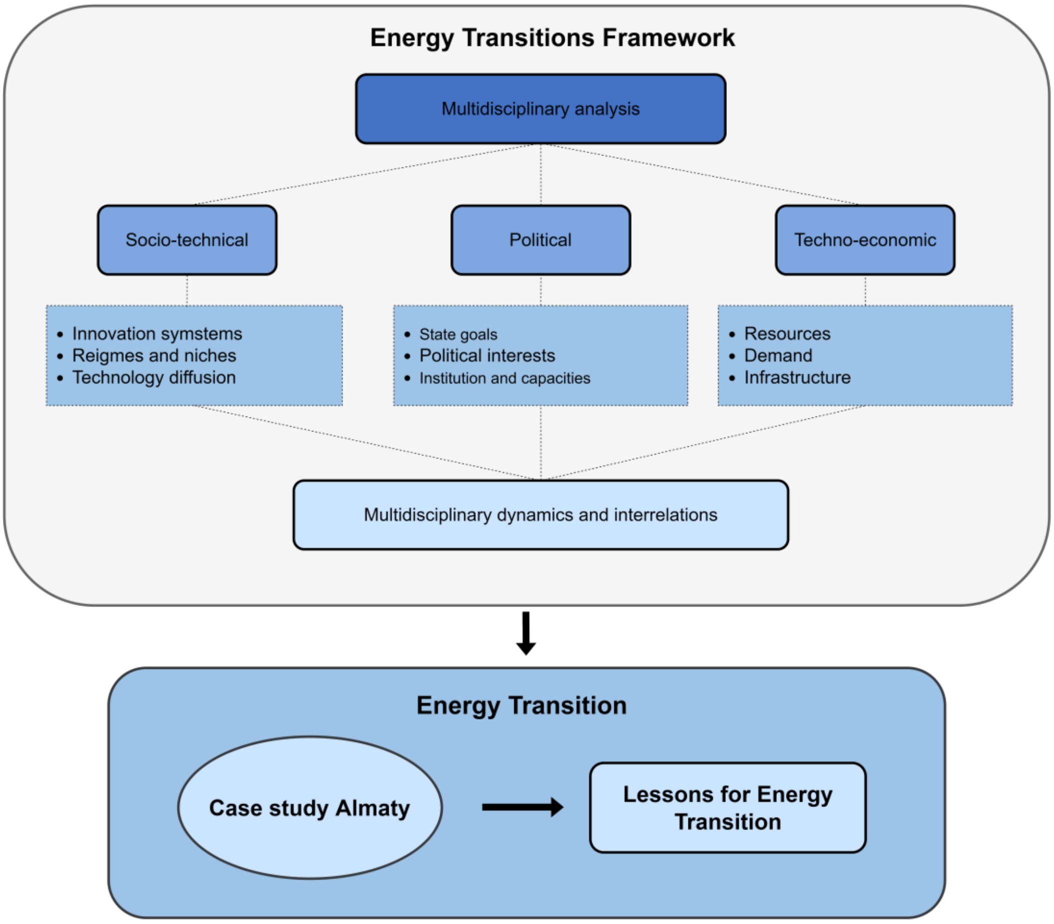


Figure F: Conceptual Framework for the energy transition case study of Almaty

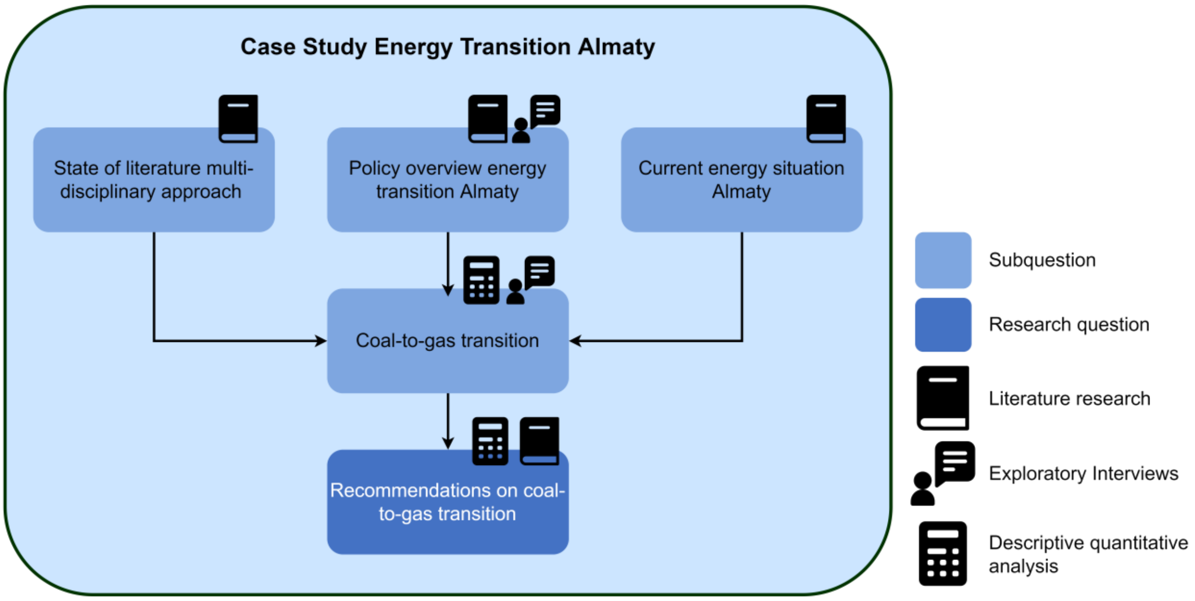


Figure G. Conceptual Framework for the energy transition case study of Almaty

Appendix B: Systematic literature review - Socio-technical dynamics energy transition

1. *Identify your answerable research question*
    a. *How does the transition from coal-to-gas fit in the wider energy transition goals of Almaty to be carbon neutral in 2060? And what are alternative Energy Transition Pathways?*

2. *Develop your protocol*
    a. *Search for scientific literature that (extensively) elaborates and analysis socio-technical approach of the energy transitions. The scientific literature is preferable leading in its subject and acknowledge by many peers*
    b. *How do these concepts, in an explorative way, fit within the Almaty case study (energy transition, coal-to-gas, energy neutrality)*
    c. *Define what concepts/theories of socio-technical approaches are relevant to analyse withing the Almaty case study, and why.*

3. *Conduct systematic searches (including the search strategy, text mining, choosing databases, documenting and reviewing*
    a. The literature review is based on the findings of the search engine Scopus since specifying your searches can be done structured and easily
    b. The articles are selected based on the relevance for the energy transition/coal-to-gas transition of Almaty, the link to socio-technical perspectives, and the reputation of the research based on the citations.
    c. For text mining various search keys are used to explore a variety of papers in this topic. This strategy should result in an overview of the current state of literature and an exploration of the aspects relevant for the energy transition/coal-to-gas of Almaty
        i. Start with recent research published in last 10 years
        ii. Search for dynamics within multidisciplinary research framework and analysis
        iii. When specifying the research keys, focus on energy transitions within socio-technical or sustainability transitions
    d. Possible related articled are evaluated based on the title, abstract, key words and sometimes the introduction/conclusion

Search Keys	Articles	Relevant topics	Citations
Energy transition AND socio-technical	- Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38–50. https://doi.org/10.1016/j.esr.2019.01.006 - Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research & Social Science*, *37*, 175–190. https://doi.org/10.1016/j.erss.2017.09.015	- Socio-economic approach - Economic and technical feasibility - Perspective to reach future energy ambitions - Analysis of techno-economic, socio-technical and political dimensions of energy transitions	944 88.9 FWCI) 198 14.92 (FWCI)
Low carbon AND socio-technical	- Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule*, *1*(3), 463–479. https://doi.org/10.1016/j.joule.2017.09.018	- Carbon/technological lock-in - Path dependence	185 (FWCI)

		- Socio-technical energy transitions - Multi-level perspective	2.89
	- Sorrell, S. (2015). Reducing energy demand: A review of issues, challenges and approaches. *Renewable and Sustainable Energy Reviews*, *47*, 74–82. https://doi.org/10.1016/j.rser.2015.03.002	- Socio-technical approach to energy reduction - Correlation between energy consumption and economic growth	406 (FWCI) 3.06
Socio-technical AND sustainability transition	- Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., . . . Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, *31*, 1–32. https://doi.org/10.1016/j.eist.2019.01.004	- History of sustainability transitions - Multi-actor dynamics - Multi-disciplinary system thinking	607 (FWCI) 72.68
	- Turnheim, B., Berkhout, F., Geels, F., Hof, A., McMeekin, A., Nykvist, B., & Van Vuuren, D. (2015). Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. *Global Environmental Change*, *35*, 239–253. https://doi.org/10.1016/j.gloenvcha.2015.08.010	- Sustainable transitions pathways - Socio-technical, techno-economic and political dynamics of sustainability transitions	254 (FWCI) 9.98
Energy transitions AND modelling AND socio-technical	- Bolwig, S., Bazbauers, G., Klitkou, A., Lund, P. D., Blumberga, A., Gravelsins, A., & Blumberga, D. (2019). Review of modelling energy transitions pathways with application to energy system flexibility. *Renewable and Sustainable Energy Reviews*, *101*, 440–452. https://doi.org/10.1016/j.rser.2018.11.019	- Quantitative elements of socio-technical transitions - Interactive modelling - Energy transitions pathways	52 0.97 (FWCI)
	- Li, F. G., Trutnevyte, E., & Strachan, N. (2015). A review of socio-technical energy transition (STET) models. *Technological Forecasting and Social Change*, *100*, 290–305. https://doi.org/10.1016/j.techfore.2015.07.017	- Quantitative energy transition modelling - Review of ET modelling tools	105 4.29 (FWCI)

Appendix C: Overview of energy reduction measures of Almaty form the *EET report*

Overview of energy efficiency measures	
Energy sector	
District heat measures 34% (1712 GWh) reduction in 2030	1.) Automated distribution & metering (5 years PB-time) 2.) Retrofit of pumping station (2 years PB-time) 3.) Network upgrade & insulation (4 years PB-time) 4.) Pipeline replacement (9 years PB-time) CHP interconnection pipelines (13 years PB-time) 5.) Turbo pumps at CHP (5 years PB-time) 6.) AKTE boiler retrofit (13 years PB-time) 7.) Advanced decentral boilers (6 years PB-time) 8.) Solar collector plant for feed-water (8 years PB-time)
Power sector 41% (1589 GWh) reduction in 2030	1.) Retrofit of distribution network (6 years PB-time) 2.) Network capacity increase to import hydropower (8 years PB-time)
Build area	
Public buildings saving of 42% (412 GWh) reduction in 2030	1.) School EE retrofit (39 years PB-time) 2.) Kindergarten EE retrofit (40 years PB-time) 3.) Health facility EE retrofit (20 years PB-time) 4.) Other building EE retrofit (29 years PB-time) 5.) LED indoor lighting program (6 years PB-time) 6.) Solar hot water program (15 years PB-time) 7.) BEMS for large facilities (9 years PB-time)
Residential buildings saving of 31% (3233 GWh) reduction in 2030	1.) Automated heating sub-stations (13 years PB-time) 2.) Individual heat metering and billing program (4 years PB-time) 3.) EE elevators (89 years PB-time) 4.) EE retrofit of buildings (33 years PB-time) 5.) Solar rooftop photovoltaic (PV) (10 years PB-time)
Transport sector	
Public sector 14% (36 GWh) reduction in 2030	1.) LED metro lighting and EE escalators (5 years PB-time) 2.) Replacement of diesel busses by CNG (41 years PB-time) 3.) Renewal of trolley bus fleet (13 years PB-time) 4.) Conversion of taxis to CNG (3 years PB-time) 5.) Extend of bike renting system (2 years PB-time) 6.) Park & ride hubs (2 years PB-time) 7.) Traffic flow optimization (20 years PB-time) 8.) Light Rail Train (LRT) (17 years PB-time) 9.) Extension of metro network (23 years PB-time)
Private sector 7% (892 GWh) reduction in 2030	1.) Enforcement of vehicle emission standards program (6 years PB-time) 2.) Fueling & charging station for low-emissions vehicles (2 years PB-time) 3.) Traffic & parking restraint in centre (2 years PB-time)
Industrial and commercial sector	
20% reduction (1592 GWh) reduction in 2030	1.) EE credit line (5 years PB-time) 2.) Solar (PV) rooftop program (10 years PB-time)

Appendix D: Analysis and overview of energy policies and political dynamics

Overview energy policies Almaty city

The political context in which societal development takes place is important to understand decision making processes and implemented policies. In order to understand and analyse the coal-to-gas transition of Almaty an overview is provided of international, national and regional policy context . This policy overview highlights the political commitments and goals, motivates strategical choices and therefore sets the playing field of Almaty's urban development plans. The overview is presented from international to regional scale to comprehend various policy levels of the coal-to-gas transition.

Political influences can be linked to the political aspects of the framework of Cherp et al. (2018). The framework consists of three main political aspects influencing the multidimensional process of energy transitions, namely *state goals, political interests,* and *institutions & capacities.* According to the framework the three selected variables consist of sub-variables that influence transitions (See table A, Appendix A). Within the various policy framework levels, international, national and regional (city-level), will be reflected on these sub-level variables of the Cherp et al. framework.

International policy context

International policy goals

When regarding the energy transition to carbon neutrality and the coal-to-gas transition of Almaty, international agreements, policies and directives relating urban development influence and steer the process. Since international agreements and treaties foster international cooperation, they set directives on the development of countries, and therefore cities. The NDCs of the Paris Accord are a clear example for this (United Nations, 2021a). Despite the country's commitment to early international climate change policies as the *United Nations Framework Convention on Climate Change* (UNFCCC) of 1992 and the *Kyoto protocol* of 1999, energy reduction strategies and climate mitigation measures were no priority for decades. However, according to the World Bank Group (2017), this trend altered in 2010 when the President placed energy efficiency and climate mitigation on the political agenda by publicly announcing to reduce the energy intensity of the economy by 10% compared to 2015 and 25% by 2020.

In line with this Kazakhstan signed and committed to the Paris Climate Accord (2015) in 2016. Ratification of this agreement is fundamental to transitioning to a low-carbon society since it binds Kazakhstan to reach an economy wide absolute reduction of GHG-emissions of 15% from 1990 levels by 2030. Besides, Kazakhstan announced a motivation to increase their mitigation ambitions to 25% from 1990 levels when additional international support, finance access to international carbon markets, and low carbon technological sharing was provided (World Bank Group, 2017). The households sector is an important polluter of GHG-emissions, causing 8% of national total CO_2 emissions in 2018. The residential sector is the fastest growing polluter regarding energy consumption in Kazakhstan. In 2000 the share of energy consumption of the residential sector increased by 9% of the total *final energy consumption* (FEC) to 27% in 2018 (IEA, 2020c).

Secondly, Kazakhstan incorporated the ambitions of the influential and substantial '*2030 agenda for sustainable development'* of the United Nations in two national policy documents (RWA, 2020b). The SDG 2030 agenda entails sustainable development in a broad way and should function as an action plan for people, planet and prosperity (United Nations, 2021c). However, at least four goals can be directly related to Almaty's energy transition; 1.) Affordable and Clean Energy 2.) Sustainable Cities and Communities 3.) Climate Action and 4.) Responsible Consumption and Reduction (United Nations, 2021c). The Kazakh department of the United Nations shows that with regard to Affordable and Clean Energy a substantial amount (7.4%) of the UN allocations is invested in this ambition. However, the other three energy transition related goals are lacking behind (United Nations, 2021b).

Thirdly, an increased collaboration between Kazakhstan and the European Union (EU) intensified connection and influence of EU's policy frameworks on development directions. This collaboration is based on the Partnership and Cooperation Agreement (1994) and a Memorandum of

Understanding on Energy Cooperation (2006) relating energy topics (e.g. energy security and investments, increasing security of supply, and promotion of industrial cooperation). The political relation reached a new level since the signing of the *Enhanced Partnership and Cooperation Agreements* (ECPA) in 2015 by both parties (European External Action Service, 2021). This agreement highlights the believe and commitment to the principles of free market economy, promotion of sustainable development and economic growth. And although the EPCA, is not legally binding, it increases EU's influence on policy implementation of Kazakhstan. The European Green Deal policy framework is probably the most important and related when it comes to energy transitioning since it for example concerns clean energy production, sustainable industries, and clean buildings. However, directives such as the '*EU Energy Performance of Buildings Directive'* that focusses on investments for a decarbonised building stock in 2050 and the directive on '*ambient air quality and cleaner air for Europe'* that aims to increase overall air quality for citizens are influencing energy policies as well (RWA, 2020b). The importance of EPCA probably commits Kazakhstan to EU energy policy goals, since the EU is Kazakhstan most important trade partner with a significant 40% of its external trade. Besides, the EU is also the single biggest investor in Kazakhstan, representing 48% of total (gross) foreign direct investment (FDI) flows and around 60% of total net FDI stocks in 2018 (EEAS, 2020). The GCAP of Almaty is a relevant example of investments that steer the policy goals and urban development strategy of Kazakhstan and Almaty in this case. The European Bank of Reconstruction and Development (EBRD) states to have invested 1.37 billion euros in green economy investment commitments between 2015 - 2020. The influence on policy implementation via these investments is a explicitly mentioned aspect of the EBRD since they state (EBRD, 2020, P. 1):

> *"We combine investments with policy dialogue to develop a good regulatory framework for sustainable energy, water and resource use. Through EBRD Green Cities, we support municipalities in developing Green City Action Plans to address key environmental challenges and to invest in sustainable infrastructure."*

Besides the ECPA the cumulative numbers of economic trade between Kazakhstan and Europe form strong incentive to maintain these relation. Currently, energy contains the major share of trade since 80% of Kazakhstan energy exports go to Europe. However, regarding the Clingendael Institute (2021), depending on the scenario, between 2015 - 2030 imports of coal will drop by 71-77%, oil 23-25%, and natural gas by 13 - 19%. After 2030, the expectation are that imports will even decrease more drastically, with oil imports going down with 78-79% and natural gas with 58-67% (Leonard et al., 2021). These drops are dramatic for the economic stability of Kazakhstan since their gross domestic product (GDP) relied for 21% on fossil fuels in 2020, ad around 70% of all its exports (World Bank, n.d.).

Ambitions in international context

Binding and non-binding policy frameworks can be related to the variables within the framework of Cherp et al. (2018). This section discusses how the international policy dynamics fit within the second-level variables.

Firstly, *state goals* consist of two sub-variables, namely the *type of state goals* (e.g. access to modern energy, climate change mitigation, and energy security) and f*actor affecting state goals* (e.g. import dependence, international competition, etc.). Looking at international policies the most important state goal regarding the energy transition probably is the binding Paris Climate Accord. The second most important probably is the EPCA trade accord with the EU is influencing their policy framework as discussed. Although, the agreement is not binding, it will probably promote and steer sustainable development even more in the future due to EU sustainability goals and the European Green Deal. Various national state goals are closely related to international (trade) agreements and international relations, but these will be discussed in the national policy section. *Factors affecting state goals* mainly concern economic stability and growth since Kazakhstan depends majorly on their export of fossil fuels for their growing wealth. As previously discussed, these exports are predicted to drastically decline in the near future. So, it is crucial to maintain a close trading relation with EU, to find alternative trade interests, and to transform trading dynamics away from majorly fossil fuel energy exports.

Secondly, the variable *political interests* consists of the second-level variables *special interests* (e.g. industrial lobbies), *party ideologies and organised social movements* (e.g. NGOs), and *voters' preferences.* From an international policy perspective the special interests are probably most relevant. Since the demand side of fossil fuel industrial activities will drastically decline in the coming future. Therefore an new focus on economic activity is needed as the major trading partner is moving away from fossil fuels relatively quick in the coming decades and Kazakhstan committed itself to sustainability goals as well. Although current industrial lobbies will still mainly be focussed on fossil fuel activities, they have to shift their focus in the coming future. Therefore, policy makers have to decide how to nudge away from fossil fuels since they are currently still attractive, but should not be in the future.

Third, institutions and activities consists of the sub-variables *state capacity* (e.g. economic and other resources, political stability), *institutional arrangements* (e.g. government and party system, variety of capitalism, etc.), and *international processes* (e.g. international agreements, policy diffusion). Regarding *state capacity* it is important to consider that various countries are heavily investing in Kazakhstan, with the main contributors Europe and China (PwC, 2021). As previously mentioned, the EU represented around 60% of total net *Foreign Direct Investments* (FDI) (EEAS, 2020). The GCAP of Almaty is largely financed by investments of the EBRD as well (RWA, 2020a). Economic growth and increasing standard of living is a major contributor to political stability (Feng, 1997) and therefore important for national policy frameworks. The international policy frameworks and trade agreements support sustainable development by investing in sustainable projects and policies, which assumable otherwise would be substantially more difficult, since Kazakhstan depends largely on fossil fuel industries in maintaining economic growth and therefore increase the political stability.

Overview of binding policy goals and political influences

Agreement / treaty	Goals / commitments	Fulfilment year
International		
Paris Climate Accord	Economy wide absolute 15% GHG-emissions reduction compared to 1990 level	2030

Table C: Overview binding international policy goals of Kazakhstan

First-level variable	Second-level variable	
International scope		
State goals	*Type of state goals*	**Paris Climate Accord:** binding commitment to reduce the GHG-emissions 15% compared to the 1990 level in 2030
		EPCA trade accord: economic dependence on Europe, due to 80% of energy export, 40% of all external trade, and 60% of net FDI.
	Factors effecting state goals	**Economic dependence:** fossil fuel exports highly depend on Europe. Current export result in economic growth, which causes political stability.
		Reduced demand: drastically demand decline forces Kazakhstan to move towards other (more sustainable) trading activities. Also if it wants to maintain strong economic partnership with Europe.
Political Interests	*Special interests*	**Technological lock-ins: d**rastic decline of fossil fuel demand forces industrial parties to find new economic activities in the future. However, current traditional activities are most profitable and sustainable activities not. The government needs to steer towards and support sustainable activities.
Institutions and capacities	*State capacity*	**Income dependence:** major share of economic resources obtained from foreign investors (EU and China)
		Political stability: trade dependence on Europe (and China) important for economic growth, and thus political stability
	International processes	**International agreements:** (non-)binding and international agreements steer policy frameworks towards sustainable development which otherwise probable would be hard due to financial dependence on fossil fuel and *technological lock-ins.*

Table D: Overview of first- and second-level political variables related to international policies, agreements and partnership that influence energy transition of Kazakhstan
Source: based on political perspective of framework from Cherp et al (2018)

National policy

National policy development and goals

International agreements and trade partnerships are positively influencing Kazakhstan's sustainability promoting policies. However, some intentions towards sustainable development and policies were already mentioned and set in motion before the Paris Climate Accord and the EPCA. In this section an overview is provided to understand the dynamics of sustainability policy frameworks of Kazakhstan from a national point of view, which assists in analysing the CtG-transition from a multidisciplinary approach.

In 1997 the 'Strategy Kazakhstan 2030' was presented, in which international security, political stability and unity, economic growth through a market economy, health and education, infrastructure of transport and communication, and energy resources were central elements (Nazarbayev, 2012). Economic growth and increased GDP were central elements for modernisation, secured political stability and increased living standards. Constant economic growth is majorly achieved by using enormous amount of fossil fuel resources, specifically oil and gas. Since 1990, Kazakhstan's GDP grew 7.6% on average yearly. Compared to 1998 the GDP increased seven fold from 1.500 USD (1998) to 12.000 USD (2012). According to former President Nazarbayev the results is that "*Today we are a middle-income country with a dynamically growing economy"* (Nazarbayev, 2012, p. 4)

As follow-up on the strategy towards 2030, the 'Strategy Kazakhstan 2050' was presented in which various development goals and challenges for the coming decades are framed. The main goal is to enter the world's top 30 most developed countries in 2050. This goal forms the centre of political decision making in which economic growth is the key performance indicator. The 'Strategy Kazakhstan 2050' concludes that economic progress is the fundament to political reforms. Besides, the strategy states "*Economy first, then politics"* (Nazarbayev, 2012, p. 2).

On the one hand this focus on economic growth is counter intuitive to sustainability policies and sustainable development goals. Especially since Kazakhstan's steep progression was merely the outcome of exploiting exhaustive natural resources (IEA, 2021g). On the other hand does the strategy focus on results in 2050 for which ten complex challenges are defined, that demand a reform of current economic behaviour. Challenge three to six all relate to environmental challenges and climate change. Challenge three and four concern food security and water shortage. Increased population, natural scarcity and climate change force the government to produce and use water and food efficiently, and thus sustainably. Challenge five concerns energy security. The strategy proclaims that developed countries heavily invest in green energy technologies, and an estimated 50% of 2050's energy is produced by renewable sources. The ambition is to maintain a central position in the energy sector for many countries. The sixth challenge is the exhaustion of natural resources. Due to its large amount of natural resources Kazakhstan holds a strong trading position. However, the strategy admits that natural resources are crucial for economic growth, limited, and therefore should be managed efficiently and wisely. Therefore, the ambitions is to transform natural resources into a sustainable and efficient vehicle for economic growth (Nazarbayev, 2012).

Maintaining a strong trading position is important to reach the world's 30 most developed countries. However, a drastic transformation of current fossil fuel based economy is demanded. Especially, since the main economic partner, the EU, set increasingly ambitious goals regarding implementing green economy principles and sustainable energy infrastructure. Simultaneously are trading agreements with the EU influencing national policy, and steer towards new and more sustainable economic income streams, in line with the European Green Deal (EEAS, 2020). Interestingly, various scholars concluded the favourable natural climate conditions of Kazakhstan for renewable energy production (Bogdanov et al., 2019; Karatayev & Clarke, 2016).

(Sustainable) economic reform has been proposed before signation of the Paris Climate Accord and the EPCA. The Strategy Kazakhstan 2050 (2012) already plead for a diversification of economic activities, with a focus on agriculture, digitalisation, and stimulation of investment climate for innovation, start- and scale-ups (Nazarbayev, 2012). In 2013 the government presented the *'Concept for the Transition of Kazakhstan towards a Green Economy',* Green Economy Concept (GEC) in short, which plead for economic transformation motivated by various deficiencies in the current economic standards and activities. Firstly, billions of economic losses occur due to inefficiencies in natural resource exploitation. Secondly, an inadequate energy tariff pricing systems disincentivises technological development and innovation. Thirdly, current economic (industrial) activities have severe negative environmental consequences. For example, almost one third of agricultural land is degraded or under significant threat of being so, a shortage of 13-14 billion cubic meter of sustainable water sources is forecasted for 2030 and environmental contamination and air pollution have severe negative impacts on citizens health and lead to diseases and premature deaths (Nazarbayev, 2013).

The GEC was adopted in 2013 and set clear goals for the water sector, energy sector, air pollution and waste recycling. These are the lates binding national goals concerning air pollution and clean energy production (PwC, 2021). The ambitions are in line with the energy In this research we will focus on the energy goals and air pollution goals, which are depicted in the table below (See table E)

Agreement / treaty	Goals / commitments	2020	2030	2050
National				
Strategy Kazakhstan 2050	Join top 30 most develop countries world wide			Top 30
Green Economy Concept	**Energy efficiency:** Reduction of energy intensity of GDP from levels of 2008	25%	30%	50%
	Power sector: Share of alternative sources[1] in electricity production	**> 3%** from solar and wind	30%	50%
	Power sector: Share of gas power plants in electricity production	20%[2]	25%[2]	30%
	Power sector: Reduction in CO_2 emissions in electricity production	Levels of 2012	15%	40%
	Air pollution: SO_x, NO_x emissions into environment		European levels	

Table E: Overview national policy goals of Kazakhstan

[1] Including solar, wind, hydro and nuclear

[2] Including switching of power plants from coal to gas in large cities provided that gas supply is secured at a reasonable price level

Source: inspired on political perspective of multidimensional framework of Cherp et al (2018)

National policy context

National policy dynamics are a combination of intrinsic national motivations to diversify economic activities, decrease climatological and health effects due to polluting activities, and increased efficiency of natural resource exploitation. These aspects should influence the decision making process of energy transition measure, approached from a multidisciplinary perspective. In the table below aspects effecting energy transitions measures are related to the three perspectives framework of Cherp et al. (2018).

First-level variable	Second-level variable	
National		
State goals	*Type of state goals*	**Economic growth:** the main goal is to join the top 30 most develop countries in 2050, which demands sustained economic growth. However, agreements and partnerships are important for this ambition too. These collaborations can influence national policy directions.
		Economic diversification: creating modernised income streams from alternative resources, that are more efficient in energy usage, less air polluting, and mitigate negative environmental effects, which a focus on closed-loop production and innovative electricity generation.
		Reform energy sector: reduced energy intensity of GDP, increased share of alternative (renewable) electricity sources, increased share of gas power plants, reduction of CO_2 emission form electricity generation, and reduced SO_X and NO_X are needed to reach ambitions.

	Factors effecting state goals	**International collaboration:** strong and reliable trading positions are important for sustained economic income and growth. Therefore economic /industrial standards should be adapted to agreements, in this context European standards.
		Fossil fuel dependence: export shares highly depends on fossil energy. But, demand will likely reduce coming decade, and thus alternative income streams are needed.
Political Interests	*Special interests*	**Industrial lobbies:** energy pricing systems and current energy demand makes fossil energy more profitable than (sustainable) alternatives. Therefore industrial lobbies probably need policy frameworks, steering mechanisms and other stimuli to invest in sustainable business cases.
		Voters' preferences: citizens value economic growth and increased GDP. Other values, such as sustainability, are probably secondary (SOURCE). Lacking climate awareness probably contributes to this. This voters' preference may result in lacking political will towards sustainable energy alternatives.
Institutions and capacities	*State capacity*	**Political stability:** closely related to voters' preferences. The growing GDP leads to political stability. Sustainable practices cannot be drastically implemented and follows international demand and standards. However, economic reform cannot wait until fossil fuels are abandoned from the market.
		Economic and other resources: these aspects are closely linked due to dependence of Kazakhstan's income by natural resources, predominantly fossil fuels. But, sustainable energy becomes increasingly important and Kazakhstan obtains favourable environmental characteristics for this as well.

Table F: Overview of first- and second-level political variables related to national policies that influence energy transition of Kazakhstan
Source: inspired on political perspective of multidimensional framework of Cherp et al (2018)

Local Policy of Almaty City

Almaty's Energy Efficiency Transformation and Green City Action Plan

Regional policy is obtained from national policy goals. Regularly regional policy translates national policy into clear and concrete measures. An example are the NDCs from the Paris Climate Accords. International agreement stimulate contributors to create clear national goals (NDCs) and these NDCs are directed to national and regional policies to accomplish commitments (United Nations, 2021a). Almaty has two main (public) documents that provide consult for policy developments in the energy sector. Both documents are collaboration between advisory groups and governmental bodies. The first document is the *Energy Efficiency Transformation* (EET)*,* created in 2017. And the second is the *Green City Action Plan* (GCAP), a document that is still being finalised. Both document provide information, local characteristics and advise on transformations and pathways towards a more sustainable future.

The **Energy Efficiency Transformation** is a collaboration of the World Bank Group, Almaty municipality, and many experts from specific fields. The study outlines an energy efficiency strategy up to 2030 by researching the energy performance of the municipal service sector, and identifying and prioritizing energy efficiency opportunities along with a detailed plan for implementation (World Bank Group, 2017). The main research objectives were to study energy consumption reduction measures, to increase the energy service proficiency of the municipality to its citizens, and to mitigate related municipal expenditures. The research mainly focussed on qualitative goals, namely reducing GHG-emissions and Primary Energy Consumption (PEC), prevent energy bills to increase when local public service provider improve their services, and create an attractive environment for private (foreign) investment for energy efficiency measures. Quantitatively, national goals of the GEC are leading in the energy efficiency study. Losses of energy transformation and distribution systems experience inefficiencies of 22%. All losses included, generation, transformation and distribution, the losses accumulate to a primary energy factor of 1.9. This entails that for 1KWh of power delivered to the final consumers, 1.9 KWh of primary energy (mix of coal and gas) is required. And since 70% of urban residents is connected to DH, this infrastructure is key to improving the energy efficiency. Specifics on the energy situation of the city is discussed in the next chapter.

The **Green City Action Plan** (GCAP) is a collaboration between the European Bank of Reconstruction and Development (EBRD) and the Almaty municipality. Besides, various advisory groups intensely participated, and especially RwA (Resource and Waste Advisory Group) with various other experts (RWA, 2020a)*.* The GCAP thrives to systematically address (urgent) environmental and urban development challenges, while taking social concerns into deliberation. The plan focusses on seven sectors: transport, buildings, water and wastewater, solid waste, energy, industry and land use (RWA, 2020a). An important (political) motivation to be involved in the green cities program of the EBRD is the severe air pollution in Almaty (RWA, 2020a). Main contributors of air pollution are the usage of many out-dated and obsolete private cars, trucks and buses (Carlsen et al., 2013), and the emissions of nearby coal fired power plants and combustion by households, especially during winter times (Assanov et al., 2021). The geographical position of Almaty result in calm weather and strong inversion-layers that suppress vertical exchange, which results in limited air ventilation and thus lead to high emission rates in the air (Zakarin et al., 2021).

Although the GCAP concerns various sector, the energy sector is fundamental due to its significant challenges and because it is intertwined with (almost) all individual sectors (mobility, buildings, industry, waste management). Challenges are substantial, for example average losses within the district heating distribution network are 17%, and 61% of the district heating network is depreciated (of which 45% is more than 25 years old) and require re-investments. The GCAP identified sectoral challenges, of which six out of eight concern district heating and renewable energy sources with regards to the energy sector. The original plan was to present the final report in September 2021. However, due to various reason, for example the COVID-pandemic, the plan was still not finalised when conducting this research (June 2022).

The EET and the GCAP both researched current energy policy frameworks based on reduction, efficiency and sustainability. Current local policy landscape is important to investigate specifics on the coal-to-gas transition within the existing frameworks. In the next chapter the local policy frameworks and dynamics regarding energy are discussed.

Policy frameworks of Almaty City

Energy efficiency was no governmental priority until the 2010's President's speech "*New decade - New Upturn in the Economy - New Opportunities for Kazakhstan*". Measurable goals were set in order to increase Kazakhstan's energy efficiency, namely reduced energy intensity of the national economy of 10% by 2015 and 25% by 2020, compared to the 2008 baseline (World Bank Group, 2017). The goal to decrease by 10% in 2015 is probably met, since the energy intensity per dollar in 2008 was 2,11 kWh/dollar, and 1,8 kWh/dollar in 2015 (Our World in Data, 2020). This leads to a reduction of 14,7%. However, the result of the 2020 goals is not undisputed. On the one hand, in 2018 the energy intensity increased again to 1,94 kWh/dollar, which means a reduction of 10% compared to 2008 (Our World in Data, 2020). But on the other hand, according to KNOEMA (a global data catalogue), the energy intensity in 2019 was 1,67 kWh/dollar, which results in a reduction of 21% compared to 2008 (KNOEMA, 2019). The data on 2019 is from another source, so maybe they calculated the energy intensity per GDP in an alternative way. Conclusive data on 2020 is not received yet.

In 2012 the "*Law on Energy Saving and Energy Efficiency*" was introduced, and amended in 2015. According to this law, energy consumers that exceed 1.500 toe/year. Have to report annually to the *State Energy Registry* (SER) and have submit energy efficiency plans. Local authorities are obliged to include these plans in local development programs (RWA, 2020b). A total of around 7.500 organisations exceed the limit of 1.500 toe/year, with 4.284 governmental organisations, 2.505 public actors and 765 private entities (World Bank Group, 2017). Besides, a state State Program "*Energy Efficiency-2020*" was approved, as well as the *"Strategic Development Plan until 2020*". According to energy efficiency legislation, municipalities are responsible to include energy efficiency measures in the local development programs, comply to state policy on energy efficiency and monitor and compare energy usage of public facilities. The municipality is responsible for planning and execution of the energy efficiency program for the city. However, despite these laws and strategies the most concrete energy goals seem to be the ones of the Paris Climate Accord, in which Kazakhstan pled to reduce emissions of 15% from 1990 levels in 2030 (World Bank Group, 2017).

The *"Law On Supporting the Use of Renewable Energy Sources"* established a Feed-in-Tariff policy in 2013 for the coming 15 years to support renewable energy uptake in de area. Besides, the single off-taker Financial Settlement Center under Kazakhstan Electricity Grid Operating Company is obliged to purchase energy generated from renewable sources. Moreover, they have to provide grid connection for RES facilities. Lastly, there should be no licensing requirements for renewable energy generation.

A local strategy that included energy measures as well was the *“Almaty 2020 Development Program”***.** This local strategy promoted the cities sustainable development for the period 2016-2020 by improving the attractiveness for people and business. The program included various energy measures, such as modernization and upgrading heat supply, install natural gas-based equipment in CHP-1 with a capacity 1300 Gcal/hour, and installing heat pipes and boilers in neighbourhoods poorly connected to the heat system. The program also set goals to achieve a total of 4,25% renewable energy of total electricity volume and increase to gas supply by 1.2 million m^3/h (RWA, 2020b; World Bank Group, 2017)

Lastly, the “*Almaty Energy Complex 2015-2020”* aimed to use energy resources to foster sustainable economic growth, in parallel with a sustained increase in quality of life, and to create optimal economic, legal, and organisational circumstances to achieve energy efficiency indicators. Eventually, 30% of potential saving was identified in the plan, which would reduce energy consumption for heating from 190 KWh/m^2 on average to 120 KWh/m^2. Several indicator could collectively achieve this decrease in average consumption, for example thermal insulation for buildings stock, automated heat points and pipes, automated block heaters and energy audits, and energy efficiency lighting. The plan also suggested to install an Energy Management Unit as legal body for the city, which should specifically focus on setting up energy efficiency measures for Almaty, and ensure legal feasibility.

The plans provide an overview of potential measurements to increase energy efficiency and reduce the total energy demand. However, the goals will not be verified within the scope of this research, but the overview provides an idea of the energy policy trend and situation of Almaty.

Agreement / treaty	Goals / commitments	Fulfilment year
Local		
Paris Climate Accord	Economy wide absolute 15% GHG-emissions reduction compared to 1990 level	2030
Almaty 2020 Development Program	Reduce the wear rate of heat supply from 65% to 57% and for electricity supply from 69% to 65%	2020
	Reduce heat loss during distribution process to 18%	2020
	Reduce electricity loss during distribution process to 14,48%	2020
	A share of 4,25% of renewable energy of the total electricity generated volume	**2020**
	Increased natural gas supply of 1,2 million m^3/h	2020
Air Quality Improvement for the City of Almaty	**Conversion of CHP-2 from coal-to-gas generated energy by 2025, and zero interest loans for dwellings to gas distribution network and for installation of gas boilers**	2025
	Support for conversion of household heating systems to gas	2025
	Energy saving measures, such as insulation for residential housing and industrial buildings and adapting the norms for indoor air temperature	2025
	PV solar energy stimulation. In 2020, amendments are caried out in SNiPs (building norms and rules) to promote energy efficient roofs	2025

Table G: Overview binding local policy goals of Almaty

First-level variable	Second-level variable	
Local Scope		
State goals	*Type of state goals*	**Modernise energy infrastructure:** Energy infrastructure of the city is highly inefficient and outdated. The heat and electricity sector experiences losses up to 22% of PEC in the energy transformation and distribution system for final district heat and electricity users. Therefore modernization and increased efficiency is needed, especially since energy demand is growing.

		Affordable energy: Increasing efficiency and modernizing the energy should not lead to increased energy costs for residents.
		Energy accessibility: only 70% of citizens is connected to DH. Municipal plans aim to increase this percentage. Besides a goal is set to increase the conversion form residential DH from coal to gas.
	Factors effecting state goals	**Investment climate:** Almaty aims to provide an attractive environment for foreign investors to invest in cleaner, more efficient and renewable energy sources
Political Interests	*Special interests*	**Industrial lobbies:** energy generation, transformation and distribution is done by a few corporation. Likely they protest against radical change due to *technological lock-ins* and path dependence.
		Voter's preference: Municipalities depend on their citizens. Citizens profit from energy security and affordable prices, and probably demand this from their municipality. On the other hand do current circumstances harm citizens heath due to air pollution caused by power plants and traffic. This is an important political motivation and responsibility the municipality should take.
Institutions and capacities	*State capacity*	**Economic resources:** Economic resources are limited for the municipality. And although energy efficiency plans should be profitable at the long term, initial investments are substantial. Therefore, (investment) funds, development banks and private investors are attracted and involved in development projects. Due to these involvements, they are influencing the decision making process as well. Therefore the World Bank and the EBRD have influence on the decisions for the EET and GCAP.
		Governmental system: Although not studied thoroughly it appears that governmental and municipal decision are executed more centralized. Besides many companies with high energy consumption are state-owned or public. The municipality has more influence in the decision-making processes of these companies probably.
		International agreements: Collaborations with the EBRD and the World Bank are no international agreements with countries, but since the banks heavily invest in developing Almaty, they can influence the decision making process. Besides, the banks invest in line with Western policy directions (e.g. climate mitigation, renewable energy production, etc.).

Table H: Overview of first- and second-level political variables related to local policies that influence energy transition of Kazakhstan
Source: inspired on political perspective of multidimensional framework of Cherp et al (2018)

Appendix E: Overview of Almaty's renewable energy potential analysis

1. Technical potential for renewable energy sources

Solar energy

Although wind and solar both contain high potential for renewable energy uptake, the circumstances in the Almaty region are most favourable for solar energy. According to PwC (2021) Almaty region contains the best circumstances for solar power uptake when regarding net capacity factor. This means that Almaty is the most efficient region for solar energy regarding the actual output of the power plant compared to its maximum output. South regions of Almaty contain the best values for solar energy production, with tops around 1750 kWh/m^2 *direct normal irradiation* (NDI) while the north regions measure around 1100 kWh/m^2. Region nearby Almaty belong to the higher measurements with averages around 1500 - 1600 kWh/m^2 (see figure H). These values are really high compared to the Netherlands for example which ranges between 900 - 1000 kWh/m^2 NDI (World Bank Group). Various papers highlight this favourable climate for solar power (Bogdanov et al., 2019; Karatayev et al., 2016; MacGregor, 2017). According to MacGregor (2017) solar power is not widely implemented due to the build inertia of the national energy system, lack of implementation regulations for private investors, and high risk investments due to insecurity about the returns.

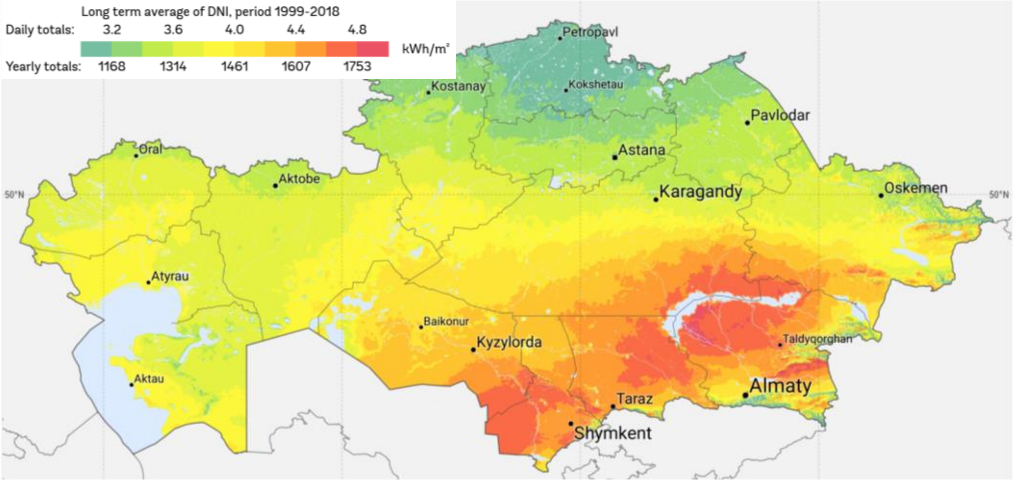


Figure H: Photovoltaic of Kazakhstan measured by Direct Normal Irradiation
Source: World Bank Group (2022)

An important aspect of implementing renewable energy sources is the availability of power grid accessibility. Within the Almaty region this grid connection is available for various voltages. Figure I presents an overview of the existing electricity grid (220kV, 500kV and 1150kV) of the Almaty region and planned extensions of the electricity transmission network (220kV and 500kV). These areas comply with the areas with high potential for renewable energy (Energydata.info, 2018).

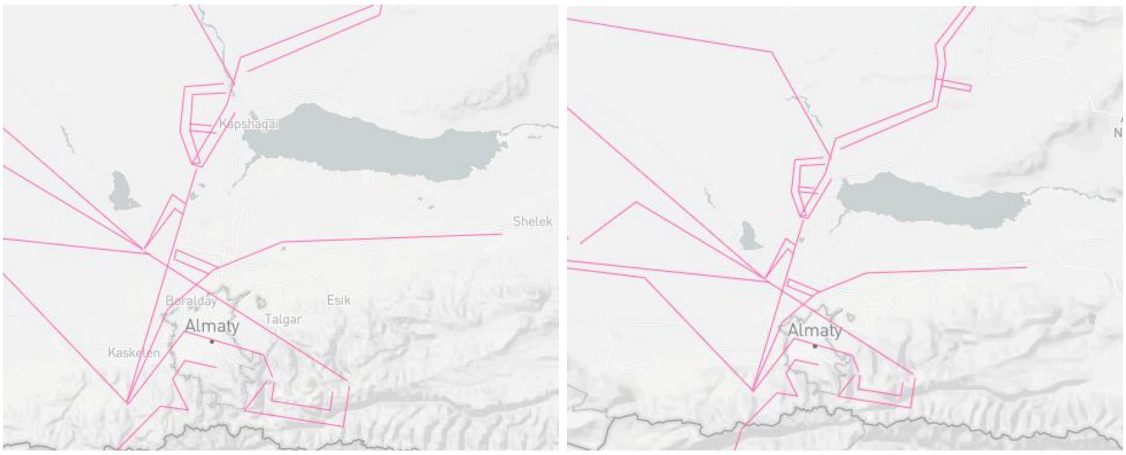


Figure I: Nearby energy networks to connect RES to (Left: existing network; Right: planned network extension)
Source: Energydata.info (2018)

Wind energy

Due to its steppe geography, wind streams create good circumstances for wind power generation in Almaty. With regard to wind energy the situation is relatively similar. Although, the Almaty region is not favourable for wind energy, still potential is available. Circumstances are most favourable in the Middle-South and South-West regions (see figure J) (World Bank Group, ESMAP, Vortex, et al., 2022). For example, the top wind energy regions, Turkestan and Atyrau, according to PwC (2021), experience wind speeds of 7.01 m/s (602 W/m^2) and 7.71 m/s (436 W/m^2) (World Bank Group, ESMAP, Vortex, et al., 2022).The Almaty region experiences wind speeds of around 6.4 m/s with energy potential of 425 W/m^2. compared to approximately 6.9 m/s (315 W/m^2) for Amsterdam and 9.3 m/s (900 W/m^2) for the North Sea nearby Amsterdam (World Bank Group, ESMAP, Vortex, et al., 2022)

According to Karatayev (2016) the total energy wind potential of Kazakhstan could generate over 18 times the total electricity demand of the republic. Hower, total installed wind capacity currently remains 183 MW (International Trade Administration, 2021). Karatayev (2016) states as well that the government announced to build around 34 windfarm by 2020, with a combined production amount of 1787 MW. However, these plans are not realised yet.

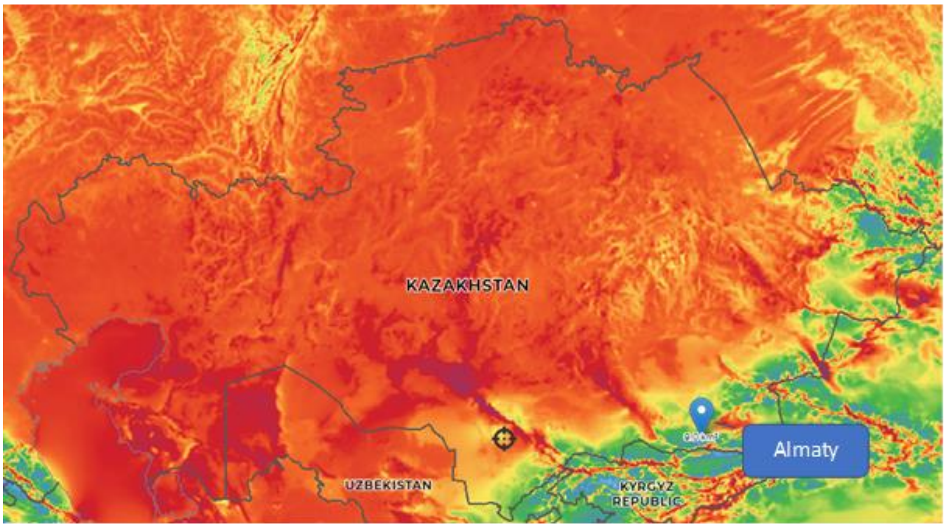


Figure J: Wind energy potential map
Source: World Bank Group, ESMAP, Vortex, et al. (2022)

Geothermal energy

Regarding geothermal energy, limited data is available. Various studies regarding renewable energy sources in Kazakhstan exclude geothermal energy (Bogdanov et al., 2019; Karatayev et al., 2016, 2016; PwC, 2021). The Thinkgeoenergy initiative provides a map of installed geothermal energy plants. This map does not include any geothermal energy plants within Kazakhstan. However, according to a study of the World Bank Group and ESMAP (2019) the W-Ily basin in the Ily region in Almaty holds geothermal potential for low temperature energy provision for direct space heating. Though, it should be mentioned that the findings of this report are based on a research of 1999, and that a geothermal facilitation has not been installed yet. The study suggests further studies are needed for exploring the potential. The study of World Bank Group and ESMAP (2019) concludes that geothermal energy cannot be competitive for power generation, but potential could be studied for direct use in district heating. Lastly, the extensive study on potential of 100% renewable energy grid for Kazakhstan from Bogdanov, Toktarova and Breyer (2019) have not included geothermal energy facilities in their 2050 scenario's, although an geothermal energy potential of 31,8 TWh/year was included in their calculations.

The exclusion of geothermal potential could be prescribed to the zeitgeist of last decades, since geothermal was not popular and our society is mainly designed on fossil based energy. However, this does not necessarily mean that there is no potential or future use for geothermal energy. Therefore the outcomes of the study of Boguslavsky et al. (1999) could still be relevant since the transition towards renewables opens possibilities for previously uninteresting options, and are therefore used again in the World Bank Study on geothermal exploration. The study specifically concludes that existing fossil energy infrastructure, especially in the South-East of Kazakhstan, forms opportunities for relatively easy implementation of geothermal energy (World Bank Group & ESMAP, 2019).

Due to currently limited information on geothermal energy potential it is not included in this study. Further research should conclude on the potential of geothermal energy before it can be concluded in future energy scenarios. Exploring site specific potential for geothermal energy sources in the Almaty region, and the W-Ily basin, is beyond the scope of this research, and is therefore excluded.

Hydro energy

Nationally hydropower does already account for around 13% of the total energy production, generating approximately 7,8 TWh. This hydropower is generated by 15 large-scale hydro energy power plants (> 50 MW) with a total capacity of 2.248 GW (Karatayev et al., 2016). Currently two large scale (> 50 MW) hydropower plants generate energy for Almaty city and the, the Moynak (HPP) and the Kapchagay (HPP). The Kapchagay HPP is the oldest hydropower plant, constructed between 1965 and 1970. The plant has a maximum power generating capacity of 364 MW (ALES, 2022). The Moynak HPP was commissioned in 2012 and had a generating capacity of 300 MW. The main purpose of the plant is to cover peak loads in the Almaty region. The plant produces between 900 and 1100 million kWh per annum (Samruk Energy, 2017).

Besides, large-scale hydropower, there are some small-scale hydro dams (< 35 MW) as well. Nationally in total 225 MW generating capacity is installed, with an production around 104,55 million kWh in the first quarter of 2020 (Laldjebaev et al., 2021). MacGregor (2017) states that 8 small HPPs are operational in the Almaty region, with a total generating capacity of 72,1 MW.

Five more hydropower plants are planned for the Almaty region with capacities of 34,8 MW, 42 MW, 24,9 MW, 15 MW, and 12 MW (Eshchanov et al., 2019). Next to these planned hydro energy plants there is limited data on future potential in the Almaty region. Although, nationally, hydropower potential would only be exploited for 15% currently (Eshchanov et al., 2019). And the PwC report (2021) states that most potential lies in the Mid-South region of Kazakhstan, but Almaty is mentioned as valuable hydropower area as well.

2. Financial analysis of renewable energy sources

The section concluded on the possibilities for generating renewable energy in the region of Almaty. Various studies confirm on the potential of solar, wind and hydro energy. Due to fluctuations in productivity and characteristics of the systems, a combination of various RES are required to fulfil the energy demand of Almaty in the future. Wind and solar are a good combination since their average productivity is more stable when installed collectively. Bogdanov et al. (2019) state that the majority of the power should be generated by solar power (50%) since this is the cheapest form of RE, but wind should generate significant amount as well (40%), as it generates energy more stable throughout the year. According to their study, wind and solar are dominant since other renewable sources reached their limits, such as biomass and hydro power.

This section provides an overview of current price levels of renewable energy compared to fossil fuel alternatives. The prices provide insight on current average electricity prices per kWh. However, when analysing the CtG-transition more variables should be included, such as investments for adaptation/installation costs, energy security and future price prospects. The LCOE which stands for *levelised cost of electricity* measures the cost per kWh of energy per type of technology. The EIA (2022) defines the LCOE as *"[…] the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle"*. The LCOE is based on a relatively simple formula that take the sum of costs over a lifetime divided by the sum of electrical energy produced over lifetime. Within this LCOE many variables are taken into account, and also the *total installed cost* impacts the average prices per kWh. The *total installed cost* according to IRENA (2022) includes costs regarding hardware (e.g. modules, inverters, grid connection, cabling), installation (e.g. mechanical installation, electrical installation, inspection), and soft costs (e.g. margin, financing costs, permitting, system design). In this study the LCOE is leading, but the *total installed cost* provide some valuable added information. For some variables country specific data on all type of energy sources is available. However, data on Kazakhstan is often still limited, therefore data of China is used as reference country for Kazakhstan. Chine is taken due to its geographic orientation and characteristics, their vast coal resources and dependency and their status an increasingly developed nation. Below an overview is presented of current and expected LCOE levels.

Energy source electricity generation	Price 2021 ($/kWh)	Price 2030 ($/kWh)	Price 2050 ($/kWh)
Coal + gas (CHP KZ)	0,042[1] (c. 0,056 excl. subsidies)	-	-
Coal (CHP)	0,060 - 0,170[2]	0,080[2]	0,095[2]
Gas (CHP)	0,100 - 0,110[2]	0,120[2]	0,130[2]
Solar (utility scale)	0,035 - 0,055[2]	0,020 - 0,040[2]	0,015 - 0,030[2]
Wind (on shore)	0,050[2]	0,045[2]	0,045 - 0,040[2]
Hydropower (river)	0,048	0,048 - 0,082[3]	0,048 - 0,082[3]

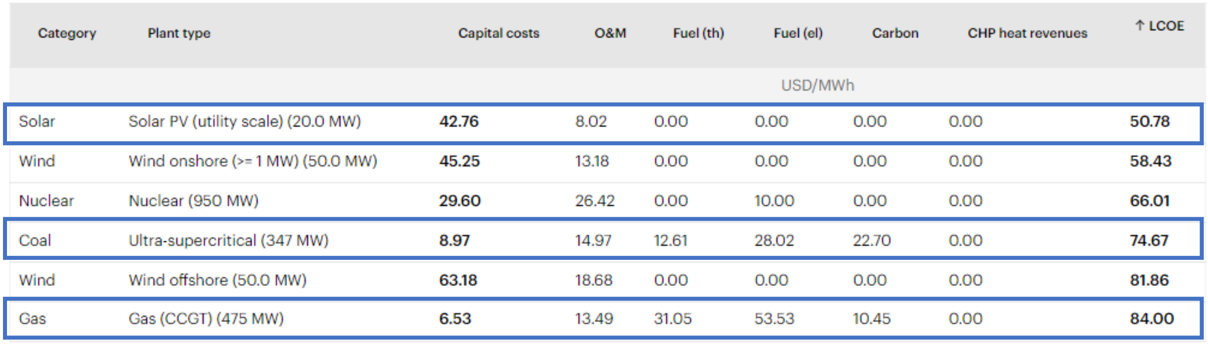
Table I: Overview LCOE per energy source

[1] Source: globalpetrolprices.com (December 2021), comparable (World Bank Group, 2017a p. 44, 2017b, p. 23)

[2] Source: IEA (2021) specification of LCOE per energy source in 2020, 2030 and 2050 per region

[3] Source: EIA (2022) specification of LCOE of hydro power in 2040, so accounted these numbers to 2030 and 2050

At first sight, current LCOE of Almaty's CHP's (coal + gas) appears to be significantly lower than the bottom range of the compared LCOE's (page 45). However, Almaty's current fossil fuel electricity prices are heavily subsidized by the government, as earlier mentioned. The average fossil fuel subsidisation rate for consumers is 32.6% (OECD, 2014). When these subsidies are included, the average LCOE of CHP electricity is almost equal to the lowest boundary of current fossil fuel LCOE (coal energy in China). Kazakhstan's LCOE, excluding subsidies, ends up to **0.056 $/kWh** in 2021, compared to **0.060 $/kWh** for the lowest LCOE (China). Second, Kazakhstan's LCOE does not include carbon pricing, while China's LCOE deos. Lastly, even with an LCOE of 0.042 $/kWh, wind and solar energy can be competitive, especially in 2030 and 2050.

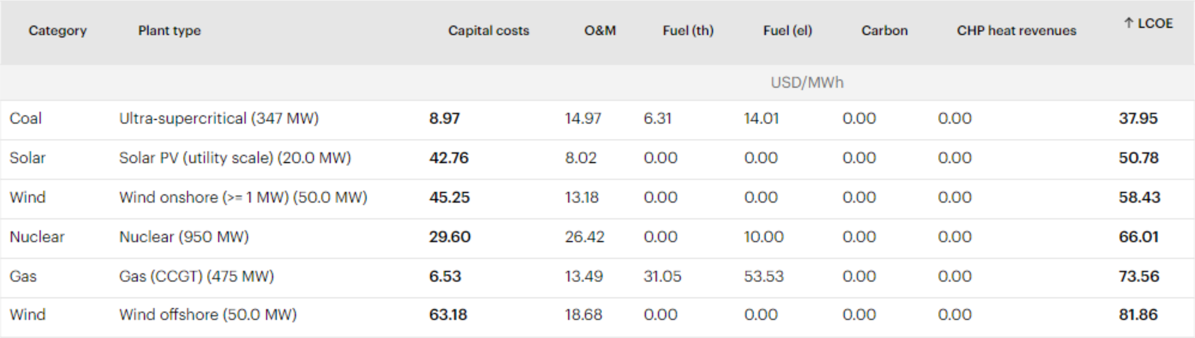


Category	Plant type	Capital costs	O&M	Fuel (th)	Fuel (el)	Carbon	CHP heat revenues	↑ LCOE
					USD/MWh			
Solar	Solar PV (utility scale) (20.0 MW)	**42.76**	8.02	0.00	0.00	0.00	0.00	**50.78**
Wind	Wind onshore (>= 1 MW) (50.0 MW)	**45.25**	13.18	0.00	0.00	0.00	0.00	**58.43**
Nuclear	Nuclear (950 MW)	**29.60**	26.42	0.00	10.00	0.00	0.00	**66.01**
Coal	Ultra-supercritical (347 MW)	**8.97**	14.97	12.61	28.02	22.70	0.00	**74.67**
Wind	Wind offshore (50.0 MW)	**63.18**	18.68	0.00	0.00	0.00	0.00	**81.86**
Gas	Gas (CCGT) (475 MW)	**6.53**	13.49	31.05	53.53	10.45	0.00	**84.00**

Table J: LCOE calculations per energy source in China (2020)
Source: IEA (2020)

In general it is interesting that since 2018 the global average LCOE of on shore wind decreased below the level of the cheapest new fossil-fuel fired power plants in the G20. Solar power achieved this milestone in 2020. LCOE averages of hydro power are hard to predict since the costs highly vary per specific case, due to natural circumstances and technological requirements (EIA, 2022). Since most potential around Almaty has already been utilised, the LCOE of hydro power is less relevant for future energy production strategies. Still ca 130 MW is planned to be implemented (Eshchanov et al., 2019), although this is substantial, it is probably not be decisive for renewable energy strategies. The IEA (2020) published a list with LCOE per energy type per country. As data on Kazakhstan was unavailable, China is selected as reference case. Therefore one could argue that production costs of renewable technologies are lower in China. However, it is not confirmed whether IEA took one global reference price, and it is assumed that this data represents reality better than the global average LCOE.

Interestingly, the LCOE of new coal projects is 1,5 times higher than for solar projects, taking into account capital costs, operations and maintenance (O&M), thermal fuel (fuel (th)), electricity costs (fuel (el)), price per tonnes emitted carbon (carbon), and CHP heat revenues. Although the outcome is still remarkable, some assumption should be taken into account (See figure 10). The LCOE of IEA 2020 takes into account current (2020) gas and coal prices, which are historically high. Although, gas and oil become increasingly scarce in the future due to short term rise of demand but decreased implementation of new projects, current high prices may not be representative for short term new projects (IEA, 2021e). However, even if one accounts for lower (50%) coal and gas prices the LCOE decreases, but remains higher than wind and solar. Next, the IEA accounts for a carbon prices of 30 $/ton. If the carbon price is additionally decreased to zero, the LCOE is lower than solar and wind (37,95 $/MWh) (See figure 11). Although, these low prices may best represent current ratio between coal-based and solar-based LCOE for Almaty, with the climate ambitions in mind, various ETS systems (Europe and China) and the announcement of CBAM, including a carbon price better represents future LCOE. For example, current EU carbon permit prices are around 85 $/tonne CO$_2$ (August 2022) and the IEA forecasts a price of 250 $/tonne in 2050 for developed economies and 200 $/tonne for other major economies (e.g. Russia, China, Brasil) (IEA, 2021e; Trading Economics, 2022). Lastly, CHP heat revenues are not included in these Chinese coal power plants. But, additional heat revenues are marginal since the price for heat is really low in Almaty.



Category	Plant type	Capital costs	O&M	Fuel (th)	Fuel (el)	Carbon	CHP heat revenues	↑ LCOE
					USD/MWh			
Coal	Ultra-supercritical (347 MW)	**8.97**	14.97	6.31	14.01	0.00	0.00	**37.95**
Solar	Solar PV (utility scale) (20.0 MW)	**42.76**	8.02	0.00	0.00	0.00	0.00	**50.78**
Wind	Wind onshore (>= 1 MW) (50.0 MW)	**45.25**	13.18	0.00	0.00	0.00	0.00	**58.43**
Nuclear	Nuclear (950 MW)	**29.60**	26.42	0.00	10.00	0.00	0.00	**66.01**
Gas	Gas (CCGT) (475 MW)	**6.53**	13.49	31.05	53.53	0.00	0.00	**73.56**
Wind	Wind offshore (50.0 MW)	**63.18**	18.68	0.00	0.00	0.00	0.00	**81.86**

Figure K: LCOE calculations per energy source in China (adjusted to low coal and gas prices and no carbon price) (2020)
Source: IEA (2020)

Solar energy price development

Prices of solar energy declined majorly due to technological improvements and increased competition. Levelised cost of electricity (LCOE) declined from 0,417 ($/kWh) in 2010 to 0,048 ($/kWh) in 2021, which results in a 8% year-on-year decrease. Although the global averaged weighted LCOE in 2021 was 0,048 $/kWh in China the lowest LCOE 0,034 $/kWh. This could be due to their vast amounts of crystalline and low-production costs, but it nevertheless show the potential. Besides solar panels become increasingly productive considered MW/ha. In 2010 the average values were between 2,37 and 2,69 ha/MW, and currently (2021) average production is between 1,89 - 1,94 ha/MW, with the 5th percentile at 0,93 ha/MW (IRENA, 2022).

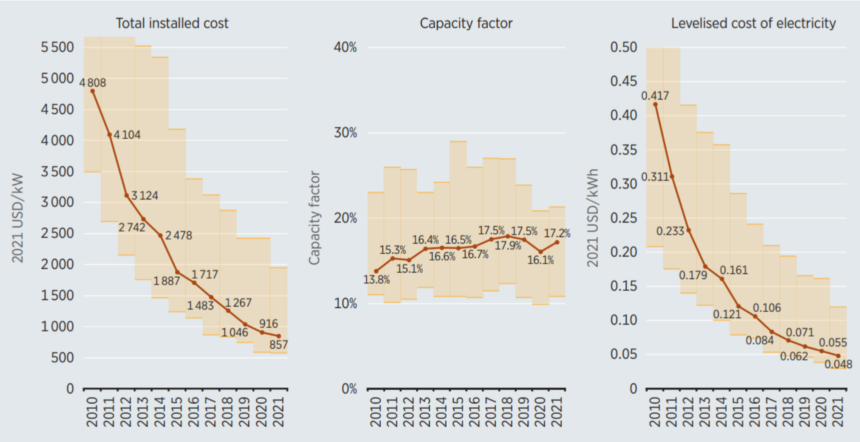


Figure K: Solar PV total installed cost, capacity factor and LCOE development

Source: IRENA (2021)

On shore wind energy price development

The global average weighted LCOE decreased from 0,102 $/kWh (2010) to 0,033 $/kWh. This means on decrease of 15% year-on-year. Total installed cost of on shore wind decreased 35% between 2010 and 2021, from 2.042 $/kWh to 1.325 $/kWh, a 5% decrease every year. Prices for on shore wind ranged between 960 $/kWh and 780 $/kWh. However, in China the costs decreased even further to 425 $/kWh. After the year-on-year price decreases, wind turbine costs increased in 2021 due to an increase in material prices. The wind turbines are also becoming more efficient in production, the *capacity factor,* average from 27% (2010) to 39% (2021).

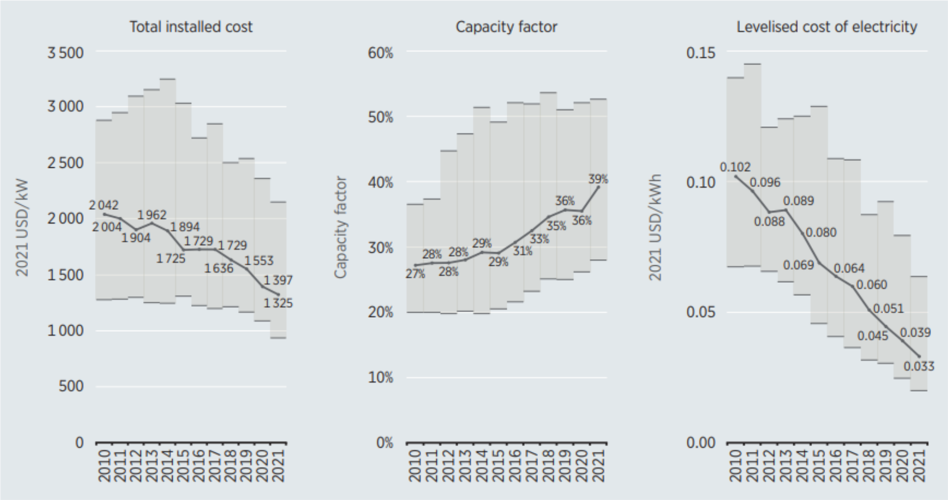


Figure L: Development of total installed cost, capacity factor and LCOE for on shore wind
Source: IRENA (2021)

Hydro power energy price development

Hydro power has been active in the Almaty energy grid for decades. However, still new technologies are developing, and for future (small) hydro power plants it is interesting to discuss the developments briefly. Hydro power is the only technique that experienced increased LCOE between 2010 and 2021 discussed in this study. In 2010 LCOE of hydro power was 0,039 $/kWh and in 2021 it was 0,048 $/kWh. However, still 85% of newly commissioned hydropower plants has cheaper LCOE than new fossil fuel-fired alternatives. The increase in cost is due to challenging locations and therefore higher install costs. The total installed costs were 2135 $/kWh in 2021 and 1315 $/kWh in 2010.

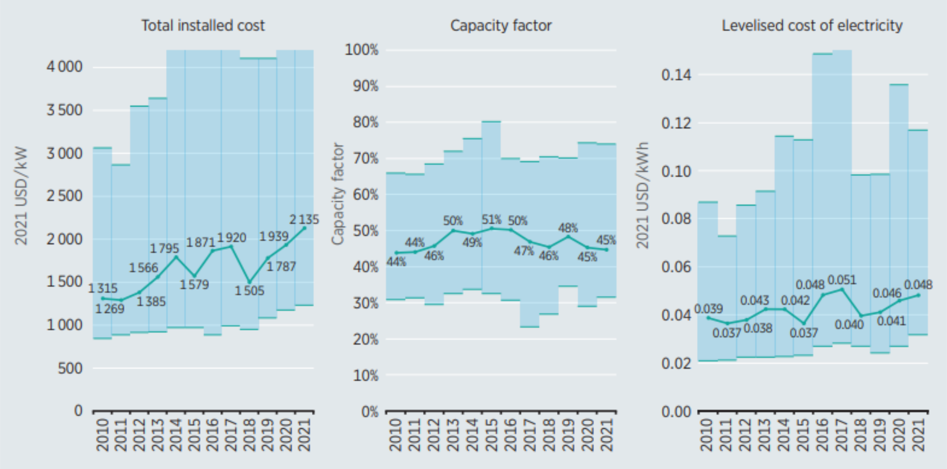


Figure M: Development of total installed cost, capacity factor and LCOE for on shore wind
Source: IRENA (2021)

3. Quantitative analysis: RES alternative for the CtG-transition

Wind and solar energy ratio

Various challenges must be overcome in order to implement large shares of RES, and even more to achieve energy neutrality. One of these challenges is to stabilise the electricity network due to variabilities in renewable energy production from natural sources such as solar and wind. Stabilising the network can be done in various ways. Hydropower is for example a suitable and sustainable way to balance the energy network. In the future battery storage or hydrogen power are probably playing a major role (Islam et al., 2018)

Moreover, a mix of complementary RES increase a balanced energy network since energy production is on average is divided over longer periods of time during the day and the year. Bogdanov (2019) states that the vast majority of RE is operated by solar energy (c. 50%), wind energy (c. 30%) and hydro energy (c.10%). Another source is the model.energy tool (2022), which calculates the optimal balance between various renewable energy sources, to come to an optimal installed capacity to stabilise the power system. The tool operates on national scale, and with the natural circumstances of Kazakhstan it calculated a 50/50 ratio of wind and solar because of their complementary characteristics (see figure N).

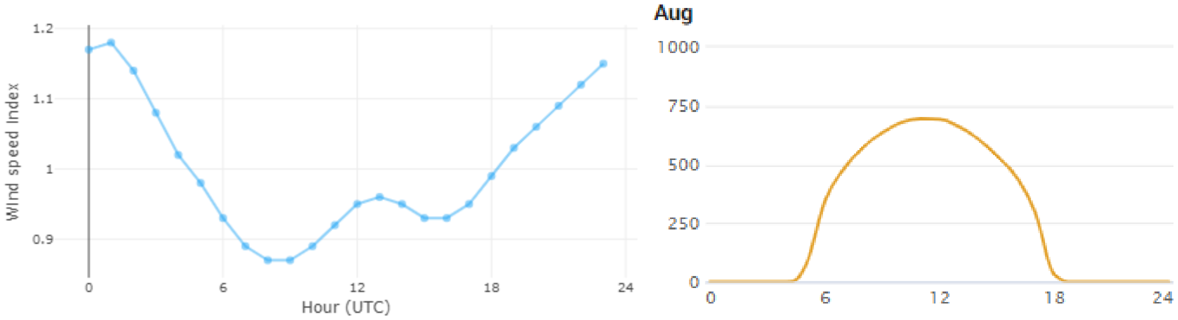


Figure N: Daily hourly wind index yearly average (right) and daily hourly solar intensity in August (left)
Source: Global Wind Atlas (2022)

However, now during the transition period towards larger shares of renewable energy, existing traditional energy sources are needed to balance the system (e.g. HPP, gas CHP, KEGOC), as hydropower alone does not suffice .

Lastly, during colder periods, in certain areas, extensive production of wind energy can be used to heat houses during cold times (IRENA, 2019b). The Annual wind intensity graph shows that the wind is more intensive during winter months, visualized bases on an index with 1 being the average (see figure O) During these months wind energy can compensate for lost solar energy, and may even use energy surplus for extra thermal energy, such as in the Denmark example (IRENA, 2019b).

Therefore, for this analysis CHP-2 energy was compensated by wind and solar in a 50/50 ratio. During the start of the energy transition, and for this study, it was assumed that this ratio suffices, since various tradition energy sources still exist, such as CHP-1, CHP-3, two hydro energy plants and imported energy from KEGOC. This conclusion lead to an equally shared amount of energy generated from wind and solar to compensate the **6,267 GWh** energy. However this amount is without energy losses and adapting to a full electrical system. The final energy demand by wind and solar is explained in the next section.

Energy demand to compensate CHP-2

CHP-2 generates heat and electricity, in which heat for a significant amount is a by-product in this process. However, solar and wind energy solely produce electricity. Therefore, to compensate for CHP-2 electric energy is needed to be converted to heat. However, power-to-heat can be converted with an efficiency of nearly 100% with electrical boilers (calculations made with 99%) (Beyond Zero Emissions, 2018; IRENA, 2019c; Schoeneberger et al., 2022).

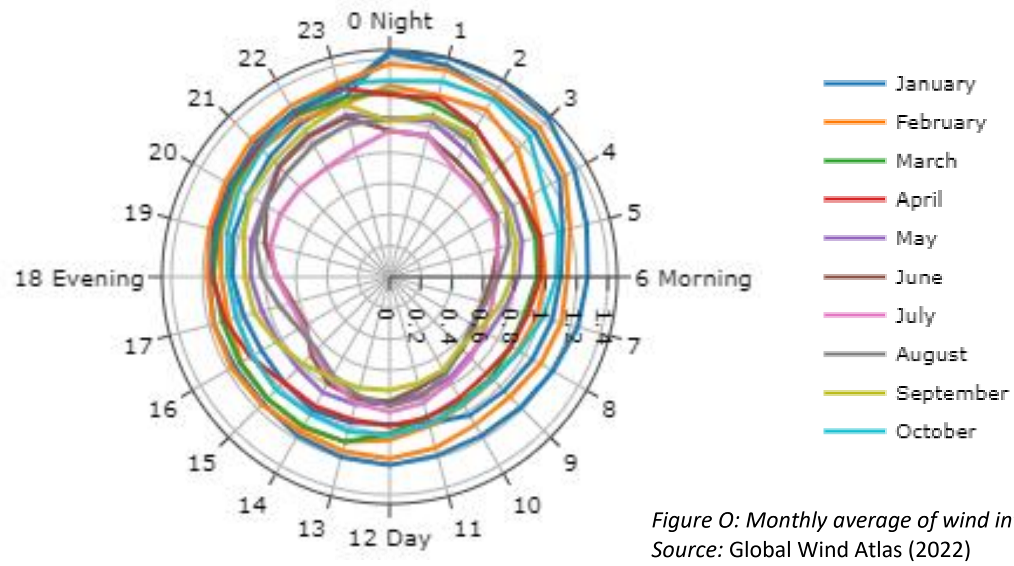


Figure O: Monthly average of wind intensity annually
Source: Global Wind Atlas (2022)

Besides the power-to-heat efficiency there are of course network losses as well. Transmission and distribution losses from Almaty's existing electricity and heat network should be taken into account. Especially heat losses are significant due to obsolete infrastructure system (World Bank Group, 2017). An overview of the CHP production, power-to-heat conversion and energy losses is presented in figure P.

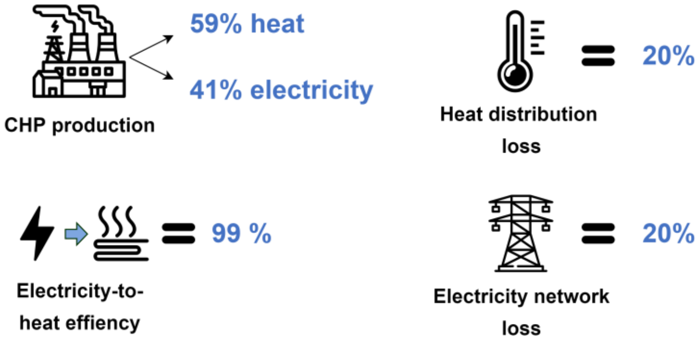


Figure O: Overview of current characteristics of energy production and losses
Source: The Word Bank, 2017

However, these loss rates do not include efficiency improvement investments, planned to be implemented in Almaty before 2030 (World Bank Group, 2017). Reducing energy demand before increasing generating capacity is conform the *Trias Energetica* principle. Therefore, it is assumed that these improvements are realised. The reduction measures of appendix C are taken into account. The efficiency improvements lead to a decreased energy demand to be compensated by RES. Below a breakdown of the required generated amount of energy by RES for heat and electricity is shown in table L.

Overall, table M. Includes a breakdown of the required generated amount of energy by RES for heat and electricity, taken into account the various consequences for compensating CHP-2 with renewable sources.

Energy reduction sector	Current energy loss (%)	Energy savings per sector (%)	2030 energy loss (%)
District heating	20%	34%	**13%**
Electricity network	16%	41%	**9%**

Table L: Almaty's energy losses and reduction in percentages based on the EET

Type of energy	Specification	Amount (GWh)
Electricity	CHP-2 net production for final usage	2,546
Heat	CHP-2 net production for final usage	3,721
	Heat distribution losses (13%)	491
	Loss power-to-heat (1%)	42
Subtotal	***Heat + electricity demand (excl. electricity network losses)***	***6,800***
	Electricity network losses (9%)	642
Total	**Heat + electricity demand (incl. losses)**	**7,442**

Table M: Breakdown of required generated energy by RES for heat and electricity

Appendix F: Data and calculations for data analysis

Chapter V. Current energy situation and reduction measures of Almaty

Figure 6. CO2 emissions and GDP growth per year for Kazakhstan (1990 – 2020)

Sources: Our World in Data, 2020; The World Bank, 2020

Year	GDP growth (annual %)	Annual CO2 emissions (1.000.000 tons/year)	Annual CO2 emissions (tons/year)
1990		281	281.461.062
1991	-11	272	271.694.827
1992	-5,3	247	247.262.845
1993	-9,2	220	219.593.222
1994	-12,6	186	185.657.718
1995	-8,2	178	178.381.106
1996	0,5	164	163.940.711
1997	1,7	156	155.571.482
1998	-1,9	150	150.160.515
1999	2,7	125	124.985.766
2000	9,8	149	149.054.077
2001	13,5	144	143.585.019
2002	9,8	161	161.037.004
2003	9,3	179	178.962.184
2004	9,6	189	188.546.939
2005	9,7	202	201.799.685
2006	10,7	221	221.130.080
2007	8,9	228	227.549.584
2008	3,3	229	228.670.094
2009	1,2	223	223.110.062
2010	7,3	249	249.066.913
2011	7,4	240	239.660.091
2012	4,8	246	245.836.489
2013	6	254	253.728.845
2014	4,2	279	279.032.098
2015	1,2	289	288.582.401
2016	1,1	289	288.685.797
2017	4,1	308	307.908.886
2018	4,1	317	317.279.662
2019	4,5	296	295.868.526
2020	-2,5	291	291.335.929

Figure 7: Share of energy type for road transport

Source: The World Bank, 2017

Amount of energy consumption per type of transport	Share	Amount (GWh)
Total amount of GWh (private cars + PT cars and busses)		**12328,29**
Gasoline (95,45%)	95,45%	11767,35
Diesel (3,72%)	3,72%	458,61
Other (e.g. mixed, LPG, electric)	0,83%	102,32
Mixed fuel (0,70%)	0,70%	86,30
LPG (0,11)%	0,11%	13,56
Electricity (0,02%)	0,02%	2,47

Figure 8: Energy consumption per transport method
Source: The World Bank, 2017

Amount of energy consumption per type of transport (public or private)	Share	Amount (GWh)
Rail	0,06%	8
Public transport (taxis & busses)	2,02%	12079
Private cars	97,92%	249
Total	100,00%	12328

Figure 9: District heat consumption per sector
Source: The World Bank, 2017

Sector	Amount (GWh)	Share (%)
Residential buildings	3967	51%
Industrial and commercial buildings	1540	20%
Public (munipal) buildings	631	8%
Heat distribution losses	1535	20%
Other	36	0%
Total	**7709**	**100%**

Figure 10: Electricity consumption per sector
Source: The World Bank, 2017

Sector	Amount (GWh)	Share (%)
Residential buildings	1879	27,26%
Industrial and commercial buildings	3405	49,39%
Public (munipal) buildings	204	2,96%
Network losses	1103	16,00%
Other	303	4,39%
Total	**6894**	**100,00%**

Figure 11: Shares of primary of energy sources in electricity and heat production
Source: The World Bank, 2017

Total of primary energy generation (heat + electricity)	Amount (GWh)
Coal	11477
Natural Gas	7149
Mazut	188
Total	18814

Figure 12: Total amount of heat and electricity production (incl. losses, and internal energy use)
Sources: The World Bank, 2017

Total energy overview	Amount (GWh)	Share
Total energy (heat + electricity)	18814	100%
Electricity	6894	37%
Heat	7676	41%
Internal usage and losses	4244	23%

Figure 13: Shares of electricity production Almaty and shares of ALES electricity production
Sources: The World Bank, 2017

Producer	Production plant	Amount (GWh)	Percentage
ALES		4343	63,00%
	CHP-1 (share of ALES)	*382*	*8,80%*
	ALES CHP-2 (share of ALES)	*2606*	*60,00%*
	ALES CHP-3 (share of ALES)	*1173*	*27,00%*
	HPP (share of ALES)	*182*	*4,20%*
KECOG		2551	37,00%
Total		**6894**	**100,00%**

Figure 14: Shares of district heat production Almaty and shares of ALES district heat production
Sources: The World Bank, 2017

Producer	Production plant	Amount (GWh)	Share
ALES		5782	75%
	CHP-1 (share of ALES)	*1396*	*24%*
	CHP-2 (share of ALES)	*3703*	*64%*
	CHP-3 (share of ALES)	*104*	*2%*
	HOB (share of ALES	*578*	*10%*
ATKE		1927	25%
Total		**7709**	**100%**

Figure 15: Amount of buildings per sector
Sources: The World Bank, 2017

Number of buildings	Amount (units)
Public (municipal) buildings	1000
Commerical & industrial buildings	37600
Residential buildings	157516
Total	**196116**

Figure 16: Energy consumption per building sector
Sources: The World Bank, 2017

Split of total amount of eneryg per sector	Amount (GWh)	Share
Public (municipal) buildings	971	5%
Industrial buildings	8107	42%
Residential buildings	10439	53%
Total	**19517**	**100%**

Figure 17: Shares of energy consumption of building stock
Sources: The World Bank, 2017

Total consumption of energy from building stock per energy source	Amount (GWh)	Share
District heat and district hot water	6156	38%
Power	5527	34%
Coal	609	4%
Other fuel (gas, LPG, oil)	4120	25%
Total	16413	100%

VI. Political dimension: overview of energy policies and political dynamics Almaty

Figure 18: Carbon emission compared to the Paris Climate Goals
Sources: Our World in Data, 2020; The World Bank, 2017

Year	Annual CO2 emissions (mln tons/year)	Paris Climate Goal (15% compared to 1990)	Paris Climate Goal (25% compared to 1990)
1990	281	239	211
1991	272	239	211
1992	247	239	211
1993	220	239	211
1994	186	239	211
1995	178	239	211
1996	164	239	211
1997	156	239	211
1998	150	239	211
1999	125	239	211
2000	149	239	211
2001	144	239	211
2002	161	239	211
2003	179	239	211
2004	189	239	211
2005	202	239	211
2006	221	239	211
2007	228	239	211
2008	229	239	211
2009	223	239	211
2010	249	239	211
2011	240	239	211
2012	246	239	211
2013	254	239	211
2014	279	239	211
2015	289	239	211
2016	289	239	211
2017	308	239	211
2018	317	239	211
2019	296	239	211
2020	291	239	211

VIII. Techno-economic dimension: analysis of Almaty's energy landscape

Table 15: Breakdown of required generated energy by RES for heat and electricity (black numbers)
Sources: IRENA, 2019, 2022; World Bank Group, 2017; World Bank Group et al., 2022

Total CtG investment	680.336.455	USD
LCOE solar PV Kazakhstan	0,042	$/kWh
kWh potential of investment	16.393.649.521	kWh
	16.393	GWh
	16	TWh
CHP-2 yearly electricity production	**2546**	**GWh**
CHP-2 yearly heat production	**3721**	**GWh**
Heat distribution losses	491,2	GWh
Previous (current) heat distribution losses	744,2	GWh
New heat distribution loss rate (after EET)	13%	
Previous heat distribution loss	20%	
EET heat distribution loss reduction	34%	
Efficiency rate power-to-heat	99%	
Efficiency rate power-to-heat	42	GWh
Total required electricity for heat	**4254**	**GWh**
Total electricity demand (heat + electricity) before network losses	*6800*	*GWH*
New electricity network losses (after EET)	9%	
Electricity network losses	16%	
EET electricity network loss reduction	41%	
Electricity network losses	642	GWh
Previous (current) electricity network losses	1088	GWh
Total electricity demand (heat + electricity) including network losses	**7442**	**GWh**

Table 16: Required land and total investment costs for the solar PV scenario (50% CHP-2)
Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group et al., 2022

Full compensation of CHP-2		
Solar GIS GWh/year per MW installed capacity	1	MW installed capacity
	1,446	GWh/year per 1 MW installed
50% compensation of CHP-2 (solar/wind ratio)		
Solar GIS	1000	kWp installed capacity
	1,446	GWh/year
IRENA average ha/MW	1,94	ha/MWh
Total annual energy production CHP-2 (incl losses)	7442	GWh
50% of CHP-2 annual produced by solar	3721	GWh
Required MW solar PV (50% solar)	**2573,39**	**MW**
Total installed costs solar		
China installed costs ($/kW)	625,4	$/kW
Germany installed costs ($/kW)	776,2711864	$/kW
Average (KZ installed costs) ($/kW)	**700,8355932**	$/kW

Required MW	2573	MW
Required kW	2573389	kW
Installed costs required	1803522718	USD
Totall installed costs (bln USD)	**1,8**	**bln USD**
Total installed costs solar	**1,8**	**bln USD**
Totall installed costs 60% solar	2,2	bln USD
Totall installed costs 70% solar	2,5	bln USD

Table 16: Required land and total investment costs for the wind energy scenario (50% CHP-2)

Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group, ESMAP, Vortex, et al., 2022

Total installed costs wind		
China installed costs ($/kW)	1157	$/kW
Germany installed costs ($/kW)	1623	$/kW
Average (KZ installed costs) ($/kW)	1390	$/kW
Required MW	2315	MW
Required kW	2314672	kW
Installed costs required	3217394116	USD
Total installed costs wind	**3,2**	**bln USD**
Totall installed costs 40% wind	2,6	bln USD
Totall installed costs 30% wind	1,9	bln USD

Land requirement for wind energy scenario		
Average MW peak production per turbine	1,5	MW
	1,75	MW
Generated GWh per turbine	2,813341	GWh/year
Total annual energy production CHP-2 (incl losses)	7442,24	GWh
50% of CHP-2 annual prodcued by solar	3721,121	GWh
Required wind turbines	**1322,67**	**turbines**
Land usage requirements		
Land use turbine per MW (IRENA)		
Lower boundary	2,5	MW/km2
Upper boundary	5	MW/km2
Assumed space use per installed capcity	3	MW/km2
	5	MW/km2
Total installed capacity (turbines * Avearge peak porduction)	2314,67	MW
Required land area (3 MW/km2)	**771,56**	**km2**
Required land area (5 MW/km2)	462,9344	km2

Years equivalent of CHP-2 fossil energy for solar PV scenario

Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group, ESMAP, & SOLARGIS, 2022

Equivalent solar energy from CHP-investment		
Total CtG investment	680.336.455,14	USD
Equivalent amount of energy from solar of CHP-2 investment	16393649521	kWh
	16394	GWh
Total electricity demand (heat + electricity) including network losses	7442	GWh
Equivalent years of fossil fuel production (incl losses)	**2,2**	**years**
Equivalent years with 10% uncertainty (incl losses)		
Equivalent amount of energy from solar of CHP-2 investment	14903317747	kWh
	14903	GWh
Equivalent years of fossil fuel production (incl losses)	2,0	years

Years equivalent of CHP-2 fossil energy for wind energy scenario

Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group, ESMAP, Vortex, et al., 2022

Equivalent wind energy from CHP-investment		
Total CtG investment	680.336.455,14	USD
Equivalent amount of energy from wind of CHP-2 investment	19438184433	kWh
	19438	GWh
Total electricity demand (heat + electricity) including network losses	7442	GWh
Equivalent years of fossil fuel production (incl losses)	**2,6**	**years**
Equivalent solar energy from CHP-investment (10% uncertainty)		
Equivalent amount of energy from solar of CHP-2 investment	17671076757	kWh
	17671	GWh
Equivalent years of fossil fuel production (incl losses)	2,4	years

Land requirement solar PV scenario to compensate 50% of CHP-2 (incl. losses and efficiency rates)

Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group et al., 2022

Full compensation of CHP-2		
Solar GIS GWh/year per MW installed capacity	1	MW installed capacity
	1,446	GWh/year
50% compensation of CHP-2 (solar/wind ratio)		
Solar GIS	1000	kWp installed capacity
	1,446	GWh/year
IRENA average ha/MW	1,94	ha/MWh
Total annual energy production CHP-2 (incl losses)	7442	GWh
50% of CHP-2 annual produced by solar	3721	GWh
Required MW solar PV (50% solar)	**2573,39**	**MW**
Area required for CHP-2 power (50% solar)	**4992,37**	**ha**
	49,92	**km2**

Land requirement wind energy scenario to compensate 50% of CHP-2 (incl. losses and efficiency rates)

Sources: IRENA, 2022; World Bank Group, 2017; World Bank Group, ESMAP, Vortex, et al., 2022

Land requirement for wind energy scenario		
Average MW peak production per turbine	1,5	MW
	1,75	MW
Generated GWh per turbine	2,813341	GWh/year
Total annual energy production CHP-2 (incl losses)	7442,24	GWh
50% of CHP-2 annual prodcued by solar	3721,121	GWh
Required wind turbines	**1322,67**	**turbines**
Land usage requirements		
Land use turbine per MW (IRENA)		
Lower boundary	2,5	MW/km2
Upper boundary	5	MW/km2
Assumed space use per installed capcity	3	MW/km2
	5	MW/km2
Total installed capacity (turbines * Avearge peak porduction)	2314,67	MW
Required land area (3 MW/km2)	**771,56**	**km2**
Required land area (5 MW/km2)	462,9344	km2

Figure 25: Annual CO2 emissions per energy scenario for three energy scenarios

Sources: EBRD, 2022; World Bank Group, 2017

Emissions breakdown Phase 1 CtG-conversion CHP2

Action	200 Mwe gas installed		
Consequence	200/510 gas based power	39,22%	gas emissions
	1-(200/510) coal based power	60,78%	coal emissions
Yearly decrease coal emissions	coal emission / years	9,80%	
Gas emission after conversion	3.500.000 tons of CO2	3,5	mln tons/year
Coal emissions	6.500.000 tons of CO2	6,5	mln tons/year

Emissions shares phase 1	**Coal emissions**	**Gas emission**	**Coal emission mln tons/year)**	**Gas emission mln tons/year)**
2023	90,20%	9,80%	6,5	3,5
2024	80,39%	19,61%	6,5	3,5
2025	70,59%	29,41%	6,5	3,5
2026	60,78%	39,22%	6,5	3,5

Emissions phase 1	**Coal emissions**	**gas emission**	**Total emission (gas + coal)**	**Coal emission mln tons/year)**	**Gas emission mln tons/year)**
2023	5,86	0,34	6,21	6,5	3,5
2024	5,23	0,69	5,91	6,5	3,5
2025	4,59	1,03	5,62	6,5	3,5
2026	3,95	1,37	5,32	6,5	3,5

Emissios brake down phases
Phase
0 = 2022
1 = 2023 - 2026

Emissions breakdown Phase 2 CtG-conversion CHP2

Action	310 Mwe gas installed		
Consequence	310/510 gas based power	60,78%	gas emissions
	1-(310/510) coal based power	39,22%	coal emissions
Yearly decrease coal emissions	gas emission / years	30,39%	
Gas emission after conversion	3.500.000 tons of CO2	3,5	mln tons/year
Coal emissions	6.500.000 tons of CO2	6,5	mln tons/year

Emissions shares phase 1	**Coal emissions**	**gas emission**	**Coal emission mln tons/year)**	**Gas emission mln tons/year)**
2027	30,39%	69,61%	6,5	3,5
2028	0,00%	100,00%	6,5	3,5

Emissions phase 1	**Coal emissions**	**gas emission**	**Total emission (gas + coal)**	**Coal emission (mln tons/year)**	**Gas emission (mln tons/year)**
2027	1,98	2,44	4,41	6,5	3,5
2028	0,00	3,50	3,50	6,5	3,5

Emissions breakdown Phase 1 RES alternative (Policy and Preparation)

Action	200 Mwe gas installed		
Consequence	Solar and wind installation	0,00%	Solar + wind
	1-(200/510) coal based power	100,00%	coal emissions
Yearly decrease coal emissions	coal emission / years	0,00%	
Gas emission after conversion	3.500.000 tons of CO2	3,5	mln tons/year
Coal emissions	6.500.000 tons of CO2	6,5	mln tons/year

Emissions shares phase 1	**Coal emissions**	**Gas emission**	**Coal emission (mln tons/year)**	**Gas emission (mln tons/year)**
2023	100,00%	0,00%	6,5	3,5
2024	100,00%	0,00%	6,5	3,5

Emissions phase 1	**Coal emissions**	**Gas emission**	**Total emission (gas + coal)**	**Coal emission (mln tons/year)**	**Gas emission (mln tons/year)**
2023	6,50	0,00	6,50	6,5	3,5
2024	6,50	0,00	6,50	6,5	3,5

Emissions breakdown Phase 2 RES alternative (Implementation)

Action			
Consequence	510/5 emissinon decrease yearly	20,00%	gas emissions
			coal emissions
Yearly decrease coal emissions	gas emission / years	10,00%	
Gas emission after conversion	3.500.000 tons of CO2	3,5	mln tons/year
Coal emissions	6.500.000 tons of CO2	6,5	mln tons/year

Emissions shares phase 2	**Percentage coal emissions**	**Percentage RES**	**Coal emission mln tons/year)**
2025	80,00%	20,00%	6,5
2026	60,00%	40,00%	6,5
2027	40,00%	60,00%	6,5
2028	20,00%	80,00%	6,5
2029	0,00%	100,00%	

Emissions phase 2	**Coal emissions**	**Emissions RES**	**Coal emission mln tons/year)**
2025	5,20	0,00	6,5
2026	3,90	0,00	6,5
2027	2,60	0,00	6,5
2028	1,30	0,00	6,5
2029	0,00	0,00	6,5

Year	CHP-2 coal	CHP-2 gas conversion	RES alternative
2015	6,5	6,5	6,5
2016	6,5	6,2	6,5
2017	6,5	5,9	6,5
2018	6,5	5,6	5,2
2019	6,5	5,3	3,9
2020	6,5	4,4	2,6
2021	6,5	3,5	1,3
2022	6,5	3,5	0,0
2023	6,5	3,5	0,0
2024	6,5	3,5	0,0
2025	6,5	3,5	0,0
2026	6,5	3,5	0,0
2027	6,5	3,5	0,0
2028	6,5	3,5	0,0
2029	6,5	3,5	0,0
2030	6,5	3,5	0,0
2031	6,5	3,5	0,0
2032	6,5	3,5	0,0
2033	6,5	3,5	0,0
2034	6,5	3,5	0,0
2035	6,5	3,5	0,0
2036	6,5	3,5	0,0
2037	6,5	3,5	0,0
2038	6,5	3,5	0,0

2039	6,5	3,5	0,0
2040	6,5	3,5	0,0
2041	6,5	3,5	0,0
2042	6,5	3,5	0,0
2043	6,5	3,5	0,0
2044	6,5	3,5	0,0
2045	6,5	3,5	0,0
2046	6,5	3,5	0,0
2047	6,5	3,5	0,0
2048	6,5	3,5	0,0
2049	6,5	3,5	0,0
2050	6,5	3,5	0,0

Figure 25: Cumulative CO2 emissions in 2050 per energy scenario for three energy scenarios
Sources: EBRD, 2022; World Bank Group, 2017

Year	Cumulative coal CO2 emissions (mln tons)	Cumulative gas CO2 emissions (mln tons)	Cumulative RES CO2 emissions (mln tons)
2015	6,5	7	7
2016	13	13	13
2017	19,5	19	20
2018	26	24	25
2019	32,5	30	29
2020	39	34	31
2021	45,5	37	33
2022	52	41	33
2023	58,5	44	33
2024	65	48	33
2025	71,5	51	33
2026	78	55	33
2027	84,5	58	33
2028	91	62	33
2029	97,5	65	33
2030	104	69	33
2031	110,5	72	33
2032	117	76	33
2033	123,5	79	33
2034	130	83	33
2035	136,5	86	33
2036	143	90	33
2037	149,5	93	33
2038	156	97	33
2039	162,5	100	33
2040	169	104	33
2041	175,5	107	33
2042	182	111	33
2043	188,5	114	33
2044	195	118	33
2045	201,5	121	33
2046	208	125	33
2047	214,5	128	33
2048	221	132	33
2049	227,5	135	33
2050	234	139	33

Figure 27: Electricity baseload and peak load production (excl. CHP-2) versus demand
Sources: IRENA, 2015; World Bank Group, 2017

Yearly electricity base load production (2015)

Electricity production per year	**Peak capacity**		**Baseload demand (electricity)**		
CHP-1	382,18	GWh/year	Yearly demand	5760	GWh
CHP-2	2605,8	GWh/year	Baseload ration of yearly demand	60,00%	
CHP-3	1172,61	GWh/year			
HPP-1 (Moinak)	182,41	GWh/year	Baseload demand (2015)	3456	GWh
KEGOC yearly production (GWh/year)	2550,65	GWh/year			
			Baseload demand losses	552,96	GWh
Total electricity production	**6893,65**	**GWh/year**			
Electricity electricity production (excl. CHP-2)	**4287,85**	**GWh/year**	**Baseload demand incl losses (2015)**	**4008,96**	**GWh**
Losses (%)	16%		Consumption growth rate	102,8%	
Total electricity baseload production	5790,666	GWh/year	District heat loss reduction factor per year	97,27%	
Electricity baseload production (excl. CHP-2)	3601,794	GWh/year	Electricity loss reduction factor per year	96,54%	
			Build area energy reduction factor per year	97,93%	

Peak capacity versus demand current (2015) situation (MWh)

Energy peak production	**Peak capacity per uur (MWh)**		**Energy peak demand (electricity)**		
CHP-1	145	MWh	Baseload demand (2015)	3456	GWh
CHP-2	510	MWh	Peak capcity 100% above baseload	100%	
CHP-3	173	MWh			
HPP-1 (Moinak)	300	MWh	Days a year	365	
HPP-2 (Kapshagay)	364	MWh	Hours a day	24	
			Daily baseload demand	9,47	GWh
KEGOC yearly production (GWh/year)	2550	GWh/year	Hourly average (GWh)	0,39	GWh
KEGOC (peak capcity/hour)	291	MWh	Hourly average (MWh)	394,52	MWh
Total electricity peak production	1492	MWh	**Peakload hourly (MWh)**	**789**	**MWh**
Electricity peak production (excl. CHP-2)	**982**	**MWh**	increased energy demand 2050	127%	

Data set for peak electricity generation capacity

Current peak capacity electricity production excl. CHP-2 (Gas CHPs, HPP, KECOG)	Peak electricity demand (2015)	Peak electricity demand (2050)
982	789	1005

Data set for baseload electricity production

Year	Production + losses sources excl. CHP-2 (Gas CHPs, HPP, KECOG)	Baseload demand (2015)	Baseload electricity demand future (incl. energy reduction + demand growth)	Baseload demand future build area + loss (EET measures)	Electricity loss baseload + EET measures (GWh/year)	Electricity loss reduction (EET measures) (2,73% annually)	Energy Baseload Build Area Electricity + EET measures (GWh/year)	Energy Build Area reduction (EET measures) (2,07% anually)	Future demand 10% increase
2015	4288	4009	4009	4009	553	1	3456	1	4410
2016	4288	4009	4029	3918	534	0,97	3385	0,98	4431
2017	4288	4009	3938	3830	515	0,93	3315	0,96	4331
2018	4288	4009	3849	3744	498	0,90	3246	0,94	4234
2019	4288	4009	3762	3659	480	0,87	3179	0,92	4138
2020	4288	4009	3678	3577	464	0,84	3113	0,90	4045
2021	4288	4009	3595	3497	448	0,81	3049	0,88	3954
2022	4288	4009	3514	3418	432	0,78	2986	0,86	3866
2023	4288	4009	3435	3342	417	0,75	2924	0,85	3779
2024	4288	4009	3359	3267	403	0,73	2864	0,83	3694
2025	4288	4009	3283	3194	389	0,70	2805	0,81	3612
2026	4288	4009	3210	3122	376	0,68	2747	0,79	3531
2027	4288	4009	3138	3052	363	0,66	2690	0,78	3452
2028	4288	4009	3068	2984	350	0,63	2634	0,76	3375
2029	4288	4009	3000	2918	338	0,61	2580	0,75	3300
2030	4288	4009	2933	2853	326	0,59	2526	0,73	3226
2031	4288	4009	3015	2853	326	0,59	2526	0,73	3317
2032	4288	4009	3100	2853	326	0,59	2526	0,73	3410
2033	4288	4009	3187	2853	326	0,59	2526	0,73	3506
2034	4288	4009	3277	2853	326	0,59	2526	0,73	3605
2035	4288	4009	3369	2853	326	0,59	2526	0,73	3706
2036	4288	4009	3464	2853	326	0,59	2526	0,73	3810
2037	4288	4009	3561	2853	326	0,59	2526	0,73	3917
2038	4288	4009	3661	2853	326	0,59	2526	0,73	4027
2039	4288	4009	3764	2853	326	0,59	2526	0,73	4141
2040	4288	4009	3870	2853	326	0,59	2526	0,73	4257
2041	4288	4009	3979	2853	326	0,59	2526	0,73	4377
2042	4288	4009	4091	2853	326	0,59	2526	0,73	4500
2043	4288	4009	4206	2853	326	0,59	2526	0,73	4626
2044	4288	4009	4324	2853	326	0,59	2526	0,73	4756
2045	4288	4009	4445	2853	326	0,59	2526	0,73	4890
2046	4288	4009	4570	2853	326	0,59	2526	0,73	5027
2047	4288	4009	4699	2853	326	0,59	2526	0,73	5169
2048	4288	4009	4831	2853	326	0,59	2526	0,73	5314
2049	4288	4009	4967	2853	326	0,59	2526	0,73	5464
2050	4288	4009	5106	2853	326	0,59	2526	0,73	5617

Figure 30: Heat peak production capacity versus realised production (assumed all heat was produced in 90 days for 5 hours pe days)

Sources: IRENA, 2015; World Bank Group, 2017

Total energy Consumption (EET P.2)	Amount (TWh)	Amount GWh
Electricity	5,76	5760
Heat	6,08	6080
Heat (coal)	2,24	2240
Total	14,08	14080

Energy saving heat and electricity	Subsector	Total reduction (GWh)	Energy consumption 2015 (EET)	Energy reduction (GWh)	Share GWh reduction
District heating (losses)		1712	5080	1712	33,70%
Power system (losses)		1589	3857	1589	41,20%
Build area	Total	0	19471	5237	26,90%
	Municipal buildings	*412*	*984*	*412*	*41,87%*
	Residential buildings	*3233*	*10439*	*3233*	*30,97%*
	Commercial and industrial buildings	*1592*	*8048*	*1592*	*19,78%*
Total				**8538**	

ALES share of heat production	Share of yearly production	Acutal share production
CHP-1 (gas)	24,10%	18,08%
CHP-2 (coal)	64,00%	48,00%
CHP-3 (gas)	1,80%	1,35%
HOB	10,10%	7,58%
Total ALES	100,00%	75,00%

Producer	Yearly heat production (Gcal)	Share (%)
ALES	5048250	75%
ATKE	1682750	25%
Total	6731000	100%
Heat used for DH	3990448	

Heat producer	Peak capacity (Gcal)	Share of installed peak capacity (%)	Peak capacity after losses (Gcal)	Share of yearly production	Actual yearly production (Gcal)	Realised peak generation (180 days, 10 hours/day)
CHP-1	1200	24%	960	18,08%	721273	401
CHP-2	1176	24%	940,8	48,00%	1915415	1064
CHP-3	200	4%	160	1,35%	53871	30
HOB	1100	22%	880	7,58%	302276	168
ATKE	1300	26%	1040	25%	997612	554
Total	*4976*	*100%*	*3980,8*	*100,00%*	*3990448*	2217

The complete data set, collected with data from The World Bank (2017), is publicly available via:

https://docs.google.com/spreadsheets/d/1VG0egNMjwTo_ZruQ5YU2eU_z4Hi1ug33/edit?usp=sharing&ouid=113416753129183688897&rtpof=true&sd=true

Appendix G: Transcribation RwA interview – 4th of April 2022

Attendees: Gabriela Gavgas (G), Ciprian Popvici (C), Jorge Rodrigues de Almeida (J), Wouter de Ronde (W)

Introduction:
All attendees introduce themselves briefly

Gabriela Gavgas: Environmental policy expert and RwA contactperson for GCAP
Cirpian Popvici: Environmental sociologist (RwA)
Jorge Rodrigues de Almeida: Energy expert (RdA)

C: Arcadis is a partner of RwA for the GCAP (Green City Action Plan) project. Current GCAP Almaty is work in progress, although it is almost finalised. We have collected a lot of information. All the data we collected are from official sources mainly, and all the databases belong to the municipality. So, we do have information. Some are reliable, and others less. For the energy sector we have quite some good data.

W: Is it correct that the GCAP is not publicly available yet.

C: Yes, that is correct. Currently it is under revision of the municipality. So, it is not done. Our wish is to finalise it by the end of June. But this will be difficult with all the delays. We seek to have a meeting in Almaty in May, where we seek to finalise the document. But at this moment it is not publicly available. However, the Technical Assessment Section (TAS) and the External Framework Report (EFR).

G: There is a consortium of three big companies active in the GCAP of Almaty: RwA, Arcadis Belgium, and a local team of ecological social analysts.

G: The GCAP project started in September 2020. Should have been a project of one year, however now it is two years later due to travel restrictions and delays. The project is divided in two phases. Phase 1: the environmental baseline, where we collected a lot of data. Data is divided in: state indicators, pressure indicators and response indicators. These indicators are collected for seven sectors: land use, transport, energy, buildings, waste, waste water, and industry.

G: All the data collection phases are done together with stakeholders consultation sessions. In total we have four of them. First, validation of data collection, challenges occurring from environmental situation, formulate a long list of action, that were debated with stakeholders and the Akimat, a short list of actions. Now we are in the second phase, which is the revision of the Akimat. Which consists of three rounds of feedback. After this the report will be publicly disclosed, and arrange a consultation session with all actors that want to be in involved. After this we will include all the feedback received and finalise the report.

G: Throughout the process we have developed some intermediate deliverables, the EFR and the TAS. EFR describe all the policy framework behind the GCAP, the regulatory framework and the current situation within each sector, and the smart gaps assessment. The smart gaps is about finding what smart solution could be used in the project. Afterwards we have analyses each indicator, and developed the TAS. The TAS describes each sectors, challenges, gaps, current responses, the city's response, and gaps within solution for the GCAP, etc.
C: We do have a database that we can share. The TAS, EFR and the indicator database can be found in the report. Data from the indicators database is collected from official sources. However, this data

appear to not be so reliable. There was some conflicting data. Therefore we collected more than ten sectoral meetings to discuss the data, validate the data and to gather more information. We even tried to identify the essential factors within the sector, even beyond the data. So, more the narrative from involved actors.

W: Does the data come from the governmental statistical database?

G: Indicator database from the energy sector involves some reliable sources, and with the international benchmarks some trends can be observed. So, you can check the report and the sources.

W: Jorge can you provide some information on the process of the energy sector, and what the strategy is for this sector. And one other question on the GCAP in general, what does the focus on smart mean/entail?

J: Smart means every type of smart technology that can be used in the sector. For the energy sectors this means smart measuring, smart meters. We have some measures that we presented that involved smart metering and data. To visualise plants and final user engagement etc.

J: The situation and the measuring. Basically, the data is available. But you will see there is a huge reliance on coal-based energy. That is the main problem of the energy sector. Almost all energy comes from coal. So, with regard to the ET, everything has to do with the coal dependency. And for example the EBRD wanted to include fourth generation district heating. Which is the main consumer there. However, this is not realistic now, as they are moving away from coal and towards gas at the moment. One of the CHP's is planned to be converted from coal to gas (CHP-2). They already have one, but they do another one now.

J: We also try to stimulate the use of RE. Basically in the build area, with heat pumps of with PV/solar heating system. But also with the position towards large scale solar and wind project, linked to auction. Some auction took place, however this were very few. These are the main strategies.

J: Keep in mind, all energy related to transport, is in the mobility section. This is about taking cars from the street. Not so much about changing to EV at the moment.

J: We did the analysis of current situation, than we present some measures that could be implemented. While presenting we reduce the measures during the sessions. From these sessions we prioritise the measures. We discussed many measures, but they only continue with few.

W: Are political forces and sustainability ambitions conflicting, or not per se?

J: At the end it is al about the financial investments. These decisions are taken by the Akimat and the EBRD. The bank determines the measures for the city. The GCAP does not only include they city, but also companies that are owned by the city council or national. So, also companies owned by the national government are involved some.

J: There are measures for incentivising retrofit of houses, but the houses are not owned by the government. So, they can only stimulate the retrofit, and not make decisions on it.

W: How is the energy sector defined in the GCAP?

J: It is buildings, power plants (generation), and distribution. Mobility is analysed under transport.

J: There is some kind of EBRD handbook. This is a methodology about how to design a GCAP.

W: How is defined what variables/sectors are included in the energy sector?

G: This is provided by the methodology of the EBRD. We have clear state indicators or additional indicators. Within these indicators we try to find the data. If some core indicators for example are not available, we try to find similar indicators. To add value to the description of the situation.

J: Some data is only available on national level, and not on local level. So than you have to extrapolate the data. In this case you can do this because many levels are the same on national or municipal level.

J: The IEA has some data for you on Kazakhstan. That is on national level, and some description on the national level. Also some data by the World Bank.

G: The Municipal Energy Efficiency Transformation plan is quite recent data on Almaty. This is provided by the World Bank. This provides a good baseline.

W: What are the main challenges in producing RES energy and energy reduction?

J: They rely for a big percentage on coal. And the costs for transitioning away from coal are quit high. It is not controlled by Almaty, but by the central government. That is a big barrier. Decommissioning coal fired plants that are owned by the central government is difficult. You need to move to gas, and the by coming technologies. Besides, you need to retrofit existing build area, as the buildings are old and the demand is high. Both on heat and energy.

J: The district heat system is really old, and tremendous investments are required. Not even to get it on fourth level generation, but even to get it on a sufficient level. Basically, there are many challenges.

W: Is gas than a transition fuel towards more sustainable infrastructure?

J: They are two pipelines that are connected to the city. On is still to be finalised. And these two pipelines are made available for the new gas power plant. This is part of the national contract and plans.

J: Gas is already a major step, because the current power plants are very old. They experienced a lack of maintenance and heavily pollute the city.

W: What are the opportunities and challenges for reduction measures?

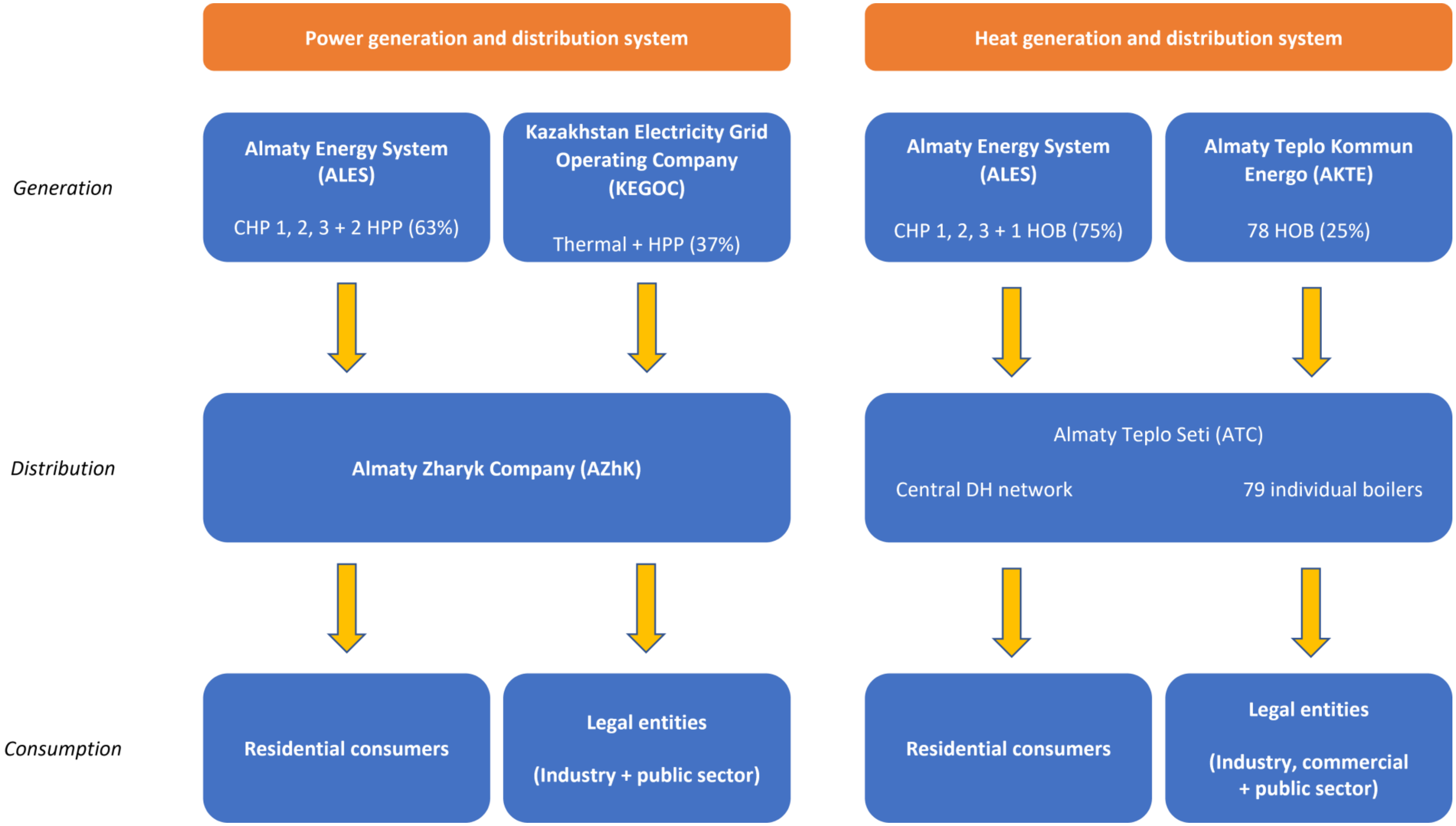
J: This can be found in the RwA report, and the link to the EET of the World Bank is provided.

W: Could an energy transition model be helpful for the government?

J: Tools to understand their position and what measures are useful for (local)governments.

The remained of the conversation was about contact persons, opportunities to keep in touch and updates about the research.

Appendix E: Overview of Almaty's electricity and heat system and related parties



Power generation and distribution system

Heat generation and distribution system

Generation

Almaty Energy System (ALES)

CHP 1, 2, 3 + 2 HPP (63%)

Kazakhstan Electricity Grid Operating Company (KEGOC)

Thermal + HPP (37%)

Almaty Energy System (ALES)

CHP 1, 2, 3 + 1 HOB (75%)

Almaty Teplo Kommun Energo (AKTE)

78 HOB (25%)

Distribution

Almaty Zharyk Company (AZhK)

Almaty Teplo Seti (ATC)

Central DH network

79 individual boilers

Consumption

Residential consumers

Legal entities

(Industry + public sector)

Residential consumers

Legal entities

(Industry, commercial + public sector)