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Article

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The Energy Sector of the Capital of Kazakhstan: Status Quo and Policy towards Smart City

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ABSTRACT

Progression in population growth of the Nur-Sultan city can lead to a load on infrastructure, energy networks, and obsolescence of planning solutions. In this light, the transition to the concept of a "Smart City" can be the best way for green urban development. This article proposes to focus on the energy system of the capital of Kazakhstan. The urgency of this study is due to the fact that currently in the research literature there is an acute lack of knowledge on the current policy of Smart City in the energy sector of Nur-Sultan. Thus, the main goal of this research paper is to identify problems in the energy system by analyzing statistical information describing the current energy system, modern urban solutions, and new approaches to urban planning based on the case study on Smart City in Kazakhstan. The article discusses the main barriers, investment policy, and necessary actions, which will allow the city to acquire the status of "Smart". Based on the policy and measures related to energy, and economically sustainable development of the city of Nur-Sultan the regression analysis on data and SWOT analysis are implemented. The results are summarized in a table that reflects some cost analysis statistics. The results of the present study are useful to academic researchers, smart city practitioners, and policymakers.

Keywords: Demand Projection, Electric and Heat Energy, Kazakhstan, Smart City, Sustainable Development, Urbanization
JEL Classifications: O13, Q41, Q56, N75

1. INTRODUCTION

Over its 23-year history, the current capital of Kazakhstan has become a modern metropolis. The rapid development of Nur-Sultan is primarily due to the high pace of infrastructural construction, including housing buildings. During this period, the territory of the city has increased 3 times, the population has grown more than 4 times by urbanism and high born rates. According to the Department of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan for the city of Nur-Sultan (2020), the average growth rates of housing construction ~15% are especially high for the last 5 years. The city's infrastructure is also developing rapidly. In the context of the fast development of the city, the problem of meeting the demand for electricity is one of the most important issues for a city with a harsh climate like Nur-Sultan. Implementation of the "Smart City" concept, which is nowadays partially described in the state programs as a "Program for the development of the city of Nur-Sultan for 2021-2025" (Nur-Sultan Development Program, 2021) addresses to solve the problem of overpopulation, and particularly the issue of overloading the energy systems ("Nur-Sultan 2050" Strategy, 2019).

This paper gives an overview of issues in the energy system by analyzing statistical information describing the current energy system, modern urban solutions, and new approaches to urban planning. There is provided extensive desktop research for comparative review analysis based on a case study of Smart City for Kazakhstan, the set of data from various sources in literature, including translation from publicly available information/strategic plans in local languages as well as by collecting expert knowledge. Also, based on the information collected, a SWOT analysis was carried out to identify strengths and weaknesses, as well as threats and opportunities. The research considers key barriers, investment policy, and necessary actions toward becoming a Smart City with all necessary elements with the help of regression analysis. The results are summarized in the table with some statistical numbers based on the cost-analyze data. Authors conclude that the development of smart technologies for urban energy systems is one of the ways to reduce energy losses at different levels. A smart thermal grid and smart electricity grid based on renewable energy may be implemented to create a sustainable energy system in the city (Lund et al., 2014). Additionally, there will be used predictive analytics based on digital technology to continuously monitor and reduce losses of utility networks (“Nur-Sultan 2050” Strategy, 2019).

Kazakhstan, as an active participant in various international environmental processes, defined its strategic directions in the environmental state policies regarding environmental protection and sustainable development (Soltangazinov et al., 2020). It is, therefore, necessary to develop environmental legislation to create a low carbon economy in Kazakhstan (Bekturganova et al., 2019).

According to Dyussembekova et al., one of the most significant commitments of the energy sector in Kazakhstan is the concept of a transition to a green economy. The opportunity to demonstrate the successful implementation of Kazakhstan’s green economic growth strategy has been enhanced by having a rich resource base for future energy, in particular, vast potential for generating electricity from renewable energy sources (Dyussembekova et al., 2019).

This directive is being implemented by several proposals in the field of sustainable development, including the implementation of the Smart City concept.

According to Calvillo, a smart city is “a sustainable and efficient urban center that provides a high quality of life to its inhabitants through optimal management of its resources” and energy management plays a vital role in constructing the successful project of a city (Calvillo et al., 2016). Thus, an indispensable component of smart city projects is the energy supply sector, which is being intensively transformed abroad, primarily due to the implementation of large-scale government programs to support the introduction of distributed generation based on wind and solar energy, as well as smart consumer metering systems (Jucevičius et al., 2014).

Currently, in the ranking of “smart” cities in Europe, according to a study conducted by Ahvenniemi et al. (2017), the leaders are Vienna (Austria), Amsterdam (Holland), and Barcelona (Spain).

The smart city project in Vienna includes such areas as renewable energy sources, including those based on waste recycling, a traffic-based street lighting system, public electric transport and charging stations, open access to data, insurance services, etc. (Fernandez-Anez et al., 2018). An example of international cooperation is the Covenant of Mayors, aimed at meeting the sustainable energy development indicators of the European Union. In the United States, projects are known in the cities of Chicago, San Francisco, Boston, Seattle, etc. In Asia, projects can be distinguished in Yokohama (Japan), Dubai and Masdar (OEA), New Songdo (Korea), as well as in India, where the 100 Smart Cities program has been launched, and China, with 200 pilot smart city projects.

All smart city projects (Table 1) are implemented in cooperation with a wide range of participants, including government officials at all levels, businesses, energy companies, power equipment manufacturers, telecommunications companies, scientific organizations and universities, developers, and residents of the city (Maier and Narodoslawsky, 2014).

This emphasizes the interest of different communities in achieving common goals, as well as the need to combine their efforts to solve a set of interrelated tasks, including territorial planning, development of a model of urban management, scientific research, development of new equipment and technologies, training of specialists, etc.

Several long-term mega projects in the European Union and the United States are “Green eMotion,” “ECOGRID,” “Pacific Northwest Smart Grid”, “Houston’s Smart Grid”, etc. They are in the nature of research projects and test sites, where new approaches to organizing energy supply are already being developed.

2. RESEARCH METHODS AND DATA PROCESSING

This study is aimed at identifying and analyzing the most significant challenges in using the energy consumption statistics for predictive analytics for further investigations in applying to the Smart City solutions. This paper outlines their advantages and limitations, existing trends and challenges, and some relevant applications in the subject of research.

The methodology for researching energy model in the smart-city context are literature review, desktop study, global trend analysis, and SWOT-analysis.

The results of the annual heat production and annual heat loss analyses were compared using the following estimation method made by the requirements of guidance documents GD34.09.255-97, GD 34 RK.09.255-2010, and GD 153-34 RK.0-20.523-02. The specific norms of heat loss for pipelines are set based on the requirements of the “Decree of the Republic of Kazakhstan Government dated January 26, 2009, No.50”. Normative heat loss is computed considering:

- Thermal insulation of pipelines of heating networks
- Normative loss of network water in heating networks consisting of normative leakage through the system in the amount of 0.25% of the system capacity by technical operation requirements (excluding open water intake).

The following initial data is used in calculations of normative technical values of heat loss in water and steam heating networks:

Table 1: Comparative analyses of the smart cities

City, Country	Note and Comments	Reference
Vienna (Austria)	Renewable energy sources, including those based on waste recycling, a traffic-based street lighting system, public electric transport and charging stations, open access to data, insurance services	(Fernandez-Anez et al., 2018)
Amsterdam (Holland)	"Amsterdam Smart City program", has a strong focus on people and profit, dominated by archetypes such as business support, automation using artificial intelligence, and the integration of sensors into the smart infrastructure	(Mora and Bolici, 2015)
Barcelona (Spain)	LED-based lighting system, use of smart bins, Low-cost and easy-to-use sensors, sustainable mobility and decreasing emissions, public network	(Eskhita et al., 2021)
Chicago (USA)	The social aspect and environmental protection, automation, flexibility, and sensor archetypes	(Eskhita et al., 2021)
Dubai (UAE)	Flexibility, citizen-centered models, and support for a competitive environment	(Batten, 2018)
Yokohama (Japan)	Social system thatcomprehensively manages the supply and demand of energy in the distributed energy systems optimize the use and application of energy, and incorporate lifestyle support services including monitoring services for the elderly, through the energy management system utilizing IT and storage energy technologies, while making use of distributed energy resources such as renewable energy and cogeneration	(Albino et al., 2015)

- Material characteristics of heating networks for the calculation period
- Normative makeup network water in heating networks and heat consumption systems for the calculation period
- Average monthly temperatures of network water in the supplying and return pipelines of heating networks
- Average monthly outdoor ambient temperature is averaged based on the actual values for the last 5 years, according to the "Center for Hydrometeorological Monitoring of Nur-Sultan city"
- Average monthly primary water temperatures are averaged based on the actual values for the last 5 years
- Average monthly soil temperatures at depths of 0.8 and 1.6 m are averaged based on the actual values for the last 5 years, according to the "Center for Hydrometeorological Monitoring of Nur-Sultan city".

Normative values of average annual heat loss through insulation are calculated by the Eqs:

For subsurface pipelining

$$Q_s^{Y-AVG} = \sum \beta q_s l \quad (1)$$

For above-ground pipelining

$$Q_{a.s}^{Y-AVG} = \sum \beta q_{a.s} l \quad (2)$$

$$Q_{a.r}^{Y-AVG} = \sum \beta q_{a.r} l \quad (3)$$

where, Q_s^{Y-AVG} - yearly average normative heat loss for subsurface pipelining area, kcal/hour;

$Q_{a.s}^{Y-AVG}$ - yearly average normative heat loss for supplying pipelines of above-ground pipelining area, kcal/hour;

$Q_{a.r}^{Y-AVG}$ - yearly average normative heat loss for return pipelines of above-ground pipelining area, kcal/hour;

q_s, $q_{a.s}$, $q_{a.r}$ - normative values of specific heat loss for subsurface and above-ground pipelining for each pipe diameter and pipelining type, kcal/hour;

l- length of the section of the heating network, characterized by the same diameter of pipelines and pipelining type, m;

β - coefficient of local heat loss, considering the heat loss of fittings, supports and compensators

Normative heat loss (considering network water leakage):

$$Q_l^{month} = acV\rho \frac{t_s^{av.m} + t_r^{av.m}}{2 - t_{CW}^{av.m}} n 10^{-6} \quad (4)$$

where, a - normative value of leakage from the heating network and local systems, set 0,25% of the network volume; c- specific heat capacity of water, 1 kcal/kg ^{0}C; V -heating network volume;

$t_s^{av.m}$ - average monthly temperature of water used for feeding the heating network;

Q_l^{month} - normative value of heat loss, considering unproductive leakage of network water, Gcal

ρ - density of water, kg/m^3; *n* - Operation hours of the heating network, hour.

Equations (1-4) are used to estimate normative technical values of heat losses for the forecast period in heating and steam networks.

3. ENERGY SYSTEM OF NUR-SULTAN NOWADAYS (STATUS QUO)

Nur-Sultan is located in the center of the Eurasian continent (Figure 1). The climate is extreme continental, winter is lengthy (5.5 months) and severe, summer is moderately hot. The average temperature in January is 16-18°C below zero, in July is 19-21°C. Nur-Sultan is the second coldest capital in the world after Ulaanbaatar, situated in the middle of the country. According to the draft Master Plan, Nur-Sultan is divided into seven planning districts.

The centralized heating system in Nur-Sultan includes Combined heat and power plant (CHPP)-1 and CHPP-2, with a total installed heat capacity of 2844.4 Gcal/h (data as of December 31, 2020) and available capacity of 2580.54 Gcal/h (including fuel oil boilers CHPP-1 ~ 210 Gcal/h); regional boiler houses consisting of 37 objects, with a total installed heating capacity of 54.8 Gcal/h and available capacity of 36.42 Gcal/h [4,6]. In CHPP-1 there are 3 power boilers, 7 water heating boilers, 3 turbine units in operation. At CHPP-2 there are 7 power boilers, 6 water heating boilers, and 5 turbine units. The existing scheme of the urban heating network is a two-piped, circular, and dead-end system, that provides joint heat for heating, ventilation, and hot water supply. The hot water supply system is closed. Water is taken from city's water supply system and is heated in heat exchangers at the required temperature. The water circulating into the heat supply system is used only as a heat carrier.

In Nur-Sultan there are two sources of electricity − CHPP-1 and CHPP-2. They are structural divisions of JSC "Astana – Energia", owned bythe municipal administration (akimat) (Table 2) (Data of JSC "Astana-Teplotransit" on the power system of the city of Nur-Sultan, 2021):

Intensive economic growth and a boom in construction caused a corresponding development of the city's heat supply system. The available heat capacity of the heating sources increased from 940 Gcal/h in 2004 to 2844.4 Gcal/h in 2020.

The existing heating system in Nur-Sultan city works in two directions: centralized and decentralized.

The coverage of consumers in Nur-Sultan with centralized heating is 78%, of which 67% are provided by CHPP-2 and 33% are provided by CHPP-1.

Figure 1: Nur-Sultan on the map of Kazakhstan

The boundaries of the existing centralized heating zone include almost all multi-storey residential and public buildings of the first (excluding sectors 30, 43, 94), the second (excluding sectors 69, 71, 80, 102 and 108), also partially the fifth (sectors 100, 99 and 97) and the third (sectors 84, 85) planning areas. The rest of the city (22%) is provided by decentralized heating sources, such as different types of boiler houses (12%) and heating stoves (10%).

The decentralized heat supply system (DHS) in Nur-Sultan currently provides 22% of the heating capacity of urban consumers in hot water and is an integral part of the city's engineering infrastructure is represented by many different types of heat sources: industrial and municipal boiler houses of the traditional type, autonomous heating systems (AHS) equipped with modern boilers, heating stoves (Table 3). Industrial and municipal boiler houses account for 12% of the heating capacity; individual heat supply accounts for 10% of the heating capacity (Figure 2).

Decentralized heating is realized by more than 200 boiler houses operating in Nur-Sultan city with a total heat capacity of approximately 500 GCal/h, including 48 units of industrial boiler houses and 146 units of communal boiler houses.

Boiler houses using diesel fuel accounts for 70% of total heating capacity and liquefied gas accounts for 17%. Coal-fired boilers account for 14% of total heating capacity. Boiler houses are mainly equipped with boilers of foreign production, such as Buderus Logano, Bosch, Viessmann Vitoplex, Viessmann Vitomax, etc.

The total length of heating networks in Nur-Sultan city (according to data of January 01, 2020) is 816 km (Table 4), including 239.1 km of main heating network, 489.2 km of district heating network, 489.2 km of steam pipeline network (Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan).

The volume of heat losses in heating networks has increased by about 20% since 2014 with the increase in the length of heating networks and the city's heat consumption (Table 4). Due to the high level of equipment wear and tear, the rate of heat losses remained relatively constant, recording only a slight decline from 13.02% to 12.1%. Every year energy transmission organization JSC "Astana Teplotranzit" carries out annual work on the modernization and reconstruction of the city's heat supply facilities by the investment plan, which requires a significant amount of funding.

Table 4 also shows forecasted heat losses in heating networks in Nur-Sultan city. Equations (1–4) explain how to calculate forecasted normative technical heat losses (Table 4). Calculations are done by transmission organizations. Heat losses are an important tariff-forming factor and one of the energy efficiency indicators of heating networks. Values of normative technical

Table 2: Main characteristics of CHPP-1 and CHPP-2

	Capacity, MW		Electricity generation by years, million kWh				
	Installed capacity	Available capacity	2016	2017	2018	2019	2020
CHPP -1	22,0	16,5	75,90	75,90	66,33	67,77	102,85
CHPP-2	480,0	415,4	3113,40	3113,36	3285,59	3331,77	3218,98

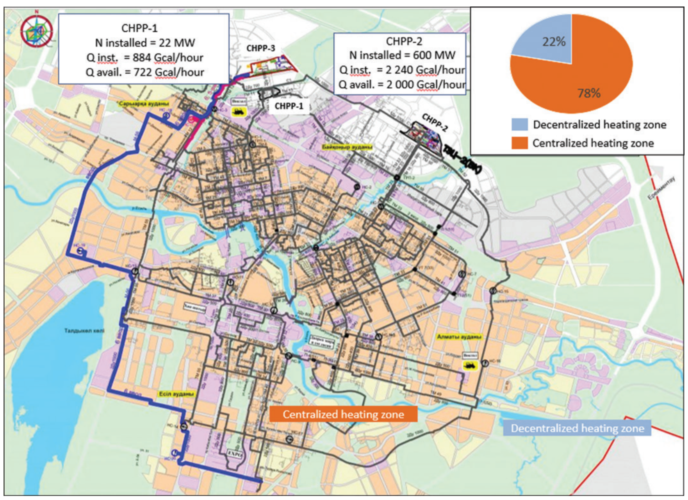
Table 3: Heating capacity of Nur-Sultan city in decentralized heating zones

Name	Provided heating capacity in decentralized heating zones, GCal/h				
	Heating stoves	AHS	Municipal boiler houses	Industrial boiler houses	Overall
Right bank	192	14	70	39	315
Left bank	49	21	174	26	270
Total	241	35	244	65	585

Table 4: Total length of heating networks and amount of heat losses in heating and steam networks in Nur-Sultan city

	Heating season (years)						
	2014	2015	2016	2017	2018	2019	2020
The length of heating networks, km	550	571	583	687	737	816	882.6
Heat energy losses in heating and steam networks, thousand Gcal	758.5	760	805.9	823.7	911.3	889.2	905.5
% (of overall supplied heat energy)	13.02	13.54	13.50	13.08	12.27	12.44	12.1
Heat energy losses in heating and steam networks, thousand Gcal (forecasted)	736.4	748.8	787	838.2	867	892.7	873
Forecasted % (of overall supplied heat energy)	14.6	14.4	13.77	13.76	13.75	12.81	12.53

Figure 2: Heat capacity distribution scheme of Nur-Sultan city



losses can be taken as a basis for planning heat supply and forming tariffs for heat energy. Annual comparison of normative and actual heat losses allows foridentifying energy-saving potential. For example, according to the "Annual report of JSC "Astana Teplotranzit" for 2019" as a result of the implemented activities of the investment program, a reduction in heat losses by 2.6 thousand Gcal was achieved, which made it possible to save up to 4 million tenge per year (with the forecasted percentage of normative technical losses – 12.81%, the actual percentage of losses was 12.44%).

Electricity transmission and distribution from CHPP-1 and CHPP-2 and external sources are carried out by JSC "Astana - Regional Electric Grid Company". "Astanaenergosbyt" LLP provides 54% of the transmitted electricity.

The main activity of Astanaenergosbyt LLP is supplying electric and heat energy (heating, ventilation, and hot water) to consumers in Nur-Sultan city. The main supplier of the company's energy resources is JSC "Astana-Energia" (CHPP-1, CHPP-2). Electricity purchased by LLP "Astanaenergosbyt" has been delivered to consumers through the networks of transporting companies JSC "KEGOC," JSC "Akmolinskaya REC," JSC "Astana-REC." Heat energy is distributed through heating networks of JSC "Astana-Teplotranzit."

Over the past 10 years, between 2011 and 2020, the increase in heat consumption by the population amounted to 84.6%. Heat consumption for municipal needs of enterprises has almost doubled (by 44.4%) and in 2020 amounted to 9.28 million GCal of heat energy, which is almost 10 times higher than it was in 2011. In 2020, the volume of heat energy productive supply showed an increase of 7% of the approved tariff estimate. Such an increase in volumes is associated with several factors: the early start of the heating season, climatic conditions of the city, an increase in heating loads due to newly connected consumers, and steam consumption increase by industrial enterprises. Since 2011, the average daily supply of heat energy per 1000 inhabitants has grown from 8.2 to 9.4 GCal. According to the data of January 01, 2021, the length of heating and steam networks increased by 51 km (6%) compared to the previous year. Thus, the total length of the heating and steam networks amounted to 867 km, 23% of which needs replacement or renovation. Electricity generation in the city of Nur-Sultan in 2020 reached 3322 million kW (Figure 3a), heat energy generation amounted to 7553 thousand Gcal (Figure 3b), increased by 44% and 56.5% respectively between 2011 and 2020 (Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan).

Electricity distribution losses in the electric grids of "Astana-REC" JSC accounted for 9.9% (3433.8 million kWh) and 10.8% (3352.2 million kWh) of total electricity transmission in 2019 and 2020 respectively.

Since 2010 amount of heat losses in heating and steam networks has grown by 41.6% and in 2020 amounted to 9.1 million Gcal (Figure 4). The high level of heat losses is mainly caused by 25–40 years old physically outdated equipment and low level of maintenance. The depreciation level of heating networks in the country accounts for 59%, in Nur-Sultan it accounts for 56%.

Over the past 10 years, the air pollution index (API) has increased from 3.1 (2011) to 7.0 (2020) (Figure 5). Nur-Sultan has been

Figure 3: (a) Electricity generation by years, million kWh; (b) Heat consumption by categories, thousand Gcal

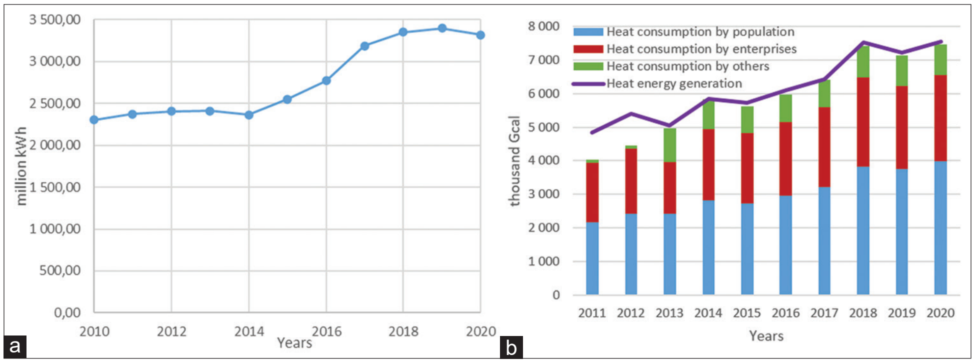


Figure 4: Growth dynamics of heat energy losses in Nur-Sultan, thousand Gcal

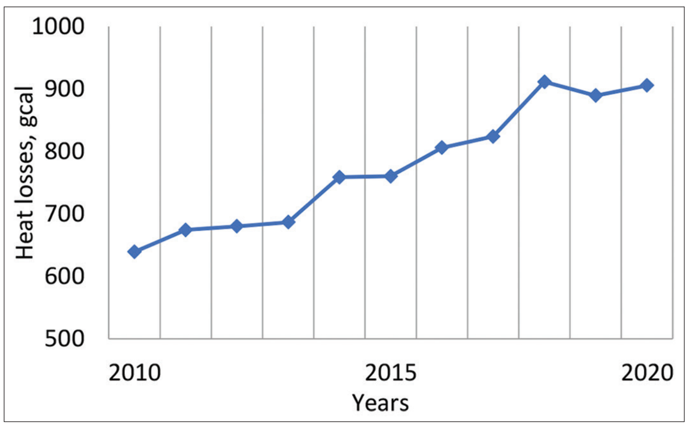
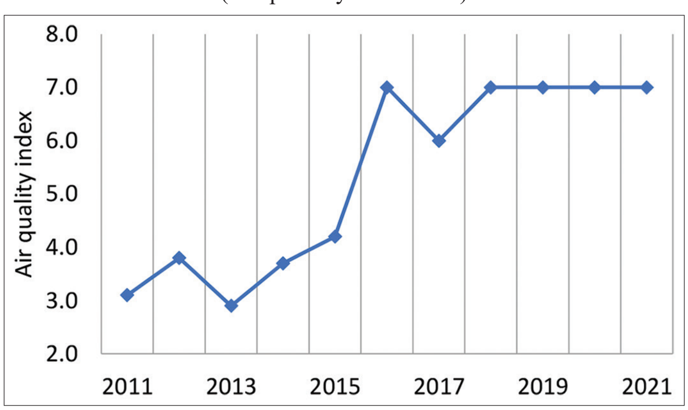


Figure 5: Atmospheric air quality depending on the influence of the energy and motor transport industry, atmospheric pollution index (API) (compiled by the authors)



classified as a city with a "high" level of air pollution (SI [9.0] and MR [29%], API=7). The impact of CHP-1, CHP-2 and boiler houses on air pollution is significant. The largest source of greenhouse gas emissions in the city are the operating CHPP-1 and CHPP-2, which account for more than 60% of emissions, while the share of private sector accounts for 6%. Private and municipal transport produced 18% and 16% of the city's total emissions respectively (Environmental protection and sustainable development of Kazakhstan, 2021).

Consumption of coal at two CHPPs in Nur-Sultan has increased by about 28% over the past 5 years (Figure 6).

Individual houses with autonomous heating are one of the largest sources of air pollution in the city. Coal is the main fuel for stoves in these types of homes. According to the statistical digest "On the housing stock of the city of Nur-Sultan in 2020," 87.7% of individual residential buildings are not connected to central heating.

A project for the gasification of the capital was developed as the solution to this problem. In 2020 the first stage of the "Saryarka" gas pipeline connecting the city of Nur-Sultan with a single gas transmission network was completed under this project. The "Saryarka" gas pipeline, originating from the Kyzylorda region, made it possible to provide the capital, central, and part of the northern regions of the country with an environmentally friendly type of fuel. Thus, it allowed Kazakhstan to reduce air pollution in cities. Thus, as of January 1, 2021, the level of gasification of the country's population reached 53.07%, or 9.5 million people received access to natural gas (Ministry of Energy of the Republic of Kazakhstan, 2021). The number of gasified domestic enterprises has doubled since 2013 - from 23,725 to 51,285 (Annual Report of "KazTransGas" JSC for 2020, 2020).

4. DYNAMICS AND PROJECTION TRENDS

The statistic shows that the population is growing dynamically in the capital. Data of April 1, 2021, shows that the population in the city has grown to 1,195,000 citizens. According to the new forecast by the Department of Architecture and Urban Planning, the population of Nur-Sultan will reach 2 million inhabitants in 2035 (Figure 7). Along with the growth of population, housing construction is intensively increasing. The city is expanding with ongoing significant construction projects. The total area of new buildings commissioned in 2020 amounted to 3421.2 thousand square meters. From 2011 to 2020 the volume of commissioned new buildings in the city nearly doubled (by 91.92%). The total area of commissioned residential buildings has grown by 119.35% since 2011. In 2019, from January to May, the rate of commissioned residential buildings decreased by 33.4% compared to the same period in 2018. Ministry of Industry and Infrastructural Development of the Republic of Kazakhstan attributed the decline to a high level of housing built in the previous year. In 2020, the total area of commissioned housing rose by 72.6% compared to 2019 and amounted to 3,078.9 thousand square meters (Figure 8). Such dynamics of growth are the reason for the increase in heat

Figure 6: Coal consumption and carbon dioxide emissions of main energy sources in Nur-Sultan city CHPP-1 and CHPP-2

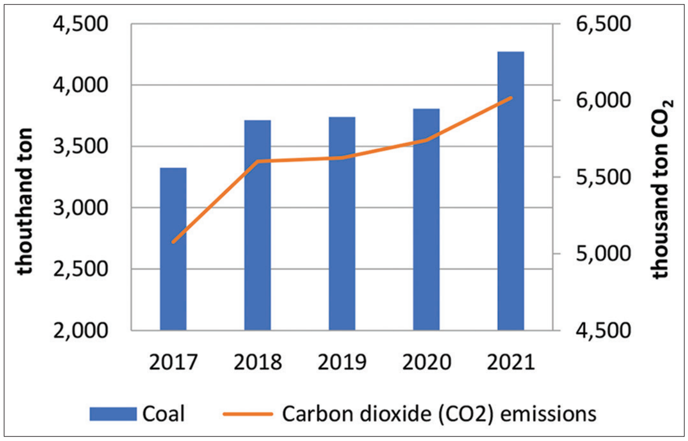
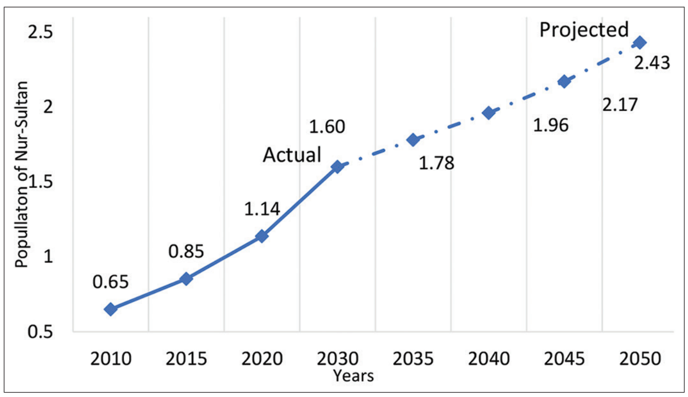


Figure 7: Population of Nur-Sultan



and electricity demand. Therefore, it is important to find innovative solutions to improve energy efficiency and develop sustainable energy systems (Sukarno et al., 2015).

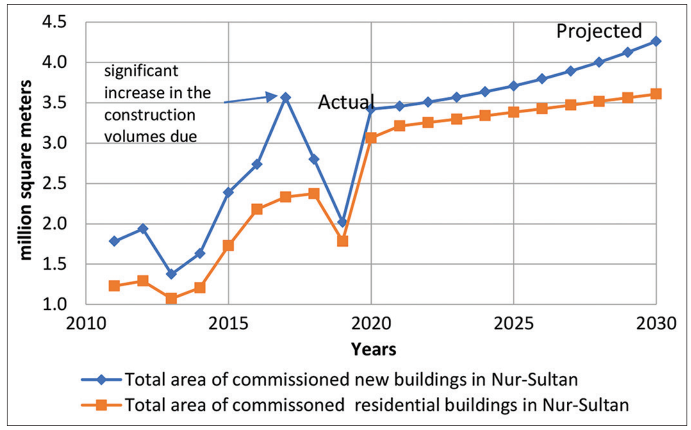
The need for further development of the heat supply system in Nur-Sultan is caused by the need to provide heat to new areas of housing and communal construction.

By 2030, the boundaries of the centralized heat supply zone will expand due to the addition of new consumers of the 1st, 3rd, 2nd, and 7th planning districts to the centralized heating system. The share of centralized heating in the city's heating system will reach 84%. The decentralized heating zone includes all residential and public buildings, including multi-stored buildings, planning areas 3, 4, 5, and 7, located outside the boundaries of district heating. In addition, the existing decentralized heating zone includes communal boiler houses located in the heating zone, which provide heating for public buildings and are subject to decommissioning as district heating sources develop.

The construction of a new CHPP-3 and a decrease in the share of decentralized heating systems will significantly increase the efficiency of the heating system in Nur-Sultan.

According to the forecast balance of heating load in the centralized heating zone of Nur-Sultan city until 2030, if the available heat

Figure 8: Change dynamics in the total area of commissioned new buildings and residential buildings in Nur-Sultan



capacity of DH heat sources remains at the current level, the city will face a heat capacity deficit of 1399 Gcal/h by 2030 (Figure 9).

The implementation of approved projects of JSC "Astana–Energia" on the expansion and construction of new energy sources will decrease the gap between energy supply and energy demand. However, forecasted data shows that these measures are not sufficient to fully cover the heat energy demand. To meet the emerging deficit in the period up to 2025, it will be necessary to commission heating capacity in the amount of 370 Gcal/h, in the period up to 2030 - another 380 Gcal/h. The increase in the calculated heating load of these areas by 2030 will be about 350 Gcal/h (175 Gcal/h by 2025), which will require the construction of a new gas-fired heat source to provide stable heat energy (Figure 10). To solve this problem, long-term projects were developed. Implementation of decisions on the development of the heating system within the framework of the heat supply scheme until 2030 includes the following measures:

- Gradual transfer of two coal-fired combined CHP plants (CHPP-1 and CHPP-2) to natural gas
- Expansion of gas-fired CHPP-3 (construction of 2nd stage)
- Construction of a new CCGT (gas turbine unit) to supply heat to new consumers in the southern part of the city
- Reconstruction and construction of new heating networks as part of the heat supply scheme in the period up to 2030
- Construction of natural gas-fired new autonomous heat supply systems of small capacity.

5. RESULTS AND SWOT-ANALYSIS

According to the general rules of the SWOT analysis, the data was divided into four categories of factors: strengths, weaknesses, opportunities, and threats. Each factor was assigned to the corresponding quarter of the SWOT matrix. For an objective assessment of the "smart city" as a concept for the sustainable development of the Nur-Sultan energy sector, the authors conducted a SWOT analysis (Table 5), which also considered data taken from the previously mentioned sources.

The main factor that unites all the strengths of the Nur-Sultan energy sector is the development of programs and strategies for sustainable development, and openness to innovation, in particular, concepts such as "Smart City."

When studying the current program for the transformation of the energy sector in Nur-Sultan, the main constraining factors of transformation were identified

- Low cost of energy resources, therefore, long payback periods for digitalization projects in terms of housing and communal services
- Insufficient elaboration in the legislation of measures to stimulate digitalization in terms of the formation of tariffs for subjects of natural monopolies (SNM)
- Lack of a unified strategy in the development of digitalization of city supply systems
- Shortage of personnel and competence
- Budget restrictions.

The high level of equipment wears and tear typical for the production and transmission of energy resources in Kazakhstan, for the city of Nur-Sultan, due to the predominantly new infrastructure, is minimal (Figure 11).

Figure 9: Estimation of the expected shortage of heating capacity in a centralized heating zone based on the calculated heating load (considering losses in heating networks), if the available heating capacity of heat sources remains at the current level

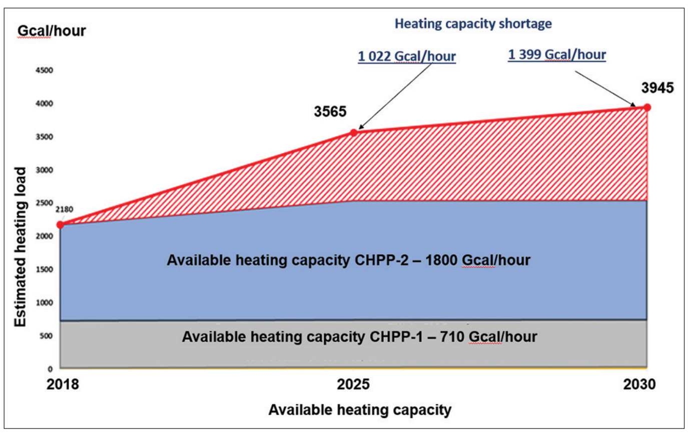
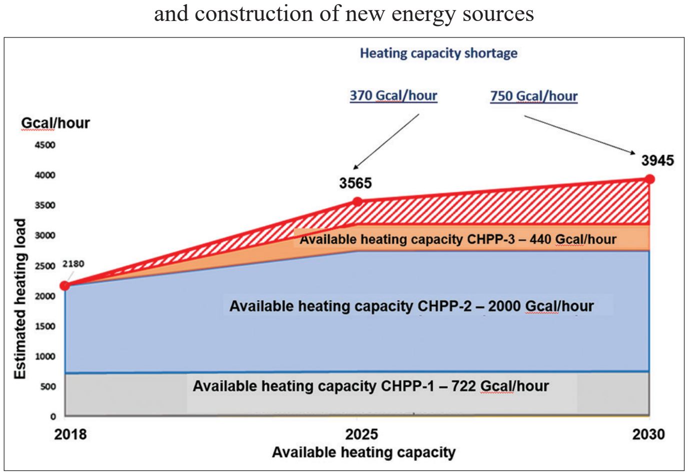


Figure 10: Estimation of the expected shortage of heating capacity in the centralized heating zone between 2023 and 2030 based on calculated maximum hourly heating load (considering losses in heat networks), with the implementation of approved expansion projects and construction of new energy sources



It is important to note the emission problems associated with the operation of coal-fired thermal power plants in Nur-Sultan. However, the existing plans for a longer period allow us to talk about the gradual transfer of CHP from coal to commercial gas.

In general, the problems of implementing projects within the Smart City depend on the level of budget financing and legislative support for digitalization within the framework of SNM tariff formation mechanisms.

In terms of digitalization of solutions not related to energy resources, an important factor stimulating the introduction of technologies is the experience of real application in other cities and a detailed economic analysis that considers both direct savings effects and indirect ones associated with repairs, and maintenance, etc.

6. DISCUSSION

In the Republic of Kazakhstan, the smart city concept was considered in the context of the nationwide state program "Digital Kazakhstan" to improve the efficiency of all city services. Nur-Sultan is one of the five cities where this concept has begun to be implemented. According to this project, the introduction of smart technologies will include the following areas: climate control, energy-saving, street lighting, water network, and billing system.

In addition, the "Program for the development of the city of Nur-Sultan for 2021-2025" analyzes the possibilities for the implementation of digital solutions to improve the quality of life in the city and increase efficiency (Nur-Sultan Development Program, 2021).

In "Nur-Sultan 2050 strategy" the smart city concept is introduced even more precisely. Innovative solutions for the development of housing and communal services and the ecology of the city include the construction of energy-efficient buildings, reducing the debt for utilities, creating a reliable power supply and heating system, and ensuring a complete transition to energy-saving lighting devices. According to the strategy, the city's long-term goal is to increase the share of renewable energy sources in the total electricity production to 20% and the share of engineering networks in unsatisfactory

Figure 11: The level of depreciation of fixed assets of the DGC of Kazakhstan (modified from the source: KAZENERGY National Energy Report, 2021)

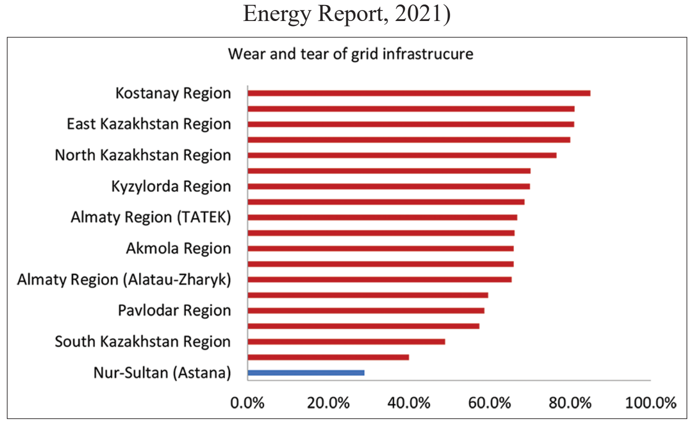


Table 5: SWOT analysis for the energy sector of Nur-Sultan city

Strengths	Weaknesses
1. Ability to reduce operating costs and losses in the transmission and consumption of energy 2. Moderately developed urban infrastructure 3. Support for the development of innovations from the municipality 4. Relatively rapid population growth and construction of urban infrastructure 5. Legislative support for the development of innovations: – State program "Digital Kazakhstan" Decree of the Government of the Republic of Kazakhstan dated December 12, 2017 No. 827 – Entrepreneurial Code of the Republic of Kazakhstan dated October 29, 2015, No. 375-V LRK (Chapter 23-1. State support for innovation)	1. High financial costs for the introduction of innovations due to the lack of technologies and software for domestic production 2. Poorly developed digital infrastructure 3. Lack of open access to data and transparency 4. Lack of qualified specialists (necessary digital skills and competencies) 5. Lack of a unified strategy for the digitalization of urban infrastructure 6. Regulatory barriers, poor planning, and an opportunistic approach to the implementation of urban planning policies) 7. Lack of formalization of digital infrastructure and lack of approaches to cybersecurity
Opportunities	**Threats**
1. Reducing the loss of energy resources and the number of emergencies in the power supply system 2. Creation of conditions for a systematic approach to planning the provision of services, repair work, construction, and development of urban infrastructure 3. Improving the quality of services for the population 4. Increasing the level of accessibility and openness of data 5. Prompt acquisition of data on the operation of urban infrastructure systems 6. Transition of communication power plants with the requirements of the new legislation to the introduction of the best available technologies and automatic emission monitoring systems	1. Reducing the level of state support due to budget constraints 2. Insufficient level of change management and public resistance to digitalization initiatives due to lack of knowledge about the energy system and a high level of environmental ignorance 3. Low investment performance of digitalization projects, long payback periods

conditions below 10%. Also, predictive analytics based on digital technology will be used to continuously monitor utility networks to reduce losses ("Nur-Sultan 2050" Strategy, 2019).

The authorities of the capital have set the goal of transforming into a "smart city" model as a long-term development plan for the city. The introduction of digital technologies to improve the efficiency of the energy system is one of the directions of this strategy.

In the concept of a "smart" city, the energy supply system retains an important infrastructural role in the urban economy and is characterized by a new level of development, for which the term Smart Grid is used. The "smart" energy supply system of the city combines three main systems: electricity, heat, and gas supply. At the same time, the integrated energy supply system can be represented as integral energy nodes, including sources and consumers of various types of energy, and complex energy links that ensure the transmission of various types of energy carriers.

The distributed management of a smart power system is built on a hierarchical basis and includes several levels of energy management systems - EMS: a system for a cluster of urban residential development (Home EMS), business and social activity - large business centers, shopping entertainment buildings and the hotel sector (Building EMS), industrial enterprises and technology parks (Factory EMS), etc. General management of heterogeneous clusters, including electric vehicle (EV) charging infrastructure, is carried out in the territorial control center (Community EMS) with information support from SCADA (Supervisory Control And Data Acquisition) in terms of collecting meter data and consumer participation in demand management. Such a smart city power system management system is being tested, for example, within the framework of the large Yokohama Smart City Project in Japan (Aki, 2017).

7. CONCLUSION

Kazakhstan has set ambitious targets to implement the 2030 Agenda for Sustainable Development. The country aims to reduce total greenhouse gas emissions by 15-25% by 2030 and has a target that 50% of energy will come from renewable and alternative energy sources by 2050.

However, the capital city of Nur-Sultan is still heavily reliant on coal-based heat and power plants to meet the significant heating demand during winter, accounting for around 80% of the total electricity output in Kazakhstan. Continuing urban population growth also poses several challenges related to energy consumption and infrastructure, as well as air quality.

One of the main problems in the energy system of the city of Nur-Sultan is the net deterioration of energy supply systems, which leads to low energy efficiency and high electricity and heat losses at the stages of production and transmission. A significant part of the electricity and heating equipment and networks was built 50-60 years ago. According to the Bureau of National Statistics, approximately 23% of the total length of heating networks needs to be replaced and significant capital investments are required for modernization.

Considering the peculiarities of infrastructure development in Nur-Sultan, the main directions of the city's energy infrastructure digitalization will include:

- Digitalization of the heat supply system and metering of heat energy consumption
- Implementation of control and optimization systems for CHPP
- Analysis of electricity quality indicators and energy consumption of outdoor street lighting

- Implementation of the smart thermal grid and smart electricity grid systems based on renewable energy to create a sustainable energy system in the city (Gorodnova and Sokolov, 2021).

This study revealed several features of the current state of the Nur-Sultan energy system. The energy system is characterized by a high degree of infrastructure deterioration and increasing electricity and heat demand due to rapid growth. Therefore, it became necessary to improve energy efficiency and air quality for citizens by advancing Nur-Sultan's transition to become a smart city. To achieve this goal, it is important to raise awareness about the possible alternatives for effective energy production and air quality management among government, policymakers, entrepreneurs, and citizens. It is also important to strengthen cooperation within the country, as well as internationally, among politicians, scientists and citizens in order to achieve affordable clean energy and sustainable growth of cities and communities.

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