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THE CONCEPT OF THE SMART CITY OF ASTANA: ENERGY-EFFICIENT TECHNOLOGIES AND SOLUTIONS FOR SUSTAINABLE DEVELOPMENT

Abstract: Digitalization of the economy is one of the priority tasks set in the development strategies of Kazakhstan. Currently, there is a rapid change in information and communication technologies (ICT). Emerging changes affect network technologies, computing and communication devices themselves, as well as data processing. As a result, information technologies are being used in an increasing number of spheres of human life and economic life. One of the relevant areas of scientific research is the sphere of the living environment, which is currently developing from the field of Smart Homes into the field of Smart City, Smart Transport system, etc.

Today, cities have become the main force of economic development and have taken a central place in production, consumption networks, the definition of social and economic relations and currently provide a significant share of the gross domestic product of many countries. Cities began to play a major role in national, regional, and global development. The quality of people's lives depends on them. Therefore, today, more than ever, special requirements are imposed on them, such as the availability of affordable urban infrastructure, high mobility, security of urban areas, environmental friendliness, and developed urban self-government. Governments and city government bodies are facing new challenges that should not only solve a whole range of emerging problems, but also carry out a radical transformation of cities. One of the key components of the transformation is intelligent electrical networks.

This article aims to identify and systematize technological, economic and other effects of the introduction of intelligent networks. The article analyzes current trends and approaches to urban planning with an emphasis on energy infrastructure. A comprehensive approach to the development of the power supply system is noted, the main directions of its intellectualization are highlighted. The general requirements for the «smart» power supply system of Astana are defined, a conceptual management model of the «smart» power system is developed, and the effects of its implementation are described.

Keywords: sustainable development, smart city, energy supply, energy system, infrastructure, management, new technologies.

Introduction

At this time, the development of society is perceived as one of the difficult goals in achieving prosperity in countries with developed economies and social institutions. But at the same time, prosperity is assessed by the concept of characteristics that reflect the social area, and not only by the degree of total income [1]. Conditions are being formed and developed for the practical realization of the goal of improving the quality of life at the latest technological stage within the framework of rapid technological development.

Electric power systems are a clear example of the joint influence on socio-technical systems and the relationship of technological and social vectors of development [2]. In the organization of electricity supply (centralized / decentralized), the nature of electricity consumption (industrial / household), the form of implementation of innovative projects (systemic / non-systemic), etc., the dependence of the technical and social systems on each other is displayed.

The development and development of customer-oriented power systems, with an emphasis on the quality of end-user service, is facilitated by the high interest of modern society in human needs and demands. Basically, the goal of improving the quality and standard of living within the framework of active urbanization is determined primarily in megalopolises and large cities.

The society accumulates the experience in planning the integral development of urban infrastructures as well as the skill of managing territorial development within the national and regional levels [3-6]. The changing periods of increasing problems and post-crisis transformations are a representation of the development of the urban environment. At the same time, the successful development of cities, including regional centers, is directly interrelated with the concept of interaction of subjects and the use of a distributed type of management, as modern experience shows.

Problem statement and fuel-energy balance

Kazakhstan has huge reserves of traditional energy resources, namely, coal, gas and oil, uranium, is provided with them for the long term and has significant export potential. Kazakhstan is among the top ten countries in the world in terms of hydrocarbon reserves, ranks second after the Russian Federation among all CIS countries. The share of fossil fuels in the Republic of Kazakhstan is about 4% of the global fuel reserves.

The Republic of Kazakhstan has 190 electric power stations. As of January 1, 2022, the installed capacity of plants in Kazakhstan was 23957.3 MW, and the available capacity was 19004 MW. Power gaps and limitations amounted to more than 4 MW. About 41% of generating capacities have been used for more than 30 years, in terms of the number – this is 40 out of 53 thermal power plants in Kazakhstan. In the total energy balance, the share of thermal power plants is 88%, hydroelectric power plants 12%. Hydropower is the second largest energy resource in the fuel balance of the electric power industry, second only to coal [4,7].

Analysis of the structure of installed capacities of plants in Kazakhstan shows that the UPS of the Republic of Kazakhstan is characterized by:

• the prevailing share of thermal power plants burning coal (75%), gas (23%) and fuel oil (2%) as the main fuel;

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• insufficient share of hydroelectric power plants in the balance of electric capacities of the republic.

By the end of 2021, electricity generation in the Republic of Kazakhstan has increased by 5.7% and amounted to 114.8 billion kWh (data from the Information and Computing Center of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (BNS ASPR RK); according to the Kazakh operator of the Electric Energy and Capacity Market (KOREM) - 114.2 billion). For comparison: in 2020 the production increased by only 2.5%. In last decade higher growth rates were recorded only in 2017, when, after the recession in the crisis of 2015-2016, electricity production increased by 9.6% over the year. Electricity consumption in 2021, according to the estimations based on monthly analytical reports of KOREM, amounted to 113.5 billion kWh (+6.0% YoY) [4,8].

Over the past 5 years, electricity consumption has increased by 16.5%. While the increase in the installed capacity of plants over the same years amounted to only 667 MW. In the future, a steady increase in electricity consumption is predicted with an average dynamics of about 4% per year.

The problems of the electric power industry include: significant development of the park resource of generating equipment, which limits the possibility of electricity production by operating power plants (at thermal power plants of national significance, the residual park resource ranges from 18-30%), high wear and tear of the electric grid (about 65-70%), a shortage of maneuverable capacities to cover peak loads due to a low share of hydroelectric power plants (about 12%) in the structure of generating capacity, uneven distribution of generating capacities (42% of the installed capacity of UPS of Kazakhstan is concentrated in Pavlodar region). Further development of the electric power industry of the Republic of Kazakhstan is impossible without the modernization of existing solid fuel power plants.

Today, energy efficiency indicators in the Republic of Kazakhstan are significantly behind the level of industrialized countries. The specific energy intensity of the gross domestic product (GDP) of the Republic of Kazakhstan exceeds the indicators of the USA by 2.5 times, Denmark by 3.5, Japan by 4. The efficiency of energy use in the republic does not exceed 30%, that is, more than 2/3 of the energy consumed is lost in the process of its use.

In Kazakhstan, the total cost of electricity includes both a fee for generating capacity and the maintenance of networks, which does not depend on the volume of consumption. These and other factors limit the competitiveness of the country's economy and hinder its industrial development (Table 1).

The change in the technological and economic model of the electric power industry in industrialized countries cannot be ignored primarily because the electric power industry can become expensive and uncompetitive. The best option for the industry development is the transformation of the existing model of the electric power industry into producers and consumers network united by a common infrastructure.

As for Astana, the population is constantly growing and economic growth is observed, which requires the expansion of a reliable energy supply system and the provision of public services. Some of the city's infrastructure, such as the central heating network, water pipelines and the stock of residential and public buildings, are outdated, have high energy intensity and energy losses. Despite the implementation of recent initiatives to improve the capacity and efficiency of public transport and programs to re-equip central heating and water supply systems, there remains a huge need to modernize infrastructure and meet future demand for energy and utilities.

Table 1. Problems of the energy industry development in Kazakhstan

Factor	Indicator
Long distances and low load density (network assets per 1 kW)	1.5 – 3.0 times more than in other countries
High cost of capital	2-3 times higher than in Europe
High cost of construction	20-40% higher than in Europe
Low utilization of network and generating capacities	The utilization of the backbone network complex is 26%, the distribution complex is 32%; the installed capacity utilization factor is 50%
Low labor productivity (number of employees per 1 MW of installed capacity)	10 times more employees than in the USA

Currently, municipal enterprises in Astana have high energy losses in the production of electric and thermal energy, as well as in the distribution of energy to end users, mainly in the residential sector. In 2021, primary energy consumption (PEC) in Astana amounted to 22 billion kWh, of which 30% accounted for losses in the conversion energy and distribution system for central heating and electricity supply [3,4,9]. The level of losses is 15% higher than the total energy consumption in the entire residential sector of the city. Due to the increased mobility of city residents, private and commercial transport has reached critical levels in terms of traffic intensity, congestion, and greenhouse gas emissions.

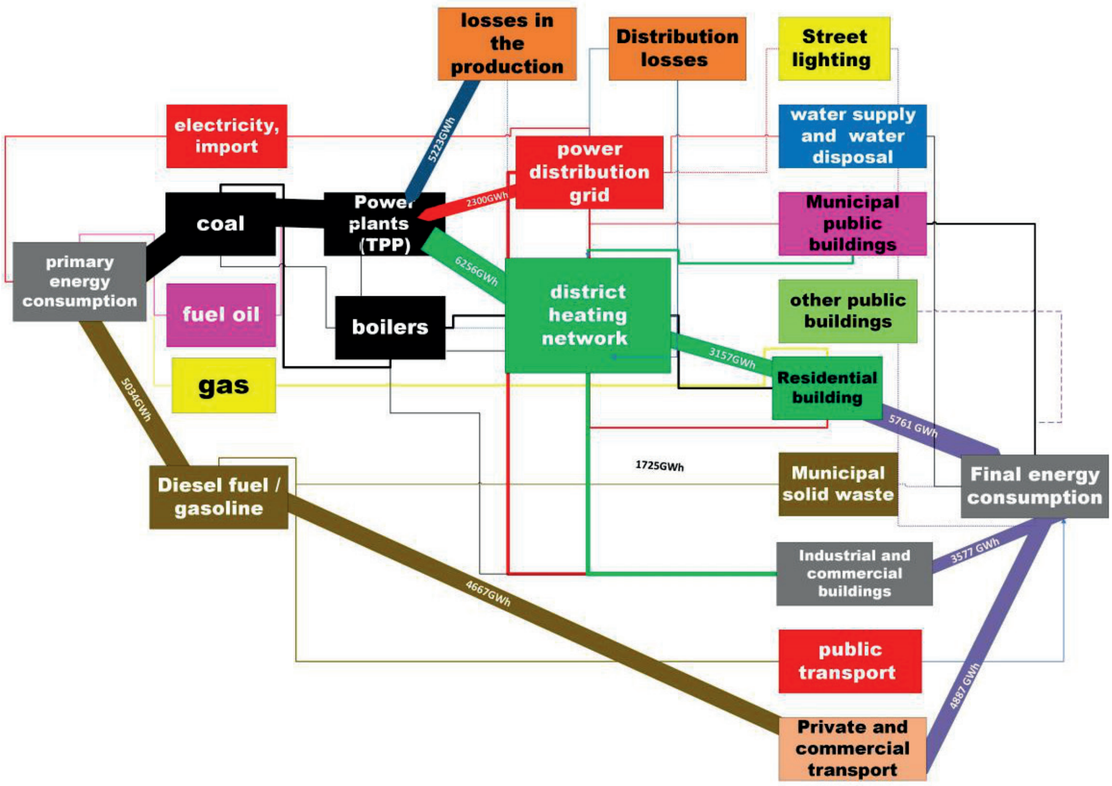

Figure 1. Sankey diagram on energy flows of Astana city in 2021, GWh/year

Based on the Sankey diagram above, it is possible to develop a mathematical model that allowed describing both the final energy consumption and the constituent elements.

The power of the site as a function of time can be represented as the sum of the power of each of the sections of the electrical network [1,10]. Thus,

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$$P = \sum_{k=1}^{n} P_k \,, \tag{1}$$

where P – the total power of the electrical system, P_k – the power of individual sections of the system.

Moreover, the capacity of each section

$$P_k = I_k{}^2 R_k \,, \tag{2}$$

where I_k – the current consumption of the site, R_k – the resistance of the site.

Taking into account that the power of each section relative to the power of the entire network is small, the Eq. (2) can be rewritten as follows:

$$dP = d(IR) \tag{3}$$

Since current I and resistance $I(t)$ are functions of time, then

$$dP = 2I(t)I'(t)R(t)dt + I^2 R'(t)dt \,, \tag{4}$$

where $I(t)$ – a function of the current consumption in time, $R(t)$ – the resistance of the site, changing over time.

Therefore, Eq (1) takes the following form:

$$P = \int_{t}^{t+T} 2I(t)I'(t)R(t)dt + \int_{t}^{t+T} I^2 R'(t)dt \,,$$

where T – the considered time interval during which the system consumed energy; t – the beginning of the countdown.

The formula for reactive energy Q is defined similarly, and therefore,

$$Q = \int_{t}^{t+T} 2I(t)I'(t)X(t)dt + \int_{t}^{t+T} I^2 X'(t)dt \,,$$

where $X(t)$ the reactance varying over time.

Resistance in the power system is a probabilistic-temporal function due to constant switching and other types of transients (2).

$$\begin{cases} R = R_{\partial em}(t) + R_{cmox}(t); \\ X = X_{\partial em}(t) + X_{cmox}(t), \end{cases}$$

where $R_{\partial em}(t)$ – the function of the deterministic component of active resistance from time; $R_{cmox}(t)$ – the function of the stochastic component of active resistance from time; $X_{\partial em}(t)$ – the function of the deterministic component of active resistance from time; $X_{cmox}(t)$ – the function of the stochastic component of active resistance from time.

Substituting these values, we find:

$$P = \int_{t}^{t+T} 2I(t)I'(t)R_{\partial em}(t)dt + \int_{t}^{t+T} 2I(t)I'(t)R_{cmox}(t)dt + \int_{t}^{t+T} I^2 R'_{\partial em}(t)dt + \int_{t}^{t+T} I^2 R'_{cmox}(t)dt$$

For reactive power:

$$Q = \int_{t}^{t+T} 2I(t)I'(t)X_{\partial em}(t)dt + \int_{t}^{t+T} 2I(t)I'(t)X_{cmox}(t)dt + \int_{t}^{t+T} I^2 X'_{\partial em}(t)dt + \int_{t}^{t+T} I^2 X'_{cmox}(t)dt$$

Substituting these expressions into the full power S formula, we get:

$$S=\sqrt{\left[\int_t^{t+T}2I(t)I'(t)R_{\partial em}(t)dt+\int_t^{t+T}2I(t)I'(t)R_{cmox}(t)dt+\int_t^{t+T}I^2R'_{\partial em}(t)dt+\int_t^{t+T}I^2R'_{cmox}(t)dt\right]^2+\left[\int_t^{t+T}2I(t)I'(t)X_{\partial em}(t)dt+\int_t^{t+T}2I(t)I'(t)X_{cmox}(t)dt+\int_t^{t+T}I^2X'_{\partial em}(t)dt+\int_t^{t+T}I^2X'_{cmox}(t)dt\right]^2}$$

It is known that electricity W is calculated by the following formula:

$$W=\int_t^{t+T}Sdt$$

The electricity costs for all sections are calculated as follows:

$$W=\int_t^{t+T}\left(\sqrt{\left[\int_t^{t+T}2I(t)I'(t)R_{\partial em}(t)dt+\int_t^{t+T}2I(t)I'(t)R_{cmox}(t)dt+\int_t^{t+T}I^2R'_{\partial em}(t)dt+\int_t^{t+T}I^2R'_{cmox}(t)dt\right]^2+\left[\int_t^{t+T}2I(t)I'(t)X_{\partial em}(t)dt+\int_t^{t+T}2I(t)I'(t)X_{cmox}(t)dt+\int_t^{t+T}I^2X'_{\partial em}(t)dt+\int_t^{t+T}I^2X'_{cmox}(t)dt\right]^2}\right)dt,$$

Now, calculating the power needed to heat one building. Using the well-known formula from (3), we calculate the heat loss:

$$Q=T\iiint_V\frac{\partial}{\partial x}\left(k\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial u}{\partial z}\right)dv$$

Now, when considering each position, we will deduce the formulas for losses in the city:

1. For residential buildings, municipal public buildings, industrial and commercial buildings, electricity costs are determined by the formula:

$$W_1=\int_t^{t+T}\left(\sqrt{\left[\int_t^{t+T}2I_1(t)I_1'(t)R_{\partial em\,1}(t)dt+\int_t^{t+T}2I_1(t)I_1'(t)R_{cmox\,1}(t)dt+\int_t^{t+T}I_1^2R'_{\partial em\,1}(t)dt+\int_t^{t+T}I_1^2R'_{cmox1}(t)dt\right]^2+\left[\int_t^{t+T}2I_1(t)I_1'(t)X_{\partial em\,1}(t)dt+\int_t^{t+T}2I_1(t)I_1'(t)X_{cmox\,1}(t)dt+\int_t^{t+T}I_1^2X'_{\partial em\,1}(t)dt+\int_t^{t+T}I_1^2X'_{cmox\,1}(t)dt\right]^2}\right)dt$$

In terms of heat supply, formulas are known for calculating heat over small time intervals, the total thermal energy is determined as follows:

$$Q_1=\int_t^{t+T}\left(\iiint_{V_1}\frac{\partial}{\partial x}\left(k\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial u}{\partial z}\right)dv\right)dt$$

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2. The formula is used to calculate street lighting:

$$W_2 = \int_t^{t+T} \left(\sqrt{\left[\int_t^{t+T} 2I_2(t)I_2'(t)R_{\partial em\,2}(t)dt + \int_t^{t+T} 2I_2(t)I_2'(t)R_{cmox\,2}(t)dt + \int_t^{t+T} I_2{}^2 R'_{\partial em\,2}(t)dt + \int_t^{t+T} I_2{}^2 R'_{cmox\,2}(t)dt \right]^2 + \left[\int_t^{t+T} 2I_2(t)I_2'(t)X_{\partial em\,2}(t)dt + \int_t^{t+T} 2I_2(t)I_2'(t)X_{cmox\,2}(t)dt + \int_t^{t+T} I_2{}^2 X'_{\partial em\,2}(t)dt + \int_t^{t+T} I_2{}^2 X'_{cmox\,2}(t)dt) \right]^2} \right) dt$$

3. For water supply and sanitation:

$$W_3 = \int_t^{t+T} \left(\sqrt{\left[\int_t^{t+T} 2I_3(t)I_3'(t)R_{\partial em\,3}(t)dt + \int_t^{t+T} 2I_3(t)I_3'(t)R_{cmox\,3}(t)dt + \int_t^{t+T} I_3{}^2 R'_{\partial em\,3}(t)dt + \int_t^{t+T} I_3{}^2 R'_{cmox\,3}(t)dt \right]^2 + \left[\int_t^{t+T} 2I_3(t)I_3'(t)X_{\partial em\,3}(t)dt + \int_t^{t+T} 2I_3(t)I_3'(t)X_{cmox\,3}(t)dt + \int_t^{t+T} I_3{}^2 X'_{\partial em\,3}(t)dt + \int_t^{t+T} I_3{}^2 X'_{cmox\,3}(t)dt \right]^2} \right) dt$$

4. For industrial and commercial buildings:

$$W_4 = \int_t^{t+T} \left(\sqrt{\left[\int_t^{t+T} 2I_4(t)I_4'(t)R_{\partial em\,4}(t)dt + \int_t^{t+T} 2I_4(t)I_4'(t)R_{cmox\,4}(t)dt + \int_t^{t+T} I_4{}^2 R'_{\partial em\,4}(t)dt + \int_t^{t+T} I_4{}^2 R'_{cmox\,4}(t)dt \right]^2 + \left[\int_t^{t+T} 2I_4(t)I_4'(t)X_{\partial em\,4}(t)dt + \int_t^{t+T} 2I_4(t)I_4'(t)X_{cmox\,4}(t)dt + \int_t^{t+T} I_4{}^2 X'_{\partial em\,4}(t)dt + \int_t^{t+T} I_4{}^2 X'_{cmox\,4}(t)dt \right]^2} \right) dt$$

$$Q_4 = \int_t^{t+T} \left(\iiint_V \frac{\partial}{\partial x}\left(k \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y}\left(k \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z}\left(k \frac{\partial u}{\partial z} \right) dv \right) dt$$

Thus, energy costs in Astana city can be determined by the formula:

$$E = \int_t^{t+T} \Bigg(\sqrt{ \begin{aligned} & \left[\int_t^{t+T} 2I_1(t)I_1'(t)R_{\partial em\,1}(t)dt + \int_t^{t+T} 2I_1(t)I_1'(t)R_{cmox\,1}(t)dt + \int_t^{t+T} I_1^2 R'_{\partial em\,1}(t)dt + \int_t^{t+T} I_1^2 R'_{cmox1}(t)dt \right]^2 + \\ & + \left[\int_t^{t+T} 2I_1(t)I_1'(t)X_{\partial em\,1}(t)dt + \int_t^{t+T} 2I_1(t)I_1'(t)X_{cmox\,1}(t)dt + \int_t^{t+T} I_1^2 X'_{\partial em\,1}(t)dt + \int_t^{t+T} I_1^2 X'_{cmox\,1}(t)dt \right]^2 \end{aligned} } \Bigg) dt +$$

$$+ \int_t^{t+T} \Bigg(\sqrt{ \begin{aligned} & \left[\int_t^{t+T} 2I_2(t)I_2'(t)R_{\partial em\,2}(t)dt + \int_t^{t+T} 2I_2(t)I_2'(t)R_{cmox\,2}(t)dt + \int_t^{t+T} I_2^2 R'_{\partial em\,2}(t)dt + \int_t^{t+T} I_2^2 R'_{cmox2}(t)dt \right]^2 + \\ & + \left[\int_t^{t+T} 2I_2(t)I_2'(t)X_{\partial em\,2}(t)dt + \int_t^{t+T} 2I_2(t)I_2'(t)X_{cmox\,2}(t)dt + \int_t^{t+T} I_2^2 X'_{\partial em\,2}(t)dt + \int_t^{t+T} I_2^2 X'_{cmox\,2}(t)dt \right]^2 \end{aligned} } \Bigg) dt +$$

$$\int_t^{t+T} \Bigg(\sqrt{ \begin{aligned} & \left[\int_t^{t+T} 2I_3(t)I_3'(t)R_{\partial em\,3}(t)dt + \int_t^{t+T} 2I_3(t)I_3'(t)R_{cmox\,3}(t)dt + \int_t^{t+T} I_3^2 R'_{\partial em\,3}(t)dt + \int_t^{t+T} I_3^2 R'_{cmox3}(t)dt \right]^2 + \\ & + \left[\int_t^{t+T} 2I_3(t)I_3'(t)X_{\partial em\,3}(t)dt + \int_t^{t+T} 2I_3(t)I_3'(t)X_{cmox\,3}(t)dt + \int_t^{t+T} I_3^2 X'_{\partial em\,3}(t)dt + \int_t^{t+T} I_3^2 X'_{cmox\,3}(t)dt \right]^2 \end{aligned} } \Bigg) dt +$$

$$\int_t^{t+T} \Bigg(\sqrt{ \begin{aligned} & \left[\int_t^{t+T} 2I_4(t)I_4'(t)R_{\partial em\,4}(t)dt + \int_t^{t+T} 2I_4(t)I_4'(t)R_{cmox\,4}(t)dt + \int_t^{t+T} I_4^2 R'_{\partial em\,4}(t)dt + \int_t^{t+T} I_4^2 R'_{cmox4}(t)dt \right]^2 + \\ & + \left[\int_t^{t+T} 2I_4(t)I_4'(t)X_{\partial em\,4}(t)dt + \int_t^{t+T} 2I_4(t)I_4'(t)X_{cmox\,4}(t)dt + \int_t^{t+T} I_4^2 X'_{\partial em\,4}(t)dt + \int_t^{t+T} I_4^2 X'_{cmox\,4}(t)dt \right]^2 \end{aligned} } \Bigg) dt +$$

$$+ \int_t^{t+T} \left(\iiint_{V_1} \frac{\partial}{\partial x}\left(k\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial u}{\partial z}\right) dv \right) dt + \int_t^{t+T} \left(\iiint_{V_4} \frac{\partial}{\partial x}\left(k\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial u}{\partial z}\right) dv \right) dt$$

The developed mathematical model enables to determine the energy costs of the city in real time, as well as to determine the potential losses that can be reduced with the help of smart city technologies.

In 2021, the annual expenditures of all sectors of Astana on energy resources amounted to about 165 Billion tenge that is approximately equal to 3.4% of the city's GDP. At the same time, the cost of energy resources consumed by all six sectors controlled by the city administration (i.e. public transport, municipal buildings, street lighting, waste disposal, water supply and sewerage) amounted to 7.5 billion tenge, which is equal to 2% of the total municipal budget (Figure 2-3).

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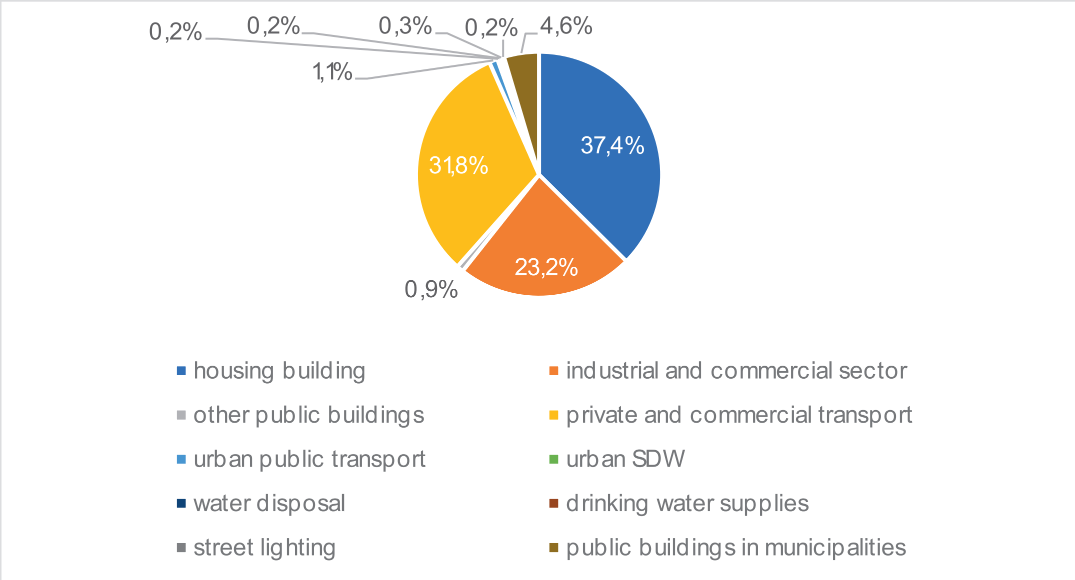

Figure 2. Final Energy Consumption by sector – Citywide

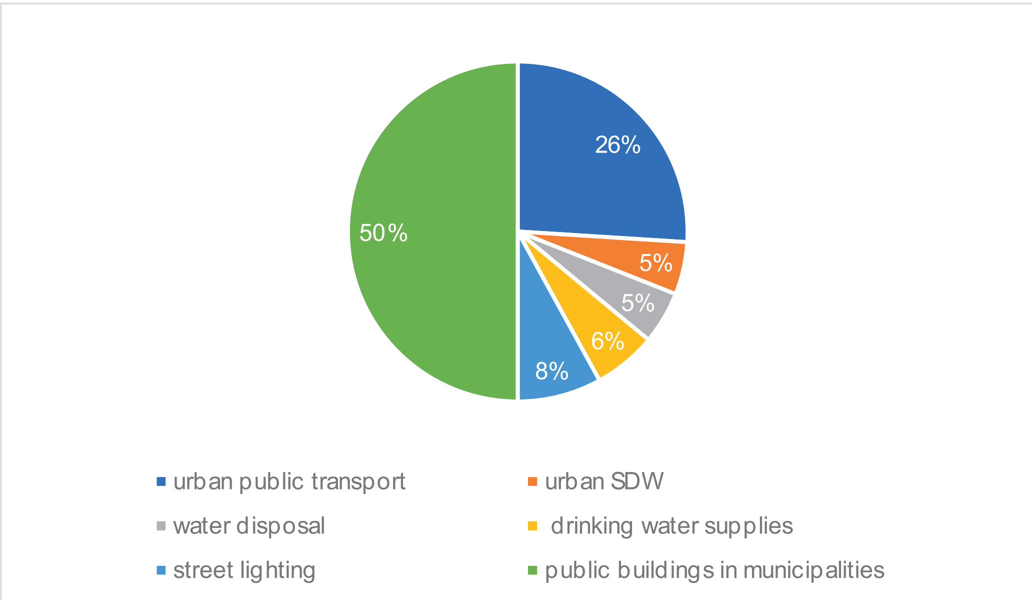

Figure 3. Energy consumption for the municipal sector (total 7.5 billion tng)

All of the above proves the need for developing its own conceptual model of the power supply system.

In order to form an approach to the intellectualization of Astana's electricity supply, a model is initially proposed – consideration of the city in the form of a system of systems (Figure 4) with infrastructure problems specific to various systems that require solutions.

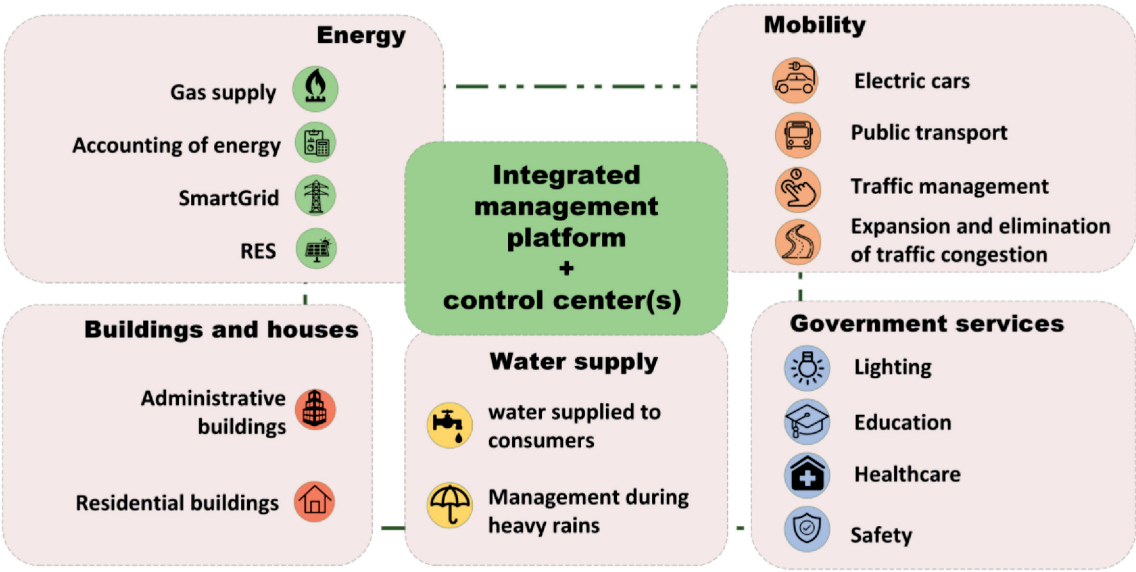

Figure 4. The model «Astana City as a system of systems»

Thus, the task of intellectualization of Astana is reduced to the task of intellectualization of its various systems.

Moreover, in order to achieve better results, wide dissemination of information, business analytics, decision support, incident management, a model of an integrated city management platform has been developed (Figure 5).

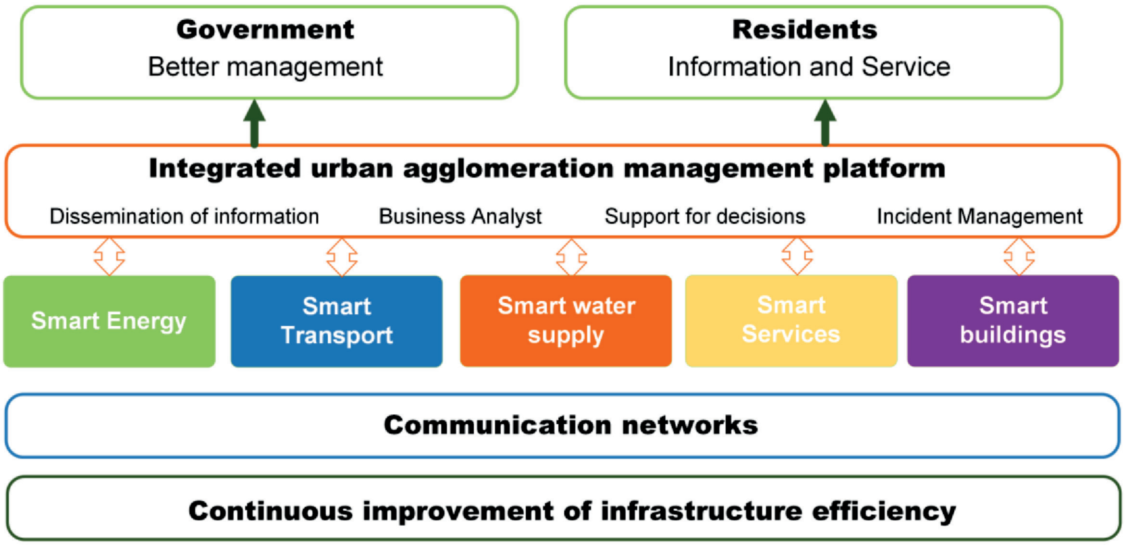

Figure 5. Model of an integrated city management platform

This kind of platform based on a developed communication and communications network allows for continuous improvement of the efficiency (including energy efficiency) of the city's infrastructure with the involvement of the government and residents in this process in real time.

The implementation of this integrated city management platform will help to change the following indicators:

- improvement of air pollution indicators;

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- reduction of energy consumption by urban infrastructure (urban lighting, including signal, energy consumption by municipal buildings, engineering structures);
- reduction of the average time spent by a resident on the way from his place of residence to work;
- increasing the intensity of public transport use, reducing traffic.

The electricity supply industry is considered an integral part of smart city projects. Based on several levels of energy management systems, a conceptual model of a smart city power system management system was developed (Figure 6).

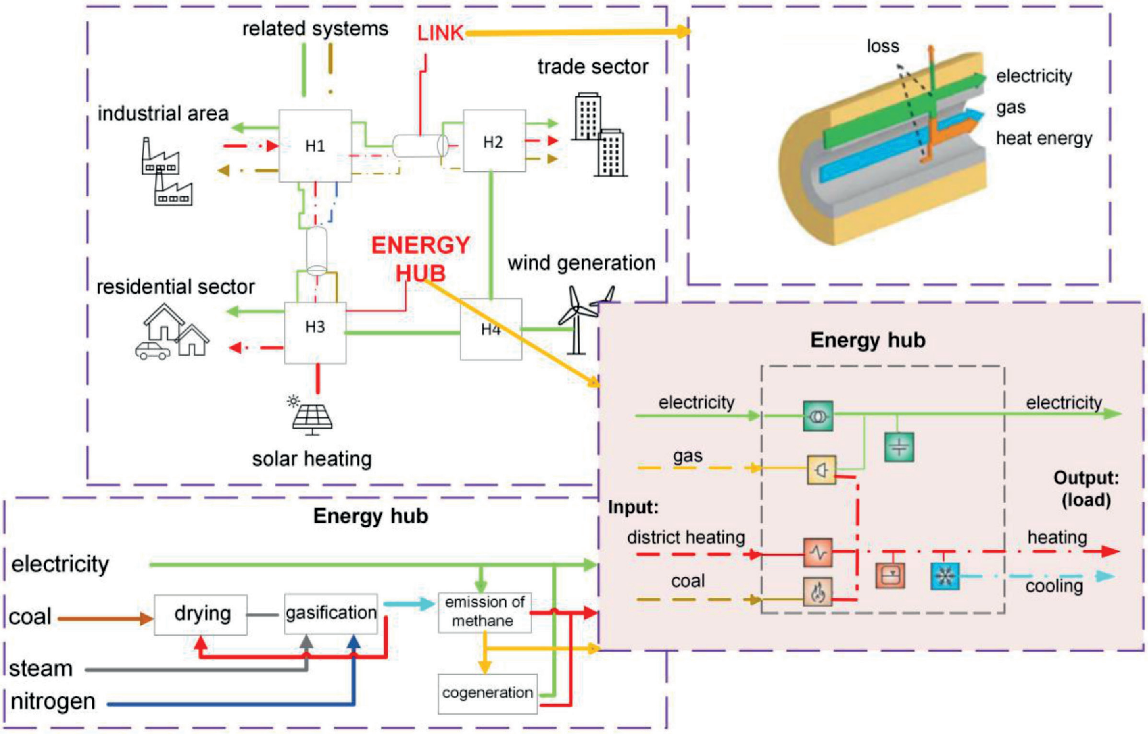

Figure 6. Conceptual model of smart power system management

Discussion

The use of the proposed model will transform the entire chain of creation and use of electricity from generation to the end user.

This model allows to implement all the necessary tasks for the introduction of a «smart» city power system:

- efficient use of equipment resources and maintenance of production assets;
- efficient selection of generating sources, including distributed generation;
- two-way communication with consumers on intelligent metering systems and power consumption management;
- automated design of the power supply system, including power facilities, and information and communication system in interaction with the infrastructure of the city;
- automatic assessment of the risks of violations, identification and elimination of the consequences of violations in the operation of the power system at all levels;
- stable operation under the influence of security threats – physical, informational and resource;
- merging into the energy system of various types of electricity sources, including renewable and low-power sources, as well as energy storage.

As for Astana, these requirements are necessary due to the continuous development: the expansion of the territory, the deployment of an electronic feedback system with residents of the city, the construction of large logistics, exhibition and business centers, the reorganization of public space and the development of transport infrastructure, the organization of high-tech clusters and technology parks that require a high-quality new level of organization of electricity supply, etc.

The city of Astana is characterized by significant specifics in the work of electrical supply: a high part of consumers who do not allow interruptions in electricity supply, a large population density and territorial development, a small part of electricity consumption in industry and a high share of energy consumption in the household and service sectors, a high part of combined heat and electricity production, high electrical load density and stable growth power consumption and high concentration of power at power facilities.

The development of the Astana power supply system meets with the need to settle a certain number of tasks - the transfer of overhead lines in the city to cable performance, reactive power compensation, replacement of high-voltage cable lines, limitation of short-circuit currents, connection of new consumers. In addition, a challenge from the position of a growing type of new high-tech and responsible consumers (data centers, clean rooms, banks, dispatch centers, airports, etc.) to provide this type and quality of electricity and sustainable energy supply.

Conclusion

The use of the developed model (Figure 6) will contribute to the settlement of the tasks of the development of the power supply system both within the high–voltage part and the distribution sector [11-14]:

- automation tools of the electric network and new switching equipment make it possible to implement instant partitioning and reconfiguration of the network, accelerating the restoration of power supply after failures;
- modern information systems for diagnostics and monitoring of equipment condition provide the ability of a flexible approach to determining the permitted load and the need for maintenance;
- new materials for power and electrical equipment, including structural and layout solutions, will help to reduce the useful area occupied by equipment, increase nominal parameters, including resources and the duration of the service interval;
- methods of vector measurements based on phasors provide completely new data on transients in the power system;
- distributed control and parallel computing technologies make it possible to assess the risks of failures in the functioning of the power system and to produce adequate responses in real time;
- powerful voltage converters have the ability to control the flow of active power in a complex closed electrical network and reduce the level of short-circuit currents, including monitoring the voltage in the connection nodes, as well as ensuring the quality of electricity;
- distributed generation sources based on recreated boiler houses make it possible to increase the stability of local power systems with the most efficient use of energy resources;
- digital accounting systems for consumers provide a variety of opportunities for consumption management;
- electric and thermal energy storage devices provide an opportunity to smooth out peak consumption in the power supply system and provide uninterrupted power supply to end consumers.

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Thus, the implementation of the developed model involves solving issues of regulatory support, organizational interaction, financing, etc. Large-scale involvement of energy companies, residents, equipment manufacturers, large consumers under the auspices of the city authorities requires the implementation of a smart city project with a common management system. Moreover, in the field of information support, it is required to develop and implement an extensive range of training and educational programs in the field of energy efficiency and environmental protection, comprehensive management of the smart city project throughout the entire life cycle.

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