Digitalization and Energy Consumption

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Abstract—**The rationale behind this study is premised on the importance of long-term projections of the demand for energy commodities as applied to the national and regional energy and economic security and policy-making that aims at improving the quality of life of the population. There is a wide range of tools and models available to facilitate the studies and projections of the fuel and energy demand. That said, ongoing changes in inner workings and development externalities of the economy and the society in general call for bringing them up to date. Today, we are witnessing dramatic developments and the ever increasing adoption of information and communication technologies that will ultimately pervade all facets of human life. Digital technologies enjoy widespread application in the final energy consumption sectors: they are employed to control industrial processes, improve work performance and safety, and identify the directions to be pursued to enhance energy saving. As of now, we still lack a clear understanding of the impact digitalization will have on the structure of the demand for energy commodities. On the one hand, intelligent control fosters energy saving, on the other hand, digital technologies themselves, as they require the processing of a great bulk of data, consume energy as well. The development of the methods that serve as a backbone of long-term projections of the demand for energy commodities has to properly account for the dynamics of the adoption of digital technologies across all economic sectors on a par with the effect they have on the structure of the demand for energy commodities. We propose one of the many possible approaches to estimate the effect of digitalization on electricity consumption in the tertiary sector. The approach is based on studying the interactions between the growth of electricity consumption and the growth of the number of connected devices. Furthermore, we present our tentative estimates of the additional growth of the demand for electricity in Russia for 2030 - 2035, caused by the accelerated development of the electric car market.**

Keywords—digitalization, energy demand, modeling, long-term forecasting, households, service industry, per capita energy consumption

I. Introduction

Projections of the demand for fuel and energy resources are an essential and fundamental part of the research that underpins the process of developing and making strategic-level decisions as applied to the national and regional energy and economic security and policy-making that aims at improving the quality of life of the population.

The prospective dynamics of the volumes and the composition of the demand for fuel and energy resources is a manifestation of the complex interactions between the economy, the energy industry, and scientific and technological advances.

There is a wide range of tools and models available that have been developed to facilitate the studies and projections of the demand for energy commodities [1-11]. That said, the introduction of new variables and development externalities into the economy and the society in general call for bringing them up to date.

Digitalization is one of those key processes that are undergoing dramatic development and transforming all aspects of the contemporary society. Digitalization in a nutshell is an ever increasing application of information and communication technologies across all sectors of the economy and everyday life of the population as well. It covers the great bulk of digital technologies such the Artificial Intelligence, the Internet of Things (IoT) and the fourth industrial revolution (Industry 4.0), and contributes to intensifying the interactions between digital and physical worlds [12]. The digital world is made up of three basic elements. They are:

- Data: digital information,

- Analytics: making use of the data to acquire new insights and to develop new knowledge and ideas,

- Connectivity: data exchange between people, devices, and machines via digital networks.

The application of information and communication technologies, the adoption of automatized control systems, information systems, alongside entertainment, computational, and other resources have been instrumental in increasing the number of data processing centers that require copious amounts of electricity. According to the estimates published by the EvoSwith company, the year 2015 saw the electricity consumption by data centers reaching 416 TWh, which accounts for some 3% of the total global electricity consumption. The data transmission networks that serve as a backbone of the digital world consumed about 185 TWh in 2015, which amounts to 1% of the total demand [13].

II. DIGITALIZATION AND THE QUALITY OF LIFE

A. Existing Condition

Digital technologies have made their presence felt in all aspects of the contemporary life and redefined the ways we work, commute, learn, consume, manage our households, entertain ourselves, and so on.

As of today, digital technologies enjoy widespread application in the final energy consumption sectors. Industry-wise, they are employed to control processes, improve work performance and safety, and identify the directions to be pursued to enhance energy saving. In the case of transportation, the Global Positioning System (GPS) meticulously defines the location of the driver, transmits live traffic data and contributes to the optimization of transportation operations and the consumption of energy resources. In residential and public buildings, smart meters that record consumption of energy are installed alongside the systems of automatic control of engineering systems and electric devices.

Making use of the state-of-the-art computer and information technologies in the everyday life enables to enhance educational, cultural, and physiological capabilities of the human, to foster personal growth and the development of creative skills, and to improve the educational level and health, as well as the life expectancy.

Making use of computers, TV sets, audio and video equipment, tablets, mobile phones, and the like boosts communication, the access to large amounts of data, broadening of the knowledge and aesthetic experiences. Safety of the population is ensured by monitoring, control and warning systems that inform of technical malfunctions and emergencies. Health maintenance and the increase in life expectancy is enhanced by the application of versatile precision medical equipment for early diagnostics of diseases, monitoring of the patient's condition, and the choice of the adequate treatment.

The appearance and the widespread use of such novel technologies as the Internet of Things (IoT) and the Internet of Services (IoS), smart house and smart city systems are transforming the requirements to be met by service providers and house keepers and are capable of drastically changing prevailing lifestyle patterns. In the future, it is likely for most of the electric appliances and devices as well as individual consumer goods such as apparel items to be connected to the Internet by means of the devices that consume energy to collect, process, store, transmit, and receive data.

B. The Effect of Digitalization on the Demand for Energy Commodities in the Tertiary Sector

Energy consumption by the tertiary sector covers the needs of the population (excluding those pertinent to personal vehicles) and the service industries. Energy consumption in this sector is determined by the energy usage for heating, air conditioning, hot water supply, lighting of various types of buildings as well as for the operation of a wide range of appliances and devices.

In 2015, the tertiary sector accounted for about 20% of the final energy consumption and over 50% of the electricity consumption globally [14].

The experts in this field [12] hold it that digitalization can contribute to cutting down the energy consumption in residential and public buildings by way of the adoption of the so called "smart control". The latter enables the following:

• the consumer can create their own scenarios of energy consumption based on the presence of people indoors, required lighting and temperature levels (by means of light sensors and motion detectors coupled with the algorithms predictive of the consumer behavior) and respond to real-time changes in the cost of electricity by shifting the energy consumption away from the peak of the load profile.

• service companies can measure and monitor in real-time energy performance indicators of buildings, energy supply systems, and equipment and detect as to where and when maintenance and repair work is to be done.

That said, increased convenience and the introduction of new kinds of services implies the installation of a significant number of appliances and devices that are always available in the stand-by mode, which can notably offset the energy saving effect.

The application of digital technologies blurs the borderline between the production and the consumption of energy. The consumer is becoming a full-fledge player of the energy market capable of both controlling their own consumption and producing energy as well [15-18]. In the future, energy systems themselves will be capable of deciding on who, when, when and how much energy to supply to at the lowest possible cost.

C. Approaches to Projections of Electricity Consumption in the Tertiary Sector

Electricity being the most versatile, convenient, and environmentally friendly source of energy is gaining ever wider use by households and in the tertiary sector. Published projections emphasize the increasing role of the demand for electricity in the overall dynamics of energy consumption in the tertiary sector caused by digitalization among other contributing factors (Table I).

TABLE I. THE CHANGE OVER TIME OF THE SHARE OF ELECTRICITY CONSUMPTION IN THE TERTIARY SECTOR, %

Country	1990	2015	2050
Europe (OECD)	24,1	58,7	61,3
USA	41,1	47,7	51,0
Canada	40,6	42,3	51,5
Japan	40,3	56,8	60,9
Russia	10,2	20,0	26,8

a. Source: [14, 19] and authors' calculations

The two basic approaches available for the study and projections of energy consumption in the tertiary

sector are the top-down and the bottom-up ones. The former does away with detailed information as it is based on the basic laws of economics. Projections of the energy consumption dynamics are developed based on the dependencies that exist between the fuel and energy demand in a given sector and key macroeconomic performance indicators such as the GDP, population, stock of residential and public buildings, availability of appliances and services, etc. [20-23]. Unlike with the above, the bottom-up approach boils down to making use of the large amount of data on each consumer and/or individual process that consumes energy. In this case, the dynamics of the national or regional fuel and energy demand is defined as a total of the resources used by all processes and consumers [24-27]. Recently, we've seen the development of hybrid approaches that make use of various methods, as well as the models that are based on neural networks [5]. It should be pointed out that the energy consumption models that cater to individual sectors of the economy prove an essential component of model and computer systems for long-term projections of the energy sector development. Each of the models is essentially a description of a varying level of detail specific to final consumption processes in various buildings broken down by types and the date of erection with likely prospective technological and price changes as applied to given regions and countries. The list of the best known model and computer systems of this kind developed abroad includes NEMS [28], MAED/MEDEE [29], LEAP [30], and PRIMES [99], with SCANER as an equally comprehensive system developed in Russia [11].

The all-pervading turbulent developments of digitalization trigger the development of existing approaches that would factor this new variable in when projecting the dynamics of the demand for electricity.

The amount of electricity in the tertiary sector as available per capita is an important indicator telling of the level of the economic development and the quality of life of the population (Table II).

TABLE II. DYNAMICS OF THE PER CAPITA ELECTRICITY CONSUMPTION IN THE TERTIARY SECTOR FOR SELECTED COUNTRIES, THOUS. KWH / CAP

Country	1990	2000	2013
Europe (OECD)	2,19	2,73	3,20
USA	8,33	8,25	8,82
Canada	8,60	8,60	8,38
Japan	3,19	4,42	5,06
Russia	1,18	1,40	1,90*

b. *2015 Source: [31, Rosstat] and authors' calculations

At the Energy Systems Institute, SB RAS, there is a dedicated model developed for projections of the per capita energy consumption in the tertiary sector. The model is based on the so-called "calculational method" [32] extended by due consideration of the features specific to a given region, the quality of life therein

and corresponding lifestyle patterns. The input data for the model are collected based on assumed scenarios of the social and economic development of the country, an analysis of both existing and those likely to realize prospective social, economic and technological factors and their interactions that define the quality of life and life patterns of the population as well as the development of service industries in the region.

The total per capita electricity consumption (kWh per capita) in a region in year T is defined as (1):

$$E^{(T)} = E^{(T)}_{resid.\ urban} + E^{(T)}_{pub.\ urban} +$$
$$+ E^{(T)}_{resid.\ urban} + E^{(T)}_{pub.\ rural} \qquad (1)$$

where $E^{(T)}_{resid.\ urban}$, $E^{(T)}_{resid.\ rural}$ − per capita electricity consumption in the residential sector in urban and rural environments; $E^{(T)}_{pub.\ urban}$, $E^{(T)}_{pub.\ rural}$ − per capita electricity consumption in the public sector in urban and rural environments.

The prospective per capita consumption of electricity in the public sector in urban and rural environments is defined based on the prospective availability of public buildings for population, existing specific energy consumption per $1m^2$, and the trends in its changes that correspond to the scenarios under consideration, and is defined as (2):

$$E^{(T)}_{pub.} = F^{(T)}_{pub.}\, e^{(T)}_{pub.} \qquad (2)$$

where $F^{(T)}_{pub.}$ − availability of public buildings to the population, m^2 per capita; $e^{(T)}_{pub.}$ − specific electricity consumption per 1 m^2 of public buildings.

Prospective per capita electricity consumption in the residential sector in urban and rural environments is defined as (3):

$$E^{(T)}_{resid.} = E^{(T)}_{light.} + E^{(T)}_{appl.} + E^{(T)}_{cook.} \qquad (3)$$

where $E^{(T)}_{light.}$ − energy consumption for lighting purposes; $E^{(T)}_{appl.}$ − energy consumption by appliances; $E^{(T)}_{cook.}$ − energy consumption for cooking purposes.

The annual consumption of electricity for lighting of residential buildings per capita for urban and rural environments is defined as (4):

$$E^{(T)}_{light} = F^{(T)} \sum_i W^{(T)}_{i\ inst.light.}\, k\, h_{max} \qquad (4)$$

where $F^{(T)}$ − minimum required availability of residential buildings, m^2 per capita, $W^{(T)}_{i\ inst.\ light.}$ − installed capacity of lighting fixtures per 1 m^2 of the total area, k − the coefficient of simultaneous operation of lighting fixtures, h_{max} − number of use hours for lighting by lighting fixtures at their maximum capacity (as depends on the climatic zone).

To calculate the demand for electricity for lighting purposes one has to estimate the prospective structure of the family, the availability of living space and public space to the population, the potential of the

development of services industries, the type and the composition of employed lighting fixtures, their specifications, and the geographical location of a given region.

Per capita electricity consumption by appliances and power processes in the residential sector in urban and rural environments is defined as (5):

$$E_{appl.}^{(T)} = \sum_i t_i \, W_i^{(T)} d_i^{(T)} \qquad (5)$$

where i – the type of an appliance; t_i – number of use hours of the installed capacity of appliance i; $W^{(T)}{}_i$ – installed capacity of appliance i; $d^{(T)}{}_i$ – the availability of an appliance of type i (appliances per capita).

To calculate the per capita electricity consumption by appliances, one has to estimate the prospective availability of appliances and public utilities to the population, the breakdown of appliances by their power and number of use hours. The availability of appliances, in its turn, depends on the family composition, its social and educational level, the availability of leisure time, the level of income, as well as on living in either urban or rural environments (due to the differences in both the availability and the range of appliances).

The demand for electricity for cooking purposes in kWh per capita per year is defined as (6):

$$E^{(T)}{}_{cook.} = 1,34 \,/3600 \; n^{(T)}{}_{el.stove} \; 10^6 \qquad (6)$$

where $n^{(T)}{}_{el.stove}$ – the coverage of population with electric stoves, %; 3600 – the conversion coefficient of 1 kWh per joule. An expert judgement suggests the consumption of heating energy for cooking purposes makes up about 1,34 GJ per capita per year.

In order to account for the effect of digitalization on the dynamics of the per capita electricity consumption in the tertiary sector, we have been developing a dedicated additional module of the model. This module breaks down (that is, provides a higher level of detail) the existing availability of lighting fixtures and appliances to the population in the baseline year by individual types, technologies, and the service life. We assume 1) a certain prospective dynamics of the substitution of existing appliances and technologies for new ones with the respective amount of energy saving; 2) the share of appliances connected to the Internet of Things and their electricity consumption when in stand-by mode. Based on the dynamics of the growth to be observed in the number of lighting fixtures and appliances connected to the control system, we arrive at the additional demand for electricity for the purposes of data processing. The latter is based on an analysis of the relationships between the growth of the electricity consumption and the growth of the number of connected devices.

A reasonably high level of economic development is a prerequisite of taking advantage of additional benefits made available by the adoption of digital technologies. Tentative estimation of the effect of digitalization on the electricity consumption in the tertiary sector can be accomplished based on the interaction of the per capita energy consumption and the per capita GDP (Fig. 1). The Fig. 1 presented here was plotted based on the projection to 2050 published by the U.S. Energy Information Administration. [14]. The authors developed an additional projection for Russia (line 2) based on the probable scenario of the Russian economy as developed by the Ministry of Economic Development of the Russian Federation back in 2013 [33] and updated based on the current values of performance indicators. As the Fig. 1 shown, the electricity consumption increases driven by the economic growth, yet the prospects of further electrification of Russia are highly uncertain.
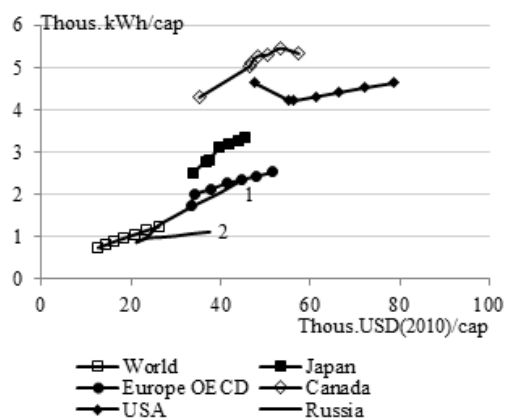
III. Digitalization on the Transport

A. Existing Condition

Back in 2015, all types of transportation altogether consumed 26% of the final energy and 2% of electricity [14]. Today, transportation has been getting increasingly "smart" while digital technologies enable higher efficiency of the use of energy. So, for example, in the field of aviation the ability to process large amounts of data enables the optimization of the flight direction and the flying distance, assists pilots in their decision making and lowers fuel consumption. Better communication between ships and ports optimises ship speed to meet requirements for port arrival timing, yielding significant fuel savings. Motor vehicles use the GPS system that allows to precisely detect the location of a vehicle, to display the current traffic information, and to optimize the driving direction and the fuel consumption. The introduction of electric cars is changing the overall direction of the development of motor vehicles. The International Energy Agency (IEA) experts predict the growth of the number of electric cars globally that will amount to almost 127 million units by year 2030. According to the data published by the "Autostat" analytic agency in 2017, the sales of electric cars in Russia increased by 28%; however, this amounts to a mere 95 units. [34]. Even though our country is lagging behind the more developed countries in terms of the electric car development, the government strategy of the vehicle manufacturing industry provides for the electric-driven transportation development as well. In this sense it is essential to have a clear vision of how the development of electric cars may influence the overall level of the future demand for electricity in Russia.

B. An Approach to Projections of Electricity Consumption in the Transport Sector

This approach is theoretically grounded in the combined use of a macroeconomic input-output optimization model of the economic development and a simulation model of the transportation energy consumption.

Fig. 1. The interdependence between the per capita consumption in the tertiary sector and the economic development for years 2015-2050

The macroeconomic input-output optimization model of the economy breaks down the macroeconomic information of the economic scenario adopted for consideration to indicators of the development of 25 branches of the economy. The basic equations of the model represent the balances of manufacturing and consumption of products of the branches in monetary terms, and is defined as (7):

$$X_i(t) = \sum_j a_{ij}(t)X_j(t) + U_i(t) + Y_i(t) + EK_i(t) - IM_i(t) + \Delta \overline{Z}_i(t) \qquad (7)$$

where $X_i(t)$ – gross output in each industry i in a year t; $a_{ij}(t)$ – coefficients of consuming of product i for the manufacture of product j; $U_i(t)$ – the costs of the products of the fund-making industries for the commissioning of new production capacities; $EK_i(t)$, $IM_i(t)$ – export and import of i-th product; $\Delta \overline{Z}_i(t)$ - change in stocks or additional demand in the i-th industry.

The criterion (8) is the maximum final consumption of goods and services for the period under consideration, taking into account the conditions and restrictions set.

$$\sum_i \sum_j Y_i(t)k_i(t) \rightarrow max \qquad (8)$$

where $Y_i(t)$ – final consumption of product i for non-production needs in the year t; $k_i(t)$ – discounting factor.

Energy consumption of the transportation sector is calculated in the simulation model based on indicators of transport development obtained in macroeconomic model and specific energy consumption. The latter is determined outside the model separately for existing and new transport modes, taking into account the dependence on the growth rate of scientific and technological advances.

The input data for our calculations were arrived at based on the probable scenario of the social and economic development of Russia [33] and our analysis of existing and projected trends in the transportation sector in developed countries abroad yet by accounting for the ways they are to manifest themselves that are specific to Russia. As is shown in Table III, the prospective replacement of 17% to 20% of the total car fleet by electric cars will lead to the increase in the demand for electricity in Russia by 2% to 3% of the total final electricity consumption projected to years 2030-2035.

TABLE III.   ESTIMATES OF THE ADDITIONAL DEMAND FOR ELECTRICITY GIVEN THE LARGE-SCALE ADOPTION OF ELECTRIC CARS IN THE RUSSIAN FEDERATION IN THE LONG RUN

Indicator	2025	2030	2035
Electricity demand project, billion kWh	1220	1285	1340
The total fleet, mln. units	56.0	59.0	65.0
The share of electric cars, %	3.0	17.0	20.0
Increase in electricity consumption, billion kWh	4.0	27.0	36.0
Reduction in CO_2 emissions, mln. tons per year	1.8	12.3	16.4

IV. CONCLUSION

The acceleration of the digitalization of the economy and the society in general exerts a substantial impact on all facets of the human life.

The application of digital technologies enables to improve the work performance and safety, the efficiency of control over technological processes and contributes to the identification of ways to enhance energy saving.

The widespread adoption of automatic control of engineering systems and appliances in residential and public buildings facilitates the increase in comfort and convenience of provision of services and can bring significant social gains.

As of today, there is a great uncertainty as to the assessment of the impact of digitalization on energy consumption. On the one hand, intelligent control fosters energy saving, on the other hand, digital technologies themselves, as they require the processing of a great bulk of data, consume energy as well.

The development of approaches to long-term projections of the demand for energy has to properly account for the dynamics of the dissemination of digital technologies across all sectors of the economy.

In Russia, the prospective dynamics of the demand for electricity will depend on the growth rates of the economy, advances in the quality of life and the speed of adoption of digital technologies.

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