Evaluation of potentials for renewable energy in the power system in Kazakhstan using a GIS-based approach

Master Thesis

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PLEDGE OF HONOUR

I hereby declare that my master thesis is the result of my personal research. I affirm that any idea, data, analysis, formula borrowed from a third party is accurately cited. I am aware that not referencing source material in the work is considered as plagiarism. My master thesis has never been submitted to any other institution before.

________________________________ Dana Kaziyeva

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CSP	Concentrated solar power
CSS	Cascading Style Sheets
DEM	Digital Elevation Model
GADM	Database of Global Administrative Areas
DLR	German Aerospace Center
GDP	Gross Domestic Product
HTML5	Hyper Text Markup Language
IEA	International Energy Agency
IET	Institute for Energy and Transport
IRENA	International Renewable Energy Agency
KEGOC	Kazakstan Electricity Grid Operating Company
NREL	National Renewable Energy Laboratory
NPP	Net Primary Production
PV	Photovoltaic solar panel
PVGIS	Photovoltaic Geographical Information Systems
REEEP	Renewable Energy and Energy Efficiency partnership
R/P	reserves to production
SWERA	Solar and Wind Energy Resource Assessment
SLD	Styled Layer Descriptor
WMS	Web Map Service

ABSTRACT

The main source of electricity and heat production in Kazakhstan comes from the refining of coal, crude oil, and natural gas. These traditional energy resources are known for being contaminative and exhaustible. Thus, a policy of Kazakhstan is taking slowly a direction to the development of renewable energy system in the state. The aim of this work is to evaluate renewable energy potentials for Kazakhstan in an existing energy system. This research is focused on the following objectives: 1) identify physically available renewable energy; 2) determine a technical energy potential; 3) integrate the estimated potential energy with existing energy system 4) develop an interactive map of renewable energy potentials in Kazakhstan. Three types of renewable energy are being considered for the evaluation of their potentials. They are solar, wind and biomass energy resources. An analysis is done in GIS environment. A calculation is based on land cover assumptions and technical constraints. A benefit of the research is a general overview for selecting appropriate locations for renewable energy installations, bound by economic constraints. The other outcome is a decrease in greenhouse gas emissions. Resulted values of renewable energy potentials are vastly spread all over the country with solar energy potential being the highest. Available lands for solar and wind energy production constitutes 0.6% and 3.49% of the total area of the country. Around 93.1% of the area is the potential resource of bioenergy.

INTRODUCTION

Around 80% of the energy used worldwide comes from fossil fuels, despite those facts, like the vulnerability of infrastructures to the weather conditions and human factors, pollution of the atmosphere with greenhouse gas emissions. As an example, hurricanes and typhoons put fossil and nuclear energy constructions under great risk. Moreover, completions of exhaustible energy resources can trigger economic and political conflicts between countries. These mentioned drawbacks of the use of conventional energy resources let many institutions and organizations to plan the transformations of energy production systems to more sustainable and environment-friendly systems (World energy council, 2013).

Kazakhstan's policy also aims to increase renewable energy generation in the country. If now only 1% of electricity is the product of renewables, by the year of 2050 a share of electricity production by renewable resources is expected to be 50% (Concept for transition of the Republic of Kazakhstan to Green economy, 2013). This is one of the objectives on a path to "green" economy. In 1992 Kazakhstan had agreed to reduce carbon emissions by 15% by 2020 and 25% until 2050 (World Bank Group, 2014). This obligation is under Kyoto Protocol. Since then there have been many legislative acts and laws adopted to encourage the development of renewables. Nowadays the process is not progressing fast, due to the deficiency of technical competence and capacities. There are also financial barriers, which the government cannot fully support to overcome. The price of electricity generated from fossil fuels is cheap and new technologies for renewables are expensive. The country does not produce any wind turbines. The recently started production of solar photovoltaic panels in Astana is a big step in solar energy promotion (Astana Solar, 2016). There are also complications with foreign investments, no instruments and clear action plans for the rapid adaptation of the transition to renewable energy.

A motivation for the government and organizations to develop renewable energy sector should first be based on predictions about possible amount of energy that technologies can provide for a given geographical location. The latter describes energy potential, which is commonly measured in watt-hours per year. The method used in the presented work to estimate energy potentials is a top-down approach. There are few steps in the evaluation (Biberacher, et al., 2008). Since it is not possible to exploit all the energy which is coming from renewable sources, the top-down approach is used to delineate first suitable areas with available energy potential (theoretical), which is physically accessible. It can be solar radiation, wind speed or biomass volume. Secondly, a technical potential has to be calculated based on land cover and technical restrictions, like conversion efficiency of installations. Thirdly, costs of installations, conversion technologies, energy storage and transportation and other financial constraints are taking into account when estimating a final economic potential. For the purposes of fast and precise calculations, the Geographic Information Systems (GIS) technologies are very usefully applied during spatial analysis.

The main purpose of this research is to evaluate the technical potential of solar, wind and biomass energy in Kazakhstan within its energy system using GIS approach. The objectives are to study an existing energy system in Kazakhstan, review different cases and methods to evaluate potential energy, make the analysis on delineating available and suitable areas for renewable energy production, compare the potential renewable energy with the traditional energy system and develop a web-based interactive map showing the results of the analysis.

1.1. EXISTING ENERGY SYSTEM IN KAZAKHSTAN

Kazakhstan is a transcontinental country between Europe and China, rich in fossil fuel resources, uranium, and minerals (iron, copper, zinc, etc.). Its total area is approximately 2.9 million km^2 and population equals to 17.5 million people (Karatayev and Clarke, 2014). It was part of Soviet Union for 70 years until 1991, the collapse of USSR (the Union of Soviet Socialist Republic). After this moment economy of the country was unstable with a decline in Gross Domestic Product (GDP). Nonetheless, starting from 1999, Kazakhstan's GDP growth strongly increased (Figure 1) (The World Bank, 2016).

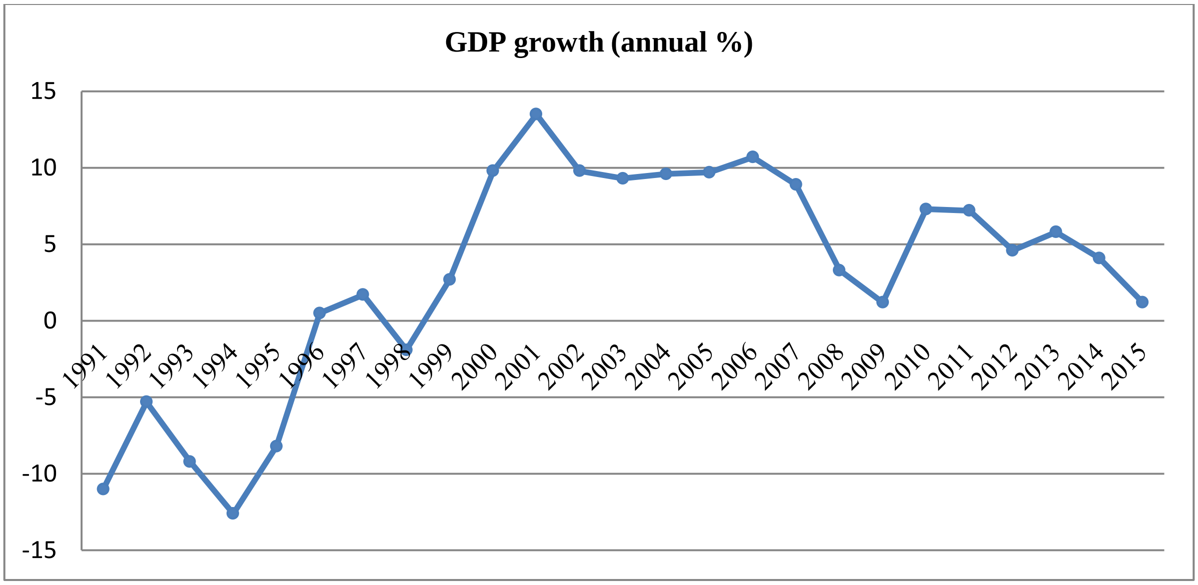

Figure 1. GDP growth in Kazakhstan according to the World Bank (own graphic)

Economic and social advances in the country are vastly due to the energy system. Kazakhstan's economy got raised fast since the first geological expeditions in the 50-60s of the last century found numerous oil and natural gas reserves. In 2013 International Energy Agency estimated around 48.2% of an existing amount of energy resources mined in Kazakhstan were exported outside the country. Figure 2 shows the shares of energy export and utilization inside the country. The values are normalized to the whole amount of energy produced by Kazakhstan together with imported energy resources. The crude oil and oil products, such as fuel oils and gasoline, are the main players on an international trade market of the country (IEA, 2013).

By the end of 2015, a ratio of oil reserves to production (R/P) was 49.3 years, R/P ratio of natural gas was 75.7 years and the coal R/P ratio became 316 years (BP, 2016). Despite the abundance of natural resources and relatively small number of population, a considerable share of fossil fuels is sold to other countries. This fact decreases the availability of conventional energy resources for the future. Another consequence of today's energy generation is the gradual rise of carbon dioxide emissions to the atmosphere. Approximately 80% of CO^2 emissions come from the energy sector (Figure 3). The reasons are old power plants. Around 15% of produced energy is being lost during transmission and distribution (Kadrzhanova, 2013). In pursuance of meeting the energy demand and reduction of CO^2

emissions new technologies are to be introduced. The most efficient and ecologically clean systems nowadays are based on renewable energies.

In Figure 4 you may see the overall production of fossil fuels and energy from renewables in thousand tons of oil equivalent. There we may find that hydropower as the renewable source of energy is the most advanced among other types of renewables. On the other hand, solar energy and biofuels are the least developed sectors in the current energy system of the state.

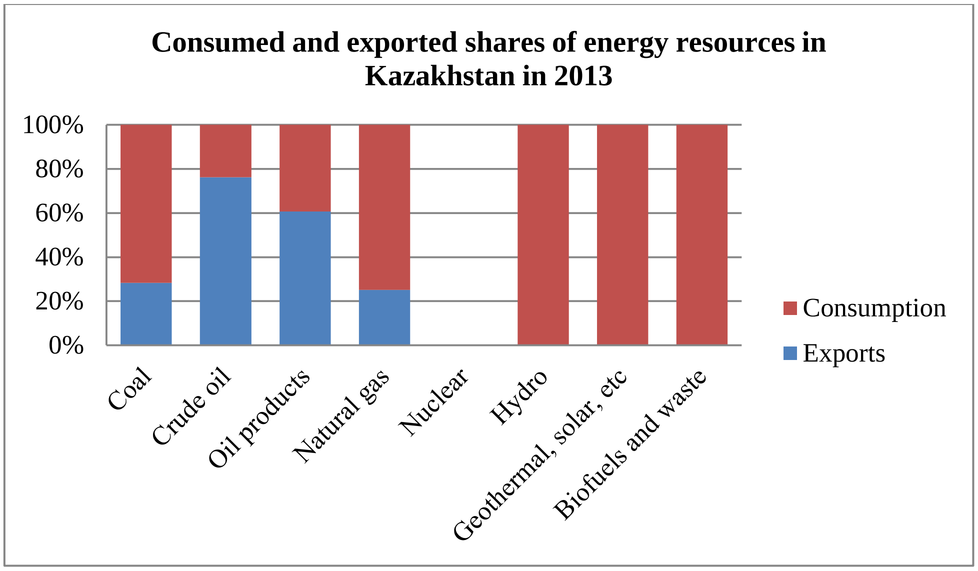

Figure 2. Normalized percent share of consumed and exported energy resource in Kazakhstan in 2013 according to IEA (own graphic)

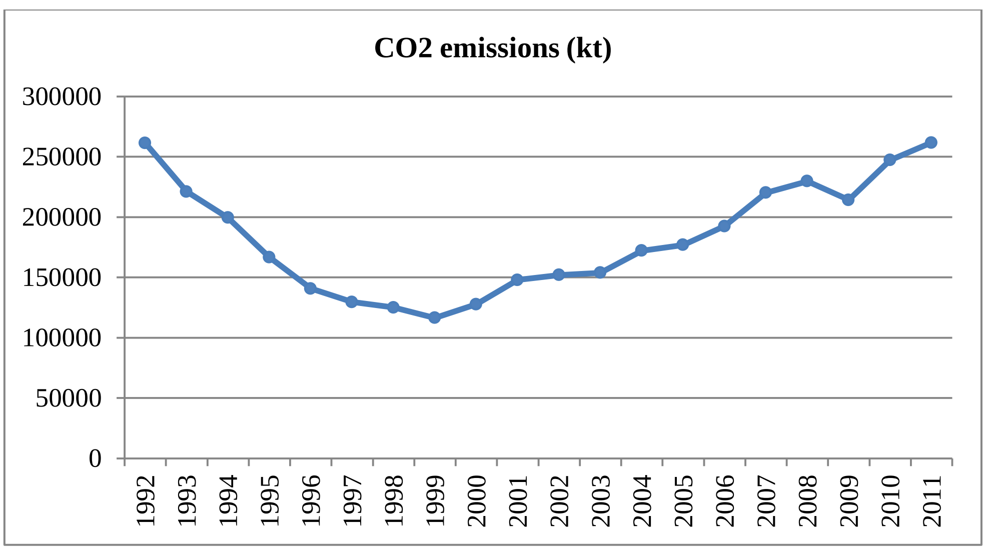

Figure 3. CO2 emissions in kilotons in Kazakhstan according to BP (own graphic)

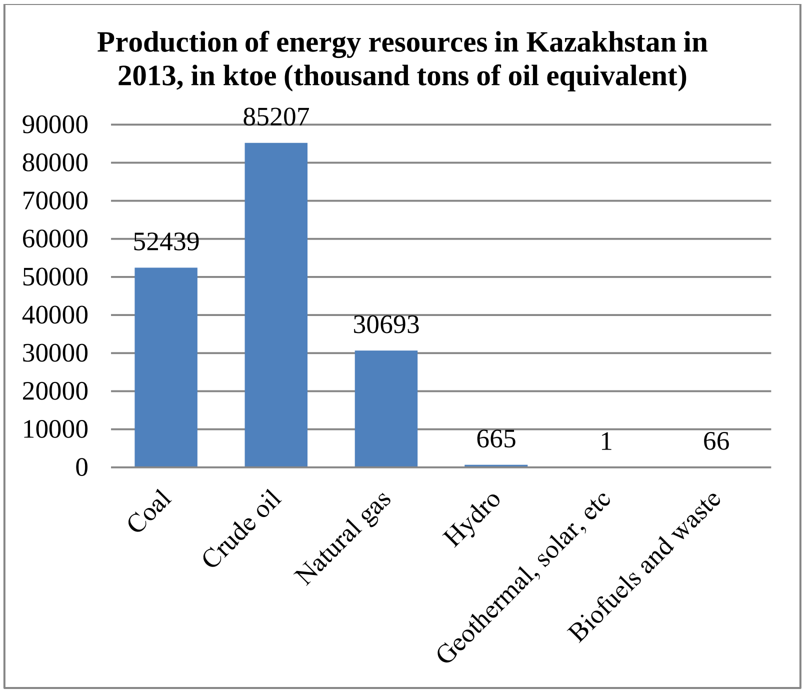

Figure 4. Production of different types of energy resources in Kazakhstan in 2013 according to IEA (own graphic)

1.2. ELECTRICITY

As stated in the work by Kadrzhanova (2013) the challenges of the post-Soviet period significantly impacted the industry of power generation in Kazakhstan. Economic growth started after approximately 10 years of being an independent country. It supported the companies to generate more energy for electricity purposes. However, the economic crisis lessened both the demand and supply of electricity until 2010, when it began to rise again. It is expected that the outcome of the introduction of new renewable energy installations and energy efficiency policies will be a generation of 150 billion kWh of electricity by 2030. However, there are some challenges. One example is in insufficient transmission lines between northern and southern regions in Kazakhstan. The problem is that the main consumer is the south of the country and most of the producers are in the north. Another deficiency is in the west of Kazakhstan, where the electricity is imported from Russian Federation to overcome the demand (Kadrzhanova, 2013).

The electricity system in Kazakhstan is a composite chain of power plants, transmission lines, distribution grids and end-use devices (Sarbassov, et al., 2013). There are 68 power stations including five hydroelectric power plants with total installed capacity of 21307.2 MW and available capacity of 17503.5 MW (Kazakhstan Agency for Statistics, 2014). About 80% of electricity is produced by coal-fired plants (Figure 5). As it was mentioned earlier, from 2015 1% of power has been generated by the wind and solar PV installations.

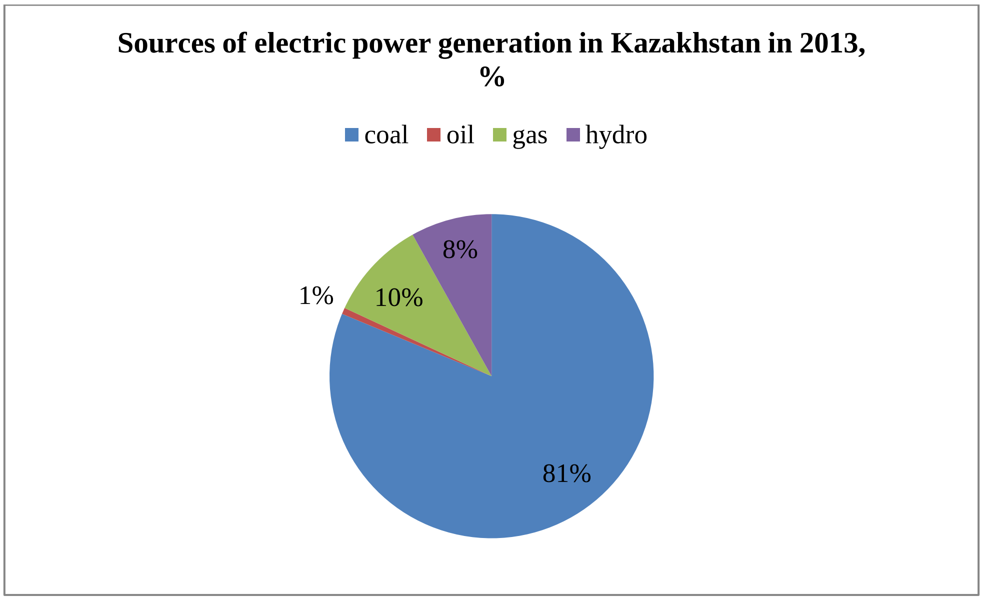

Figure 5. Sources of electric power generation in Kazakhstan in 2013 according to IEA (own graphics)

Currently, an electric power system includes power stations of national importance, regional importance and for industrial use. An electric network is a set of substations, switch gears and interconnecting transmission lines. The voltage of the network is 0.4-1150 kW for the transmission and distribution of electricity. The National Power Grid allows connections between the country's regions and electric networks of Russian Federation, Uzbekistan, and Kyrgyzstan (KEGOC, 2016). The main consumer of electricity is the industrial sector with almost 70% share, including the electricity consumed by power plants. The next one is the residential sector with 12% share. A chart with shares of electricity consumption, excluding production losses, is illustrated in Figure 6. The mean values of consumption share are estimated based on the data for the period of 2008-2013 (Kazakhstan agency for Statistics, 2014).

Total production of electricity by power plants had a growing tendency over past years (Figure 7). Whereas the consumption of electricity is slightly fluctuating. In 2008 the demand was higher than the production of energy; however, in later years there was enough generated electricity to cover the demand.

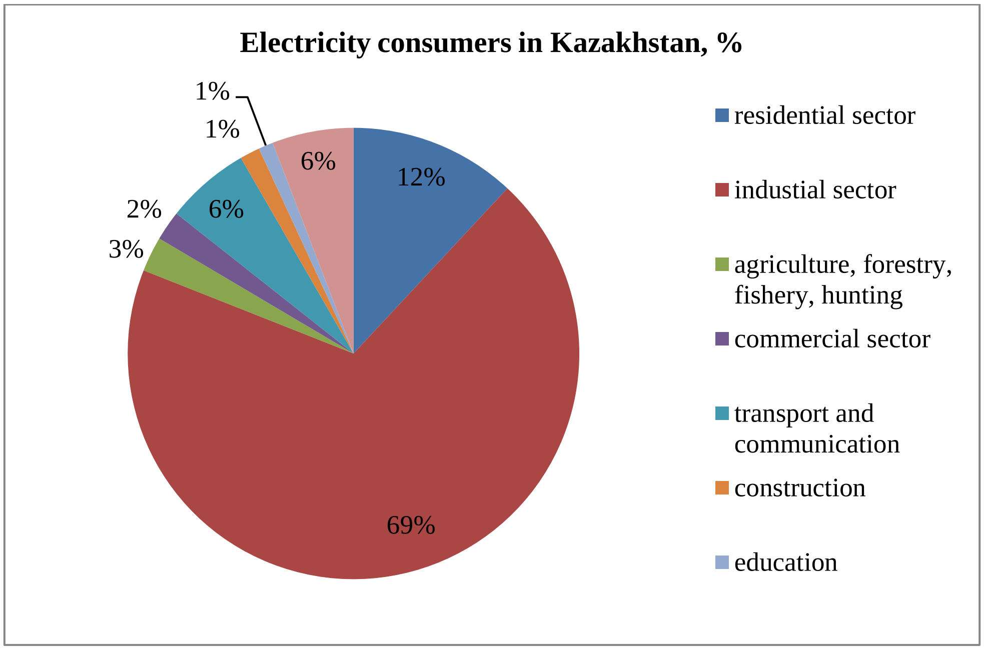

Figure 6. Electricity consumption in Kazakhstan according to Kazakhstan Agency for Statistics (own graphics)

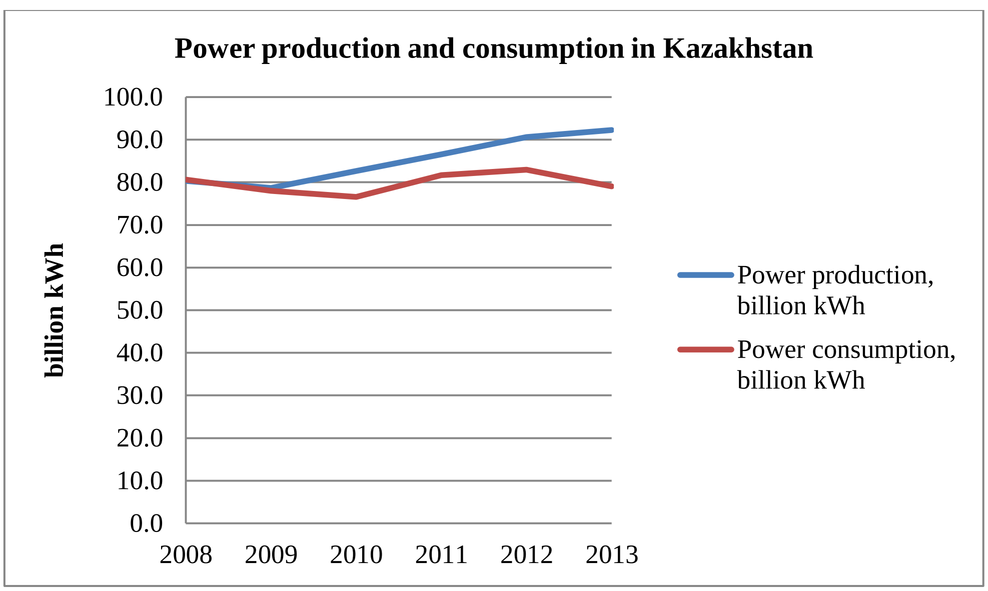

Figure 7. Electricity balance in Kazakhstan in 2008-2013 according to Kazakhstan Agency for Statistics (own graphics)

1.3. HEATING SYSTEM

Heat generation plants, transmission lines, distribution grid and consumption are the parts of district heating systems. A number of heat generating facilities equals to 2443 according to Kazakhstan Agency for statistics (2014). They are of two types: thermal power plants with the capacity of 29065.46 MW and boiler houses with the capacity of 21118.8 MW. Approximately 78% of heat generation is provided by thermal power plants. The rest accounts for thermal houses. The main source of energy for the heat is coal (99%) (IEA, 2013). The total length of heating networks is 12100 km (Kazakhstan Agency for Statistics, 2014). Heat consumption groups are residential sector, industrial sector with household and production needs, and other companies, which resell the heat energy. Figure 8 shows the share of all consumers in in Kazakhstan. The share values are the mean estimates of consumption for the period of 2008-2013.

A general trend of a heat energy balance in Kazakhstan for a period of 2008 - 2013 is visualized in a graph in Figure 9. It is clearly shown that the heating system is able to cover the heat demand.

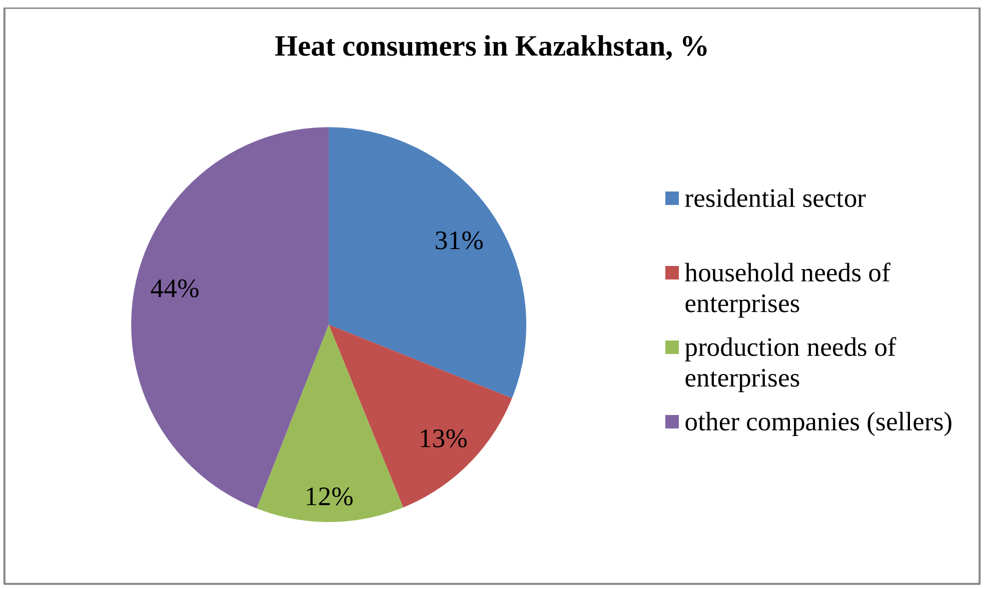

Figure 8. Heat consumption in Kazakhstan according to Kazakhstan Agency for Statistics (own graphics)

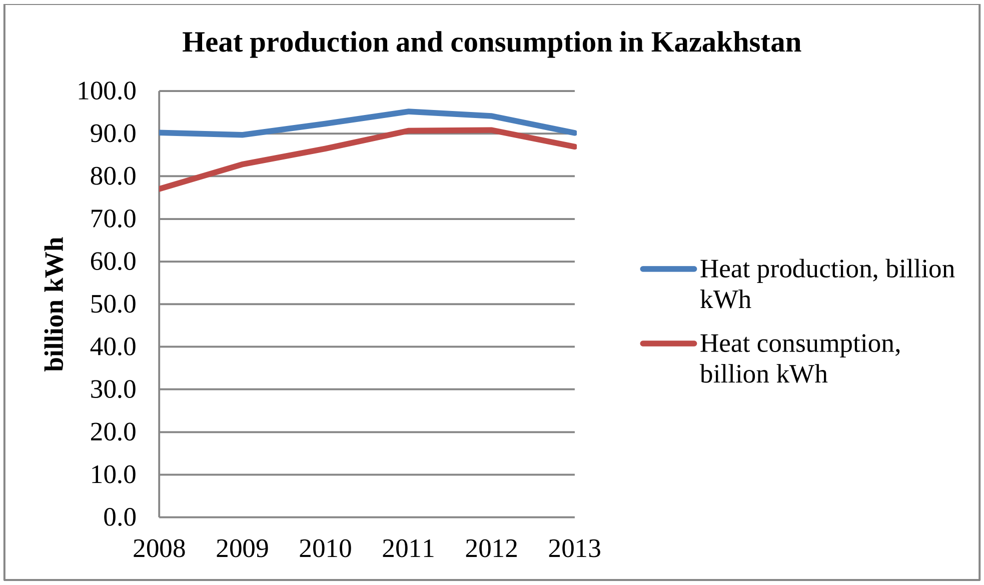

Figure 9. Heating balance in Kazakhstan in 2008-2013 according to Kazakhstan Agency for Statistics (own graphics)

1.4. HYDROPOWER

The power generated from using the water force has been applied worldwide. The advantages are low operating costs, simple technology, and absence of CO^2 emissions or waste. However, like every technology nowadays it also has some drawbacks, like slight ecological succession processes on a micro level, due to micro climate effects. Despite this fact, it is still cleaner than traditional fossil fuels. In Kazakhstan hydropower provides 13% of generated energy distributing approximately 675 ktoe yearly (Karatayev and Clarke, 2014). Its resources are mainly spread in the eastern and southeastern regions of Kazakhstan. The biggest amount of energy is produced by Shulbinsk (702 MW). There are also Bukhtarma (675 MW), Kapchagay (364 MW), Ust-kamenogorsk (332 MW) and Shardara (100 MW). By 2020 there are few more power plants expected to generate the energy of more than 500 MW (World energy council, 2013). This type of energy is reviewed in this section to generally outline the existing energy system in the country. Yet estimation of hydropower potential is out of the scope of current research.

1.5. SOLAR ENERGY

This type of energy is the most plentiful on Earth. It can be transformed to heat and electricity in both its forms. Direct form is solar radiation and indirect form is through hydropower, biomass, wind, etc. Solar energy, which incidents on the earth's surface through time, is called solar irradiance or insolation. This solar irradiance changes throughout the day and with the seasons. It has different values all over the surface, depending on the geographic position, climate and topography. The technologies to collect solar energy are divided into two types: solar thermal collector and solar photovoltaic (PV) collectors.

Concentrated solar power (CSP) plants use mirrors to concentrate the direct solar irradiation. This energy heats the air or fluids and then converts the steam to electricity, like in traditional steam engines. Here the conversion of thermal energy to mechanic energy with following conversion to electricity is well-known from power plants, which use fossil fuels. The advantage of CSP plant is that it has an ability to store the collected thermal energy and use it for electricity production when it is necessary. It makes solar energy be independent from the day time. At the moment the technological capacities of CSP plants allow collecting the heat with the temperatures between 200^{0}C and 1000^{0}C. As any other thermal power plant, CSP collector also needs an access to water for cooling. Also one of the requirements is the relatively close electricity transmission grid (World energy council, 2013).

The PV collectors translate sunlight to electricity directly at the atomic level without involving the heat engine. There are particular materials which can absorb photons of light and release electrons. This capability is called photoelectric effect. The electricity is created from capturing of these freely released electrons to electric current. Solar photovoltaic appliances are stand-alone systems, which provide energy from microwatts to megawatts. Examples of such devices are watches, calculators, satellites and space crafts, etc. PV panel lifetime is about 30 years nowadays. The most accepted panels consist of crystalline and polycrystalline silicon solar cells. Furthermore, they do not require additional space, being constructed on the roofs, and do not interact with natural ecosystems. Another advantage is in their suitability in the isolated areas. In general, any solar energy system has few positive outcomes, like high reliability at the expense of absent moving assets, quick installation (World energy council, 2013).

There is only one solar power plant called Burnoye and located in Zhambyl region. Its power capacity accounts to 50 MW (European Bank for Reconstruction and Development, 2015). The goal of the government is to increase electricity production to 77 MW by introducing 3 more solar power plants.

1.6. WIND ENERGY

Wind is available everywhere on earth, admitting the wind strength, which is diverse depending on the location. The wind itself is the form of solar energy. It is generated because the sun irregularly heats the atmosphere. When the earth rotates these irregularities of air temperature causes the wind. Additionally, the landscape with different vegetation and topography alter the wind speed on the earth's surface. Applications of the wind energy are various. Examples are sailing, flying the para planes or parachutes, electricity, etc. When the wind energy is applied to generate electricity, then the captured kinetic power of the wind is converted into mechanical power by wind turbine installations. Later this mechanical power is converted to electricity (World energy council, 2013).

There are two groups of wind turbines: the horizontal-axis wind turbines and vertical-axis installations. The first type is more popular and the main part of the construction is the blades. They can be two or three per turbine. Wind turbines also differ by size. Depending on that they can produce from 100 kW to several MW. Large turbines are proved to be more cost effective and they deliver more energy because the blades are located higher, where the wind speed is greater. They are normally grouped into wind farms and provide bulk power to the electrical grid. Small wind turbines, which can generate up to 100 kW of electricity, are used for farms, single houses, water pumping, etc. Such turbines are installed in the isolated areas with no connection to the utility grid (World energy council, 2013).

The wind turbines can be placed onshore or offshore in the water bodies like oceans or lakes. Offshore wind turbines have larger resource potential and impact less on the environment. Although the construction and maintenance costs are higher.

The overall benefits of wind energy resource are the plain technology and the fast installation of the turbines. There are no fuel costs, no waste. Although the wind energy is discrete, meaning that its generation depends on the weather. The environmental impact is also under critique, as wind turbines generate the noise and are influencing birds' movements (World energy council, 2013).

Around half of the territory of Kazakhstan is suitable for wind installations as the average wind speed is around 4-6 m/s. At the moment there is only one construction project which has been finished. The constructed wind power plant with the capacity of 45 MW is now operating close-by to Ereymentau city. It gives 172.2 million kWh of electricity per year. There are planned projects to install few more wind power plants in the Djungar Gates, Chylyk, Mangystau mountains, peak Karatau, Chu-ili mountains, mount Ulutau, Mugodjary mountains (Karatayev nad Clarke, 2014).

1.7. BIOMASS ENERGY

The biomass has been used for countless years. It is an organic material which stores sunlight in the form of chemical energy. When the biomass is burned to receive energy, almost the same amount of CO^2 is released as from the fossil fuels. Nonetheless, when the new plant grows it consumes CO^2, whereupon the latter is being removed from the atmosphere. The general groups of biomass feedstock are plants, forestry and agricultural residues, organic waste (municipal solid waste, animal waste) and also aquatic plants, like algae (World energy council, 2013).

The types of biomass technologies are several: biofuels, biopower, and bioproducts. Biofuel is the biomass directly converted to a liquid fuel. It is used in the transportation sector by cars, buses, trucks, trains and airplanes. Bioethanol and biodiesel are the most common types of biofuel. In order to generate electricity or heat, there is biopower type of biomass.

Biopower technologies comprise of direct combustion, co-firing, gasification and anaerobic digestion. Direct combustion technology is the most popular nowadays. It uses traditional boilers, where the wood is burned first creating the steam. Later the steam spins the turbine converting thermal energy to mechanical energy. The turbine then activates the engine that produces electricity. The least-cost renewable option can be co-firing technology, which is based on replacing the part of fossil fuel in coal-fired plants with the biomass. In gasification process, the solids of heated biomass are converted to a synthesis gas. Such gas can be then used in traditional boilers or in turbines. Through anaerobic digestion, bacteria dissolve the organic matter of biomass in the environment conditions without oxygen. Afterward, bacteria produce methane and several other byproducts, which all together form natural gas. The last biomass technology produces bioproducts, which are chemicals and materials that serve as renewable alternatives to many products, like plastics, industrial chemicals, fertilizers, etc. Traditionally they are created from petroleum and natural gas (World energy council, 2013).

The potential of bioenergy production is driven by the abundant amount of biomass wastes and residues from steppes, agricultural lands and forests in the country. In the northern region of Kazakhstan, the Biokhim factory annually produces and exports 4.4 million liters of biofuel (World energy council, 2013). The straw of cereal crops acts as the most anticipated resource for the purpose of biodiesel and bioethanol production. The abundance of poultry and agricultural livestock is another source of bioenergy, as the cattle waste produces a great amount of methane.

2. RELATED WORK

Nowadays, when the technology progress is running fast, we are provided by the significant amount of good quality data, tools to estimate values with high accuracy and within appropriate time limits. This abundance of possibilities to study social, environmental or any other phenomena brought up new techniques. Topics of renewable energy get more and more attention. The research perspectives in this area span from an estimation of geographical implications of renewable energy potentials to considerations regarding economic and socio-political constraints.

The GIS Decision Support System is one of the first methods to evaluate renewable energy resources suggested by Voivontas, et al. (1998). The authors specifically focused on the advantages of GIS technologies, like its compliance in data management and handling, its ability to feature the relationships between data sets. Hoesen and Letendre (2010) proposed a slightly different way of estimating solar, wind and biomass energy potentials for rural communities, which are isolated or heavily dependent on the electricity network grid. Similarly, Janke (2010) used multicriteria GIS modeling to find the best location for solar and wind farms in Colorado. A general revision of actual methods, tools and data sources for the estimation of renewable energy potentials was given by Angelis-Dimakis, et.al. (2011). Wang, et al. (2014) carried out not only the estimation of technical potentials but also analyzed the self-sufficiency of the energy system of Fukushima region with calculated potential and primary energy consumption. Blechinger, et al. (2016) developed an energy system simulation tool to compute the least-cost hybrid combination of PV solar energy, wind energy, battery storage and diesel power. The model calculates the techno-economical potential for small islands.

PVGIS (Photovoltaic Geographical Information Systems) is an open-source tool to calculate the potential electricity production for solar photovoltaic (PV) installations in a grid system or stand-alone system at any remote location in European, Asian and African countries. It is developed by Joint Research Center from the European Commission’s science services. There are several parameters which have to be considered in order to calculate potential energy. They are PV technology type, installed peak PV power, system losses, mounting position, slope, etc. (IET, 2012)

GISA SOL, developed for northeastern regions of Brazil (Tiba, et al., 2010), calculates solar, aeolic and biomass energy sources. It helps to plan and manage the insertion of mentioned energy sources on state and municipality levels.

A comprehensive potential analysis for solar PV generation on a regional scale was carried out by Sun, et al. (2013). The complexity of the analysis was based on calculating solar irradiation from digital elevation model (DEM) and coefficient of the atmospheric transmissivity. Next constituent was the estimation of geographical, technological and economical potentials with the analysis of economic feasibility for PV investments. They also checked the effectiveness of CO^2 reduction for PV facilities.

There are many studies on how to place electricity and heat production at remote locations. The work by Sarralde, et al. (2015) investigates the scenarios of solar energy integration in the urban energy systems and finds the relations between energy efficiency and urban morphology. By optimizing some parameters of building roofs and facades the solar potential can increase. The results can be used for later constructions or modification of existing buildings in the city to harvest more solar energy.

Probably one of the first attempts to delineate most suitable locations for wind farms was this simplified approach suggested by Baban and Parry (2001).They collected information to identify criteria, policies, and factors influencing the suitability of wind farms. The information was acquired from a perspective of council bodies and companies in the UK via questionnaire and from published literature. Next step was to group the factors and weight them by importance to the subject. Each factor was also scored, setting the limits for suitability to every cell on a map. They defined the approach as flexible because the users may weight factors depending on their expertise and purpose of investigation.

Constructions of wind power plants require land with satisfactory wind resources, closeness to the electricity grid. Moreover, it should suit the environmental requirements and has minor or no visual impact. Rodman and Meentemeyer (2006) developed an analytic framework to identify suitable placements for wind turbines considering all the listed prerequisites. The visual impact was a big concern in regards to the previously proposed installation of the power plant within the area of Northern California, as the power plant could negatively influence on the tourism and subsequently lead to a loss of money coming from visiting tourists (as cited in Rodman and Meentmeyer, 2006). A decision support system, based on multi-criteria decision making for site selection of wind turbines, developed by Aydin, et al. (2010), also focuses on the potential environmental impacts. Sliz-Szkliniarz and Vogt (2011) evaluated wind energy distribution in one of the regions in Poland and also used geographical, technical and economic constraints. Hossain, et al. (2011) made a statement that since technology is changing, values of energy potentials should be recalculated as well and be considered by the government and organizations on the example of India. They reassessed the wind energy potential and found the difference in values from those calculated in the 90s. Another problem that Grassi, et al. (2012) had encountered in their work is the insufficient interconnections of transmission lines in the United States. The proposed methodology on technical and economic assessment of wind energy potential included an identification of different interconnection options with comparative costs. Mentis, et. al. (2015) assessed technical wind energy potential on a continent scale for Africa, delineating the most and least suitable countries. An analytical site modeling tool proposed by Cavazzi and Dutton (2016) is the recent development, which estimates economically accessible off-shore wind resource.

A precise research focused on an evaluation of biomass potential from agricultural residues was conducted by Voivontas, et al. (2001). A GIS decision support system consisted of a database with all initial data and the analyzing tool, which calculated theoretical amount of biomass energy, taking into account conversion technology, optimal locations for power plants, distribution of biomass to these power plants, transportation to the nearest road network, electricity production costs. Panichelli and Gnansounou (2008) in their approach defining least-cost locations for bioenergy facilities paid attention to competition between power plants for available bioenergy resources.

Evaluation of the technical potential of biomass residues from a forest and agricultural lands in a region of Portugal was carried out by Fernandes and Costa (2010). In their work, they relied on the previously mentioned approach suggested by Voivontas, et al. (2001). Haberl, et al. (2010) reviewed the literature on global technical potential estimates for bioenergy in 2050, taking into account the expectations of technologies, food demand, and ecological situation. As a result of a comparison, they concluded that the estimates range because of differences in technological assumptions and area availability. Blaschke, et al., (2013) suggested to bound evaluation of bioenergy potential with a landscape concept, where the perception of an environment by humans can be another influencing factor, when modeling biomass energy potential.

An bundant number of research institutes and associations are concerned about renewable energy development. One of them is National Renewable Energy Laboratory (NREL), which develops energy-efficient technologies, tools, and practices. Its mission focus lies in research on solar, wind, geothermal and hydro energies, sustainable transport, energy efficiency of buildings, and integration of energy systems. NREL's tools, like Solar and Wind Energy Resource Assessment (SWERA), PVWatts, Geothermal Prospector, RE Atlas all provide visual content of renewable energy resources, estimate energy production and cost of energy, design and simulate energy systems on different scales and more (NREL, 2016). Yet NREL concentrates most of its attention on the research for the United States area. International Renewable Energy Agency (IRENA) is, in fact, is an organization, whose duty is to help and support countries worldwide in the transition to the renewable energies. Its interactive global atlas allows accessing the data about renewable energy potentials for any country. Although the economic potential is not available for every country due to lack of data, but the theoretical potential is globally available for all existing types of renewable resources (IRENA, 2016). German Aerospace Center (DLR) also massively contributes to the topic of renewable energy, targeting on the technology development for solar and wind power. The Green Energy System Analysis Tool (greenius) is one of the DLR products, which predicts electricity generation from solar thermal power plants, solar collectors, PV power plants and wind power farms (DLR, 2016).

3. METHODS

As has been noted the top-down approach was used to evaluate technical potentials of solar, wind and biomass energy. Below is the list of steps conducted in this work:

1) Identification of physically available renewable energy in the study area;

2) Determination of technical energy potential for electricity and heat production;

3) Integration of estimated potential energy with existing energy system

4) Development of interactive map of renewable energy potentials in Kazakhstan.

Spatial analysis was done in ArcGIS 10.3 and QGIS 2.14 software. Capabilities of mentioned software allow to handle spatial data, translate formats, overlay different data sets, make raster and vector calculations and find interconnections between layers for the purpose of this work. Visualization part is done using Open Layers 3 framework, its library permits to build map applications on the web in JavaScript programming language. HTML5 (Hyper Text Markup Language) and CSS (Cascading Style Sheets) languages were used to visualize non-spatial content and style the structure of the application. An overall workflow is visualized in Figure 10.

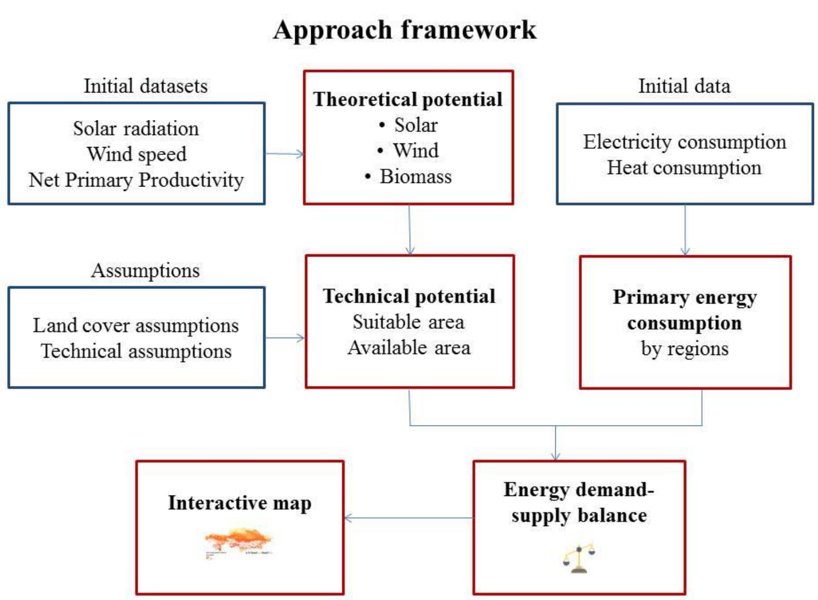

Figure 10. Workflow of estimation of technical energy potentials and their visualization (own graphics)

The first pre-processing step was data collection (Table 1). Every renewable energy technology receives energy in different amounts depending on the land cover. Land cover is everything physical on the earth surface that thematically grouped into classes. For the evaluation of suitable area I used global land cover data from Geography department, the University of Maryland (Hansen, et al., 2000). The data had a spatial resolution of 1 km^2 and 14 classes.

Global Meteorological Forcing Dataset for land surface modeling was acquired from Terrestrial hydrology research group in Princeton University (Sheffield, et al., 2006). The data was stored as NetCDF document having values for years in a range of 1948-2010. Average values were retrieved in order to use them in further calculations. Spatial resolution was 1.0 degree; a temporal resolution was 3-hours with daily and monthly aggregates. The data included downward longwave at the surface, downward shortwave at the surface, wind speed, etc. I was interested in downward shortwave at the surface, which is solar radiation emitted by the sun, later scattered, absorbed or transmitted by the atmosphere and reflected or absorbed by the earth surface. This dataset was needed for solar energy potential evaluation. Wind speed was another dataset necessary for the estimation of wind energy potential.

Biomass energy estimation included Net Primary Production (NPP) values, calculated by Eisenfelder, et al. (2014) for different types of land cover in Kazakhstan. NPP describes the amount of carbon produced by plants per day, week or year.

For the final comparison of energy demand and supply, regional statistical data on electricity and heat consumption were acquired from Kazakhstan Agency for Statistics. In addition, administrative boundaries were acquired from the Database of Global Administrative Areas (GADM, 2015).

Table 1. Initial datasets

Data	Resolution	Source
Land cover	1 km^2	Department of Geography, University of Maryland
Solar irradiance	1 degree	Terrestrial hydrology research group, Princeton University
Wind speed	1 degree	Terrestrial hydrology research group, Princeton University
NPP estimates	1 km^2	Eisefelder, et.al. (2014)
Electricity and heat consumption	Regional administrative level	Kazakhstan Agency for Statistics
Administrative boundaries	Regional administrative level	GADM database of Global Administrative Areas

3.1. SOLAR ENERGY POTENTIAL

To define the theoretical potential of solar energy only solar radiation dataset is needed without any other assumptions. Initial solar radiation data was coming for the whole world and contained monthly averaged values from 1948-2010. QGIS is able to read a NetCDF file that is why it was used to get an average value of solar radiation given in W/m^2. Similar actions were done to the wind speed data. The rest of calculation were carried out in ArcGIS. Global data was clipped to Kazakhstan outline and resampled by the spatial resolution of 1 km^2 because later calculations include land cover dataset with the resolution of 1 km^2. To get annual solar radiation which is theoretical potential, the following formula was used:

$$E_{theo} = P_{solar} * 8760h \quad (1)$$

where E_{theo} is solar energy potential (Wh/m^2), P_{solar} is solar radiation (W/m^2), 8760h are hours in one year.

It is necessary to mention that CSP installations are not considered in the analysis since they need stronger solar radiation to effectively perform. The lower limit should be 1900 kWh/m^2 which is way too much for the territory of Kazakhstan (Deng, et al., 2015).

The technical potential of solar energy is based on theoretical potential constrained by land cover assumptions and technological characteristics of solar installations. As it was mentioned in the overall approach framework (**Ошибка! Источник ссылки не найден.**), suitable and available areas have to be delineated for technical potential estimation. Suitable area for PV installations depends only on the type of land cover. I omitted proposed by many methodologies the topographic and environmental factors, like a slope or protected areas. It is an additional constraint when analyzing energy potentials on a smaller scale with high accuracy data. Available area is defined by share assumptions. Land cover assumptions represent the share of land that can be used for harvesting the energy. The share differs depending on the land cover class. I took global assumptions for PV installations estimated earlier by Deng, et al. (2015) (Table 2). Thus, areas which weren't suitable were excluded by 0% of share from land cover data, and available areas were calculated by multiplying the area of every raster cell by corresponding share value.

A conversion efficiency of PV panels acted as a technological constraint. Depending on its value, every PV installation is able to convert incoming energy to electricity. Deng, et al. (2014) also suggested average values for conversion efficiencies of existing technologies. The value for PV panel was estimated as 20% in 2010. To sum up all the constraints, the overall technical solar energy potential can be estimated by the Eq. (2) (Deng, et al., 2015):

$$E_{tech} = E_{theo} * A * 0.2 \tag{2}$$

where, E_{tech} is the technical potential of solar energy, E_{theo} is the theoretical potential of solar energy, A is available area per every raster cell ($1 km^2$), 0.2 is the conversion efficiency.

3.2. WIND POTENTIAL

Theoretical wind energy potential estimation was based on getting average wind speed values. The source of wind speed data is the same as for solar radiation that is why procedures were similar. Average wind speed values were calculated from the collection of values for 1948-2010.

Next step was to delineate suitable and available areas, where wind facilities could possibly harvest wind energy. Depending on the land cover type, the share assumptions were also different for wind installations (Table 2). I took into account only on-shore wind facilities because there is not enough wind above the continental sees in Kazakhstan to effectively convert it to electricity. As stated by Deng, et al. (2015) off-shore technologies capture energy from the wind with speed of at least 9 m/s. For the estimation of the technical potential, I used the formula given by Taylor (cited in Gormally, et al., 2012) with little modification. The initial approach was simplified in the sense of 1 wind turbine per 1 km^2 could be installed for energy production. The land cover share assumptions were not considered. With an average rotor diameter (d) of 60 m for wind turbine, I concluded that 1.3% of 1 km^2 is used. On this basis, I calculated specific coefficient (C) which results in share values per 1 km^2 in the Eq. (3) depending on share assumptions stated in Table 2 In other words, this land cover specific coefficient changes the size of the available area and consequently a number of wind turbines per 1 km^2.

$$E_{tech} = K * v^3 * A_t * T * C \tag{3}$$

where E_{tech} is the technical potential of wind energy in kWh/km^2, K = 3.2 is a constant related to a performance of typical turbine, v is wind speed in m/s, A_t is sweep area of the turbine in m^2, T is a number of turbines, C is coefficient.

$$A_t = d * \pi \tag{4}$$

3.3. BIOMASS POTENTIAL

Regarding biomass energy, the only theoretical potential was estimated without any restrictions concerning land availability, conservation areas, areas for food, and technical parameters of energy production technologies. The potential was calculated based on the Net Primary Production values for every land cover class Table 2 and the gross caloric value of dry matter biomass (V), which equals to 18.5 MJ/kg (= 0.00518 kWh/g) as cited in Haberl, et al. (2011). It is assumed that total amount of aboveground NPP of biomass can be harvest for bioenergy production. The values of NPP were merged with land cover data used in previous calculations. The following equation calculates biomass potential:

$$E_{theo} = NPP * V \quad (5)$$

Table 2. Land cover assumptions and NPP values (Deng, et al. (2015), Quaschning, V. (2000), Eisefelder, et.al. (2014))

Land cover class		Solar, %	Wind, %	C, coefficient	NPP, g C/m^2
0	Water	0	0	0	0
1	Evergreen Needleleaf Forest	0	1	0.777	263.8
2	Evergreen Broadleaf Forest	0	1	0.777	264.1
3	Deciduous Needleleaf Forest	0	1	0.777	263.8
4	Deciduous Broadleaf Forest	0	1	0.777	264.1
5	Mixed Forest	0	1	0.777	263.95
6	Woodland	0	3	2.331	0
7	Wooded Grassland	0	3	2.331	0
8	Closed Shrubland	0	3	2.331	205.1
9	Open Shrubland	0	3	2.331	112.0
10	Grassland	1	6	4.662	140.0
11	Cropland	0,5	6	4.662	224.5
12	Bare Ground	1	6	4.662	73.0
13	Urban and Built-up	0	0	0	0

3.4. BALANCE OF ENERGY DEMAND AND POTENTIAL SUPPLY

Every administrative unit, a piece of land, a household has different energy needs. The common categories of energy consumers in Kazakhstan are household, industry, transport, service and agriculture sectors (Gomez, et al., 2014). They use energy in the form of power and heat from main suppliers, like Combined Heat and Power (CHP) plants, heat boilers, and hydropower plants. Many houses in rural areas use firewood for heating. The way to understand how much of energy the system requires lies in defining a number of available energy resources, an efficiency of existing technologies, quality of end-use devices to save the energy, etc. Defining demand - supply balance is an adequate option on a country scale to have an overall view of the energy system.

The data gathered from the Kazakhstan Agency for Statistics contain electricity and heat production and consumption values per administrative region. They do not include energy losses and energy coming from neighboring countries or regions. That is why some regions may produce way more energy and distribute it all over the country, and some don't have enough energy to cover their own demand. The most recent data about energy production and consumption are published for 2013 by Kazakhstan Agency for Statistics. Even if the values may have risen for the last years, the difference should not be considerable. In this study consumption values represent demand side. An amount of energy produced by existing sources is served as one part of supply side, another part being the estimates of renewable energy potentials. The analysis of the demand-supply balance was done in ArcGIS 10.3. For this purpose dataset with administrative boundaries for Kazakhstan was obtained and previously mention production and consumption data were added. Regarding the estimated potentials, I summed the values of all raster cells fallen in each particular zone of the administrative unit.

3.5. WEB MAP APPLICATION DEVELOPMENT

It was decided to visualize results of potential estimations and demand - supply analysis on an interactive map built as a web application, where users can actively access the data. There were few steps in application development visualized in Figure 11.

First of all data layers were styled and published as Web Map Services (WMS) in Geoserver, an open-source server for geospatial data storage, sharing, processing, and editing. Web Map Service is a protocol to serve images which are georeferenced over the Internet. They can be both raster or vector layers initially. The styles and legends of the layers were uploaded to Geoserver in the format of the Styled Layer Descriptor (SLD). Later OpenLayers3 functions allowed connecting to Geoserver WMS and accessing stored layers. JavaScript was used to make the web application to function, HTML5 passed the non-spatial context and CSS styled the page.

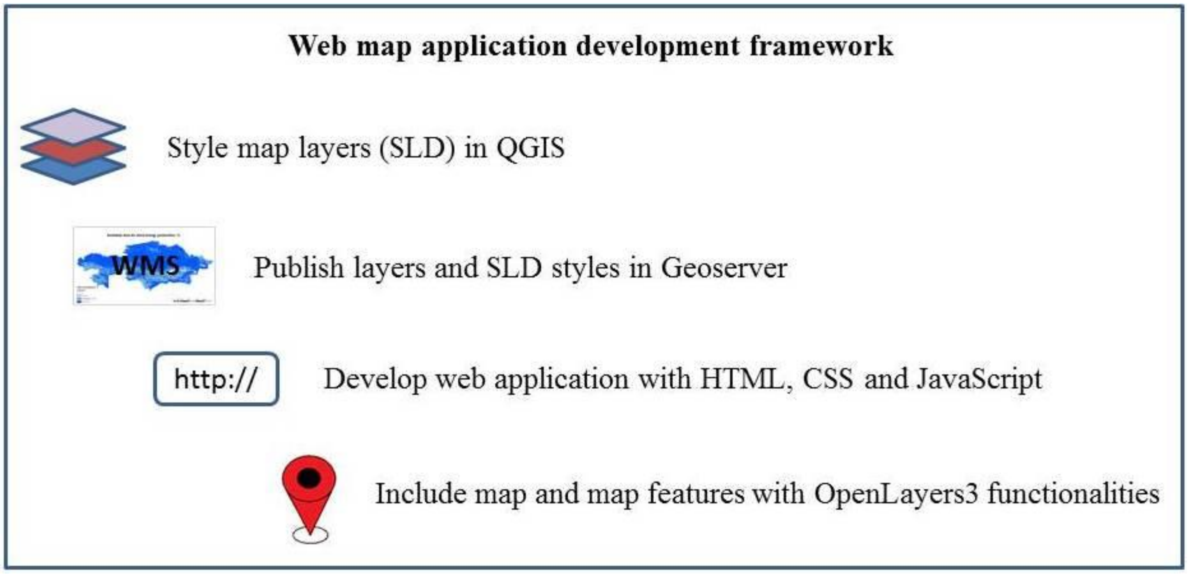

Figure 11. Web map application framework (own graphics)

4. RESULTS AND DISCUSSION

4.1. RENEWABLE ENERGY POTENTIALS

The theoretical potential of solar energy which represents physically available solar radiation without any constraints is depicted in Figure 12. Kazakhstan receives solar radiation in the range of 1.2 – 1.7 MWh/m^2. It is clearly visible on the map that the radiation increases from north to south. The overall amount equals to 6.59×10^{15} kWh per year. However, the assumptions on the suitability of land cover for energy production exclude areas with the highest theoretical potential. In Figure 13 you may see areas which are suitable and what share of these lands is possible to use for building solar panels. When suitable areas are restrained by share assumptions, available areas appear. Favorable grassland, cropland, and bare ground areas together constitute 66.6% of the whole country. But only 0.6% of country's land can actually be used for energy purposes.

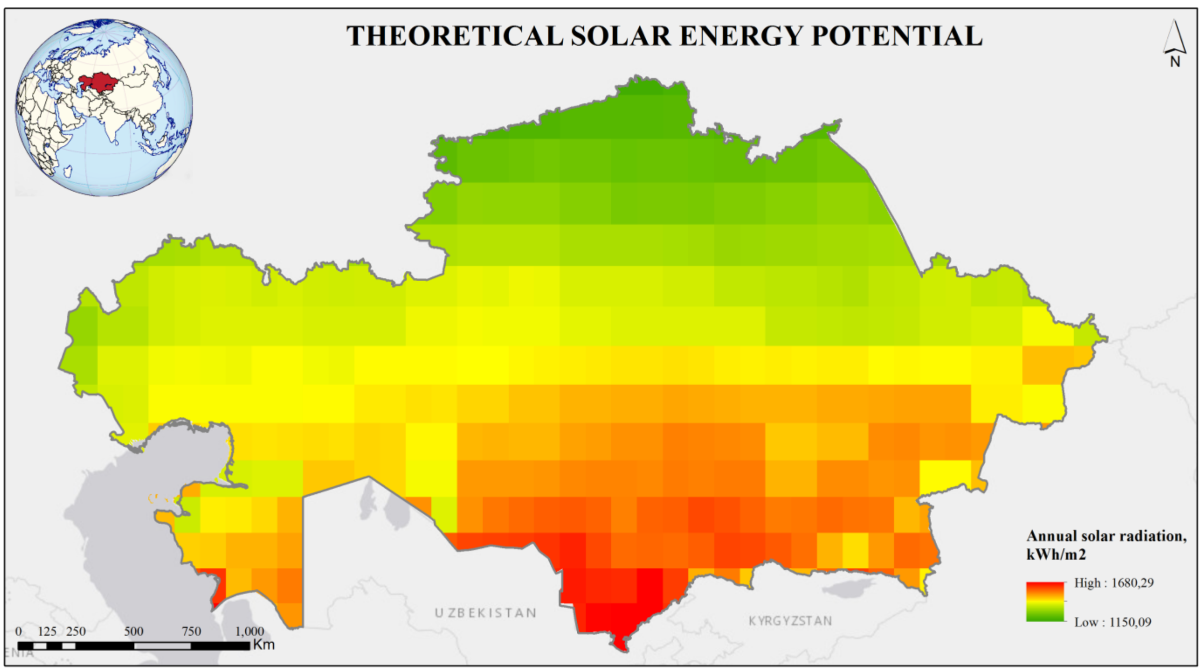

Figure 12. Annual theoretical potential of solar energy in Kazakhstan (own graphics)

Thus, considering factors mentioned above and also average conversion efficiency of solar panels, 7754.66 billion kWh per year appeared to be the technical potential of solar energy in Kazakhstan (Figure 14). Bare ground on the south results to be the most appropriate location for solar panels with the highest potential of 3 kWh/m^2 in average. The majority of grasslands which cover the most of the territory fall into a range of 2.5-3 kWh/m^2. Croplands on the south with high solar radiation can be used only in a proportion of 1:200 of the area. In addition, open shrublands with abundant solar radiation were not considered as the available area at all in the approach I used. This oversight can be thought over in the future analysis.

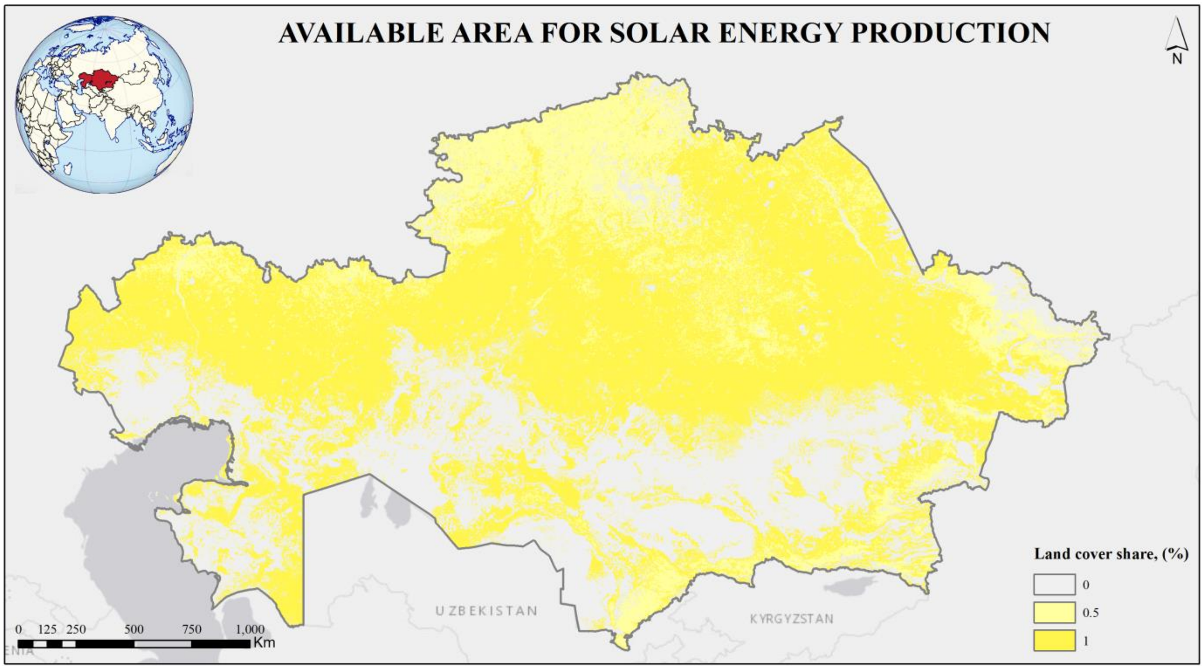

Figure 13. Available area for solar energy production with share assumptions in % in Kazakhstan (own graphics)

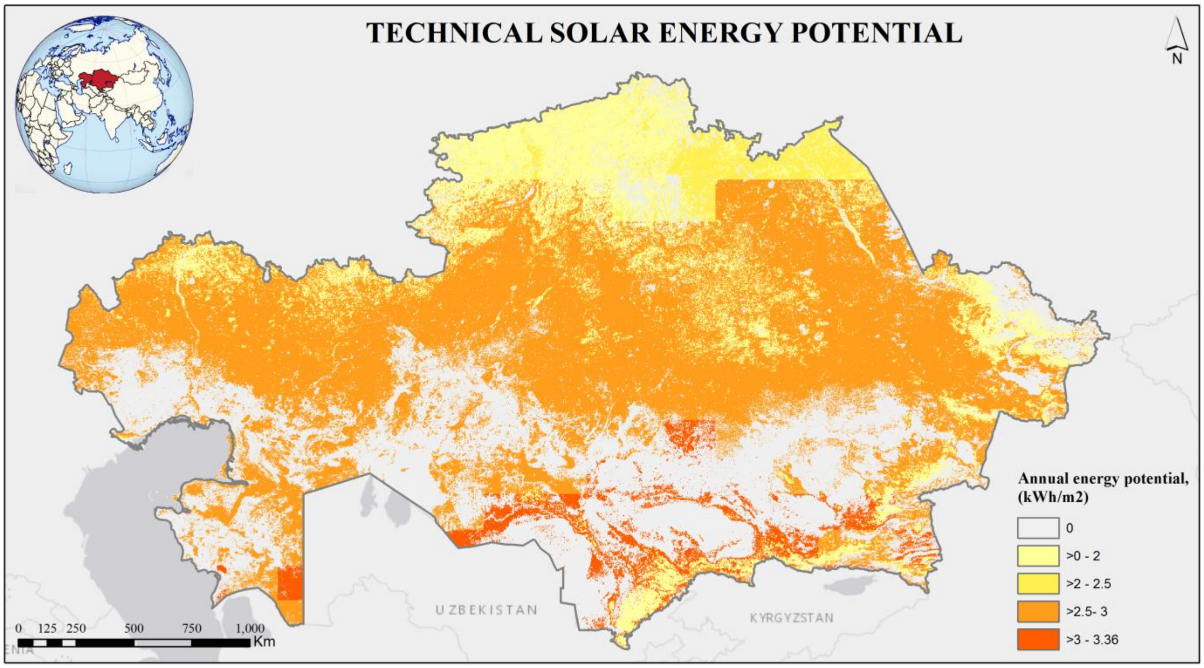

Figure 14. Technical potential of solar energy in kWh/m2 in Kazakhstan (own graphics)

Physically available wind above surface represents theoretical potential. It is given as wind speed in Figure 15. Places with the highest potentials are on the west near the Caspian see, also in the middle range of Kazakhstan. The averaged wind speed values range from 2-6 m/s approximately. About 97.1% of total area is suitable for on-shore wind energy production, leaving only urban areas and water bodies useless (Table 3). However, land use restrictions shrink the value of area considerably to 3.49% of the entire area. Figure 16 shows the available area under different land cover assumptions. Consequently, the potential restrained by technical possibilities of wind turbines to transform the upcoming energy to electricity is ended up to be 407.43 billion kWh per year (Figure 17). Lands with the bare ground on the southwest part of Kazakhstan have the highest wind energy potential, which is greater than 0.3 kWh/m^2. Croplands spread all over the country may potentially produce wind energy in the amount of 0.2-0.3 kWh/m^2.

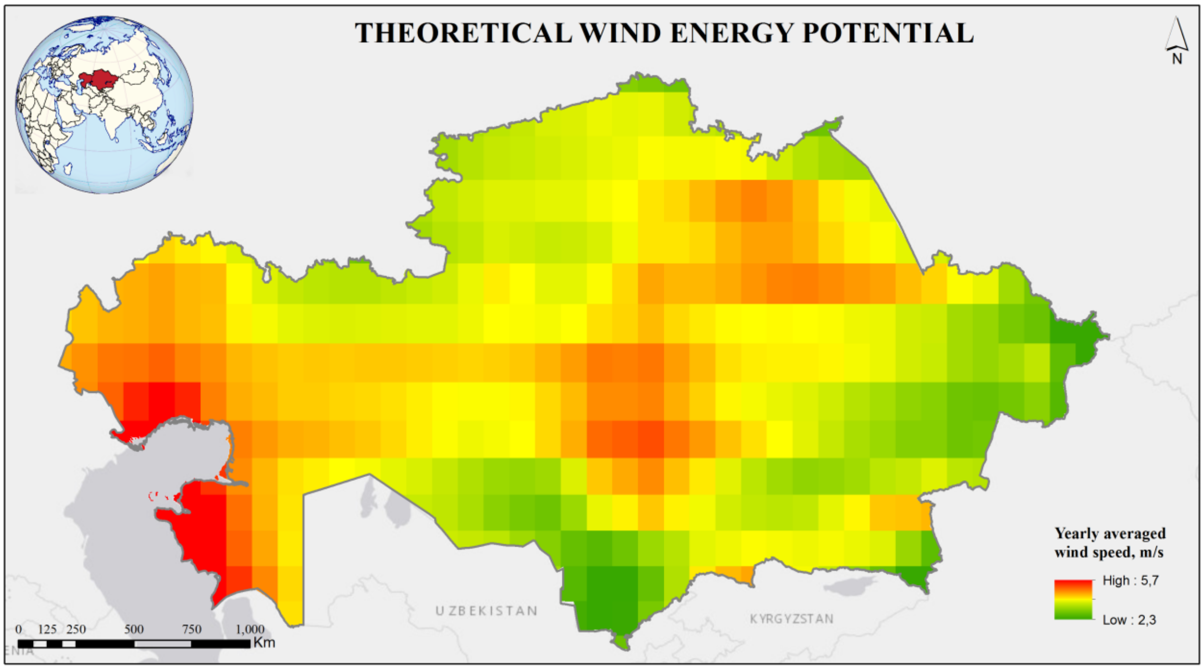

Figure 15. Theoretical potential of wind energy in m/s in Kazakhstan (own graphics)

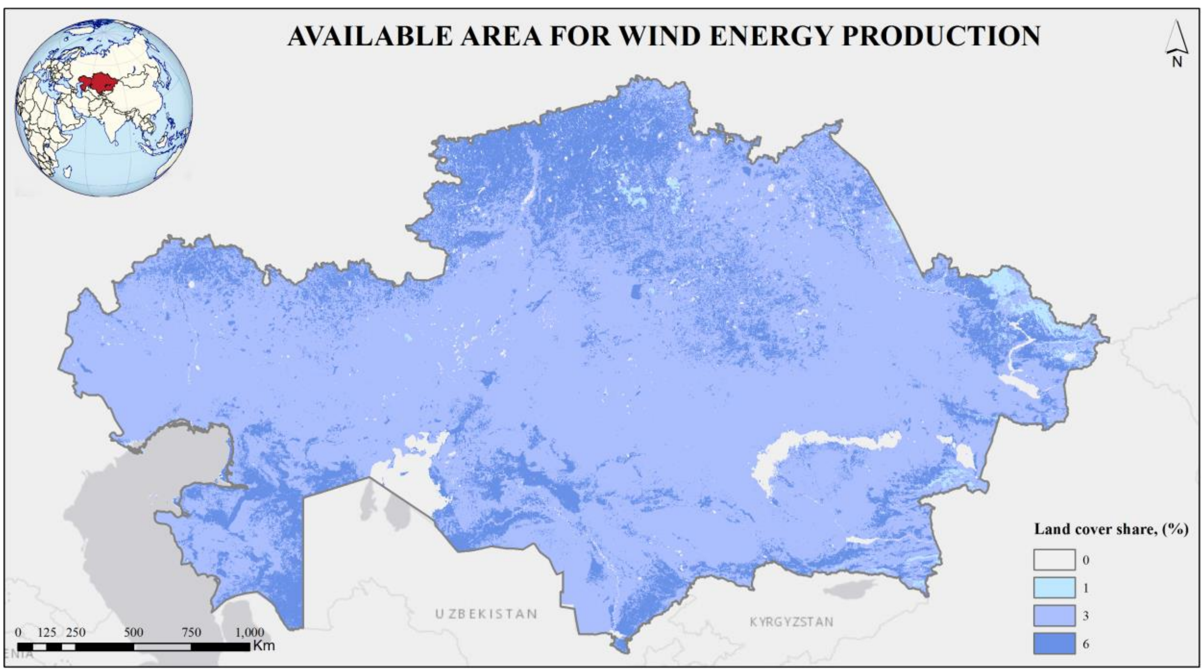

Figure 16. Available area for wind energy production in % in Kazakhstan (own graphics)

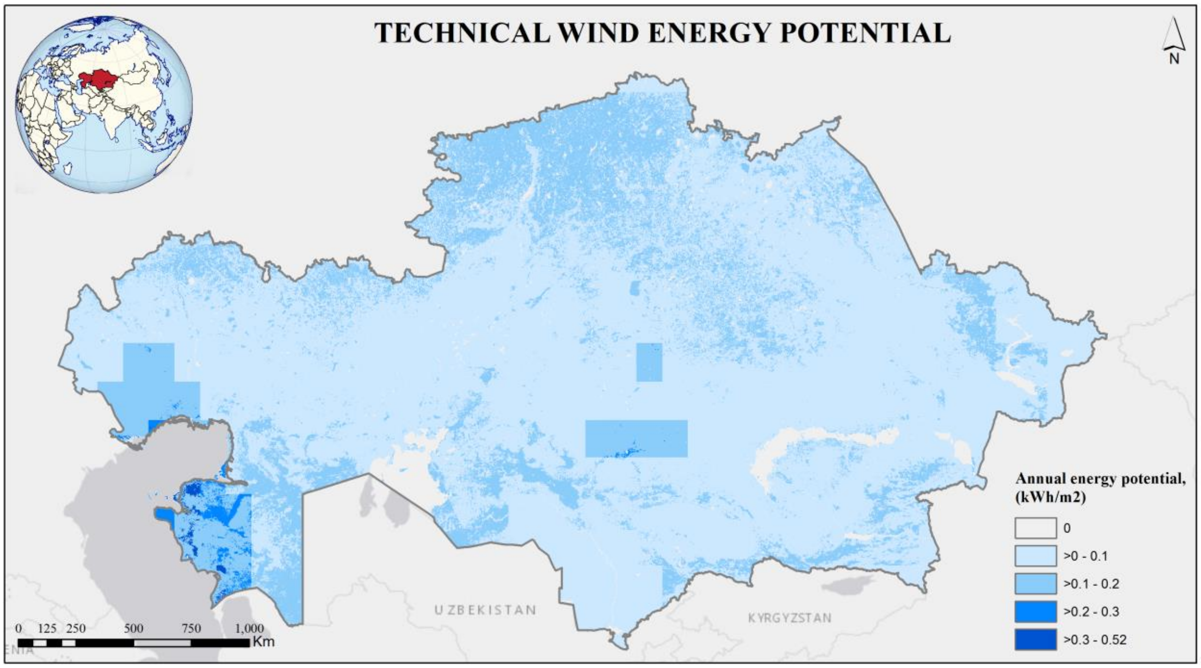

Figure 17. Technical wind energy potential in kWh/ m2 in Kazakhstan (own graphics)

Biomass potential energy was calculated based on the NPP values and resulted in 3265 billion kWh (Figure 18). 93.1% of the entire area assumed to be suitable (Table 3). This potential is not restricted by technical characteristics of related technology and by land cover assumptions. Theoretical potential per area ranges from 0 to 1.36 kWh/m^2. The highest values are located on croplands on the north and south, mixed forest on the east and little patches of closed shrublands on the south and the east.

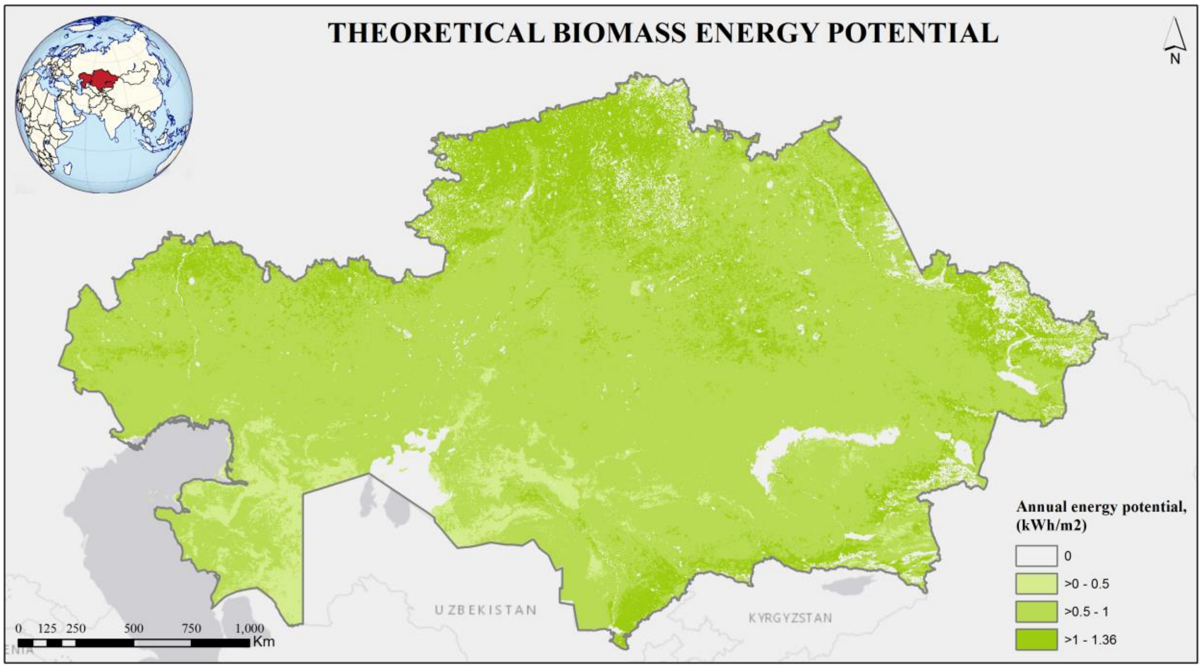

Figure 18. Theoretical potential of biomass energy in kWh/m2 in Kazakhstan (own graphics)

Table 3. Suitable and available areas in Kazakhstan for estimation of theoretical and technical potentials

Type of energy	Suitable area		Available area		Theoretical potential		Technical potential	
	km^2	%	km^2	%	kWh	kWh/m^2	kWh	average, kWh/m^2
Solar	1.9×10^6	66.6	17359.9	0.6	6.59×10^{15}	1395.2 8	7754.66×10^9	1.54
Wind	2.8×10^6	97.1	101533.9	3.49	-	-	407.43×10^9	0.09
Biomass	2.7×10^6	93.9	-	-	3265×10^9	0.69	-	-

4.2. DEMAND – SUPPLY BALANCE

In order to decide which areas in Kazakhstan experience a lack or an abundance of energy produced within a region, it is useful to analyze the current energy production and consumption trends per administrative unit. Transformed energy becomes available to consumers in the form of electricity and heat. As mentioned in the introduction overall annual electricity production in the country was 92.6 billion kWh and the consumption was 79 billion kWh in 2013 (Kazakhstan Agency for statistics, 2014). On a regional scale, the relation of demand – supply has an interesting pattern visualized in Figure 19. Most of the electricity is generated in Karaghandy and Pavlodar regions, the latter being electricity provider for those regions who cannot satisfy their own energy needs. In addition, there is a part of electricity coming from neighboring countries, which is not considered here. Talking about heating system, 4 regions have greater demand than the actual heat production (Figure 20). The regional authorities solve this problem by receiving additional heating energy from adjacent regions. The heat production in 2013 ended up with the value of 90.4 billion kWh and its consumption was 86.8 billion kWh (Kazakhstan Agency for statistics, 2014). According to all these facts, Kazakhstan balances its energy demand – supply systems by the interregional flow of electricity and heat. As it has been stated, the majority of energy comes from the use of fossil fuels. An introduction of renewables can improve energy system which is not working perfectly, due to losses, old equipment, worn-out transmission lines and uncomfortable positions of power stations, built during the soviet period without care of borders (Kadrzhanova, 2013).

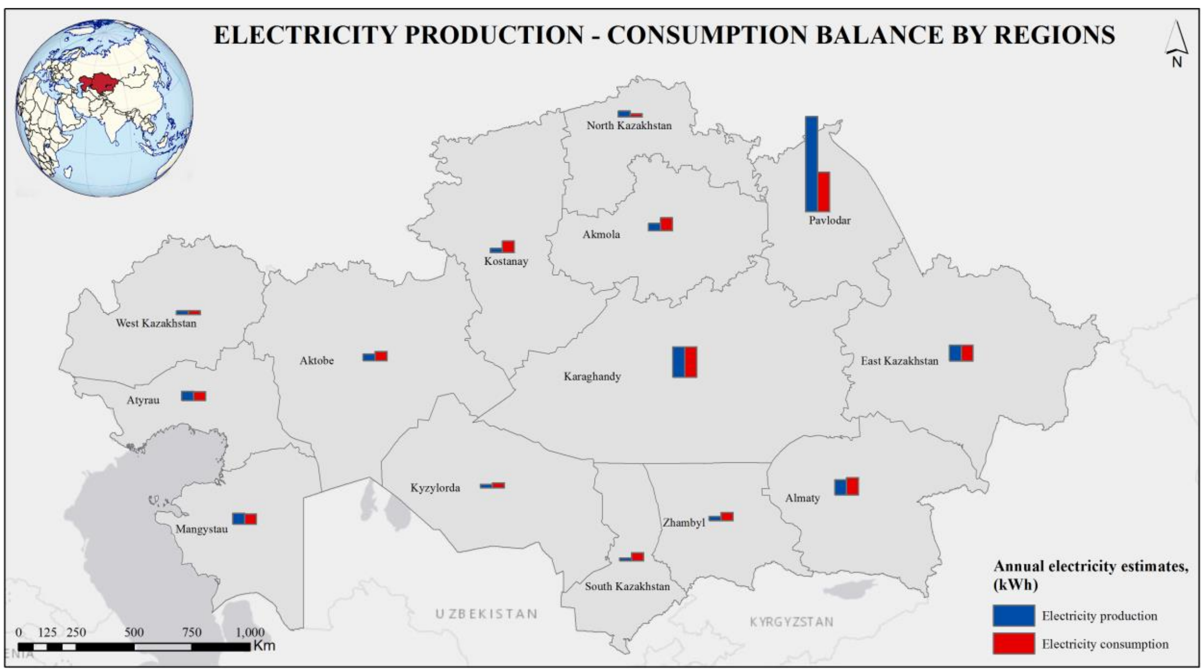

Figure 19. Balance between electricity production and consumption in Kazakhstan by regions (own graphics)

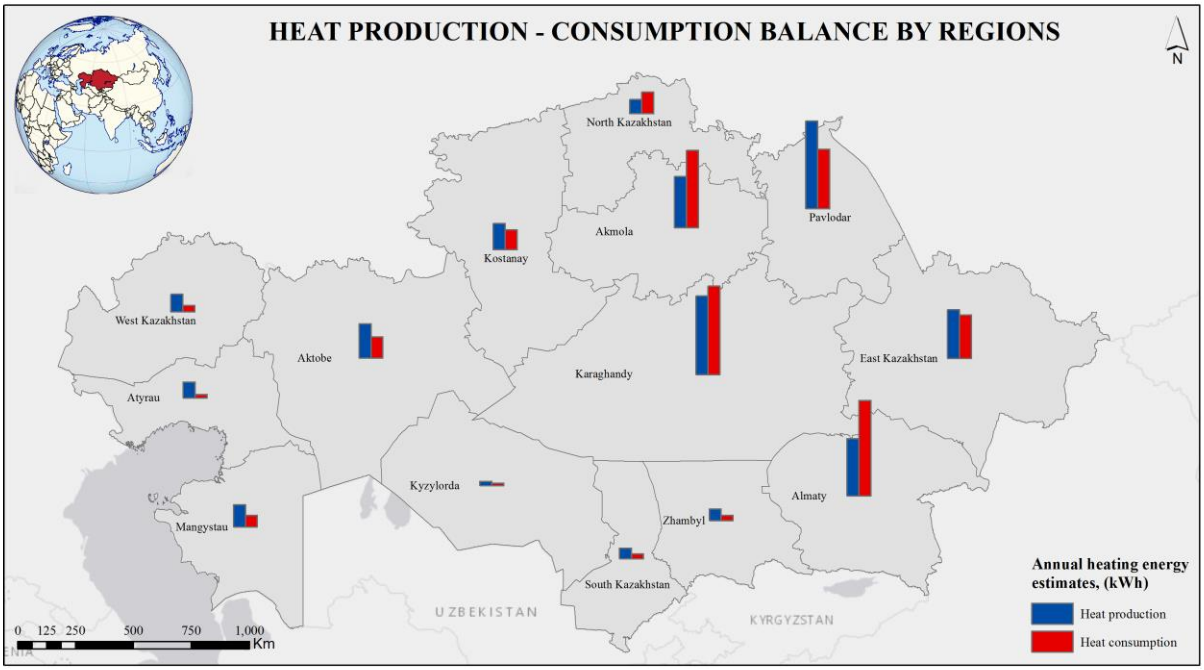

Figure 20. Balance between heat production and consumption in Kazakhstan by regions (own graphics)

Table 4 includes all the estimated energy potential values together with data from the Kazakhstan Agency for Statistics, which corresponds to energy demand and supply in each region. Obviously, the technical potential energy is much higher than consumption of power and heat together. Such a surplus is usually expected, when considering a limited number of constraints for energy potential evaluation. Nonetheless, these estimates can be useful information for decision makers and planners to see an evidence for a development of renewable energy in those regions with abundant renewable resources and deficit of energy production at the moment. Regions that have the biggest values of solar and biomass energy potentials are Karaghandy, Aktobe and East Kazakhstan. Furthermore, Karaghandy, Aktobe and Mangystau possess with the highest values of wind energy potential. Aktobe among the others does not produce enough electricity or heat to overcome the demand, but on the other hand, it is characterized by high solar and wind energy potential, which makes it an attractive target for improvement. An insufficient situation in heat generation in Karaghandy can be optimized by introducing bioenergy production.

Moreover, it is necessary to say that some regions have greater energy potential, because of their bigger areas, like in the case of Karaghandy. When looking to the different energy potentials on a regional scale, Figure 21 can show the most favorable energy type for every single region. There is a general trend that solar energy is prevailing in every region. The wind energy potential is smaller than biomass energy, however, I need to remind that estimated potential for biomass energy is only theoretical and it would be illogical to truly rely on this comparison.

Table 4. Indicators of existing energy system according to Kazakhstan Agency for Statistics and estimated potentials of renewable energy

Region	Electricity production, billion kWh	Electricity consumption, billion kWh	Heat production, billion kWh	Heat consumption, billion kWh	Solar energy potential, billion kWh	Wind energy potential, billion kWh	Biomass energy potential, billion kWh	Area, thousand km2
Almaty	6.5	7.4	10.8	18	392.50	24.24	218.28	225.33
Akmola	3.1	5.6	9.6	14.5	533.35	27.05	218.74	152.00
Aktobe	3	4	6.5	4	1025.52	42.45	369.46	335.04
Atyrau	4	3.8	3	0.7	198.80	21.67	118.72	137.99
East Kazakhstan	6.8	6.8	9.1	8.2	906.49	30.68	352.62	281.73
Mangystau	4.6	4.3	4.2	2.2	350.53	40.33	130.19	196.27
North Kazakhstan	2.6	1.4	2.7	4.1	259.73	20.30	169.86	102.14
Pavlodar	41	17	16.5	11.2	511.98	20.34	175.77	126.68
Karaghandy	13	13	14.8	16.6	1546.08	66.49	532.51	445.31
Kostanay	1.8	5	4.9	3.7	726.07	32.59	312.70	213.51
Kyzylorda	1.6	2.2	0.8	0.5	370.72	24.81	176.81	248.63
South Kazakhstan	1.2	3.4	2	0.9	172.85	12.04	128.44	122.43
West Kazakhstan	1.6	1.6	3.3	1.2	580.30	26.99	215.08	181.52
Zhambyl	1.8	3.5	2.2	1	179.75	17.45	145.82	145.12
Total	92.6	79	90.4	86.8	7754.66	407.43	3265.00	2913.71

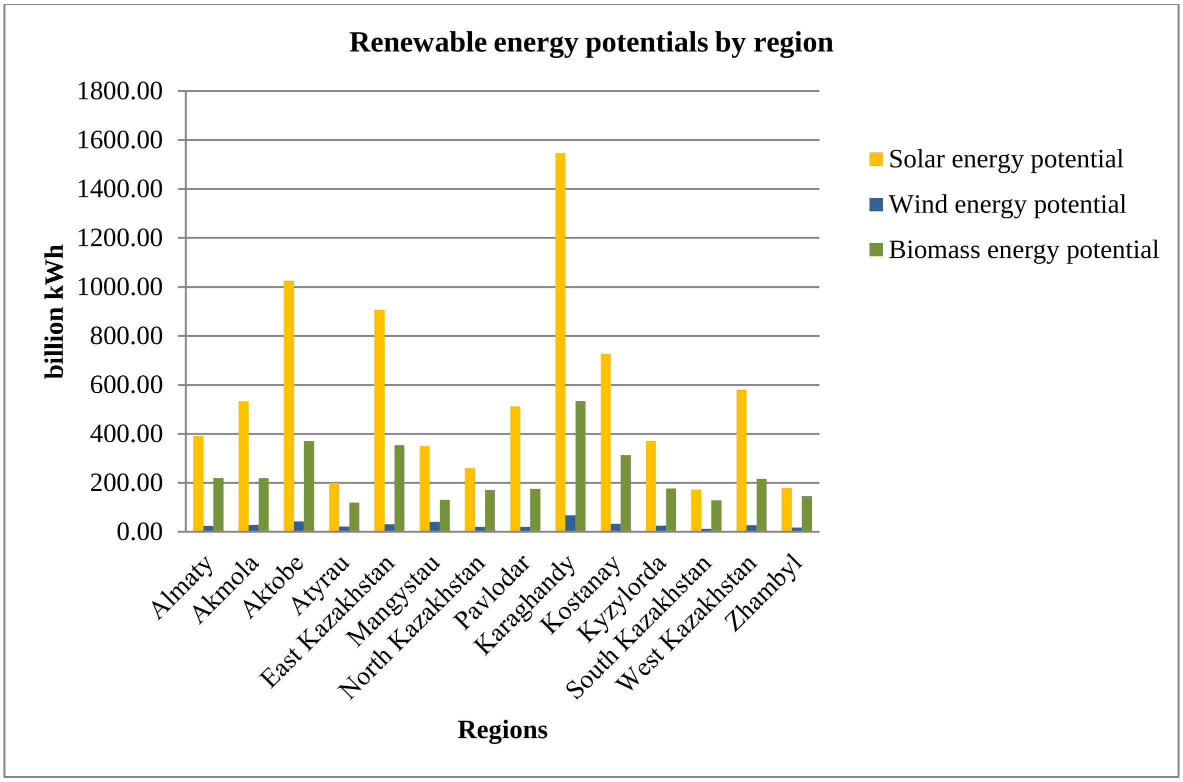

Figure 21. Solar, wind and biomass energy potentials by regions in Kazakhstan per year (own graphics)

4.3. VALIDATION

There are many approaches developed so far, which evaluate renewable energy potentials. They all share some similarities and differences. Even the definitions of theoretical, technical and economic potentials can be interpreted slightly differently by every author. Assumptions made from observations of existing renewable energy systems also differ depending on the scale and location of study area. All these circumstances make it difficult to validate the results. The common validation based on the comparison of estimates received from other approaches can lead to big discrepancies. Navarro, et al. (2016) applied several methodologies to estimate solar energy potential for the same study area. Some results exceeded for more than 100% the others. Moriarty and Honnery (2012) tried to compare published global estimates of technical potentials and concluded that the values span an enormous range. These uncertainties raise questions about practicality and value of the technical potential figure.

To validate the technical solar energy potential I compared the estimates with the results of research made by NREL (2008). They used the same approach, however, initial solar radiation dataset was different and the averaged conversion efficiency was assumed to be 10%. The result of presented work is 13.8% greater compared to the outcome of NREL (Figure 22). I suppose this dissimilarity is not serious on a scale of the whole country and the result can be valid.

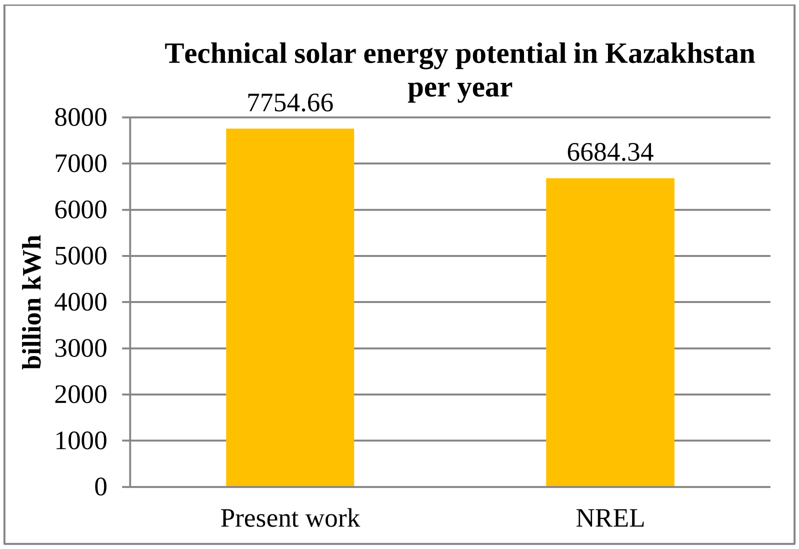

Figure 22. Comparison of technical potentials of solar energy for Kazakhstan (own graphics)

When talking about wind energy potential, it becomes a little bit more complicated, since there are many approaches, which uses different assumptions. I compared the results of presented work with predictions given in Clean Energy Info Portal (reegle) developed by Renewable Energy and Energy Efficiency partnership (REEEP). The portal provide energy profiles for every country. The predicted estimate of wind energy in Kazakhstan equals to 1820 billion kWh, which is 4 times greater than the results of this work (REEEP, 2014) (Figure 23). The difference can be explained by the divergence of opinions about types of potentials and requirements in order to evaluate them.

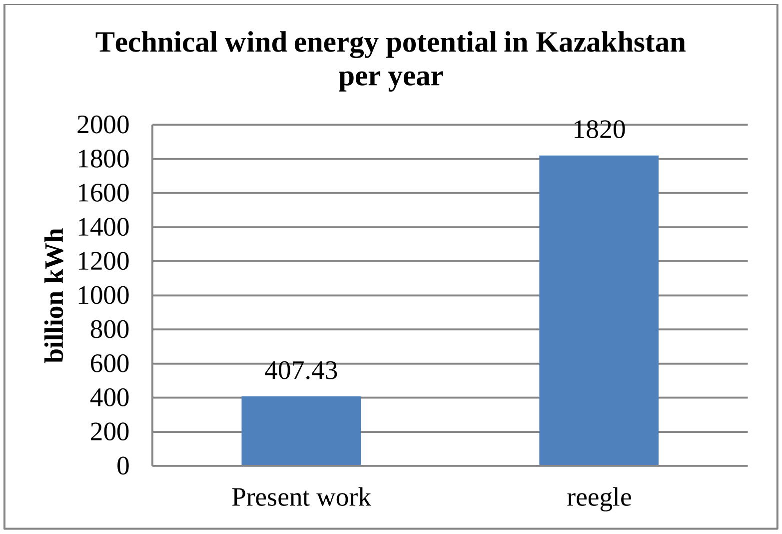

Figure 23. Comparison of technical potentials of wind energy for Kazakhstan (own graphics)

35 billion kWh of annual electricity generation potential from biomass was calculated by Energy Partner (2014), a company that provides engineering and consulting services in an energy efficiency sector in Kazakhstan. They also provided bioenergy potential estimates of 51.1 billion kWh for heat generation. These values together constitute 86.1 billion kWh of biomass energy potential. The calculated theoretical potential of bioenergy in this work differs significantly. It equals to 3265 billion kWh (Figure 24). The reason for the huge gap between these values is that estimated theoretical potential needs to be further constrained.

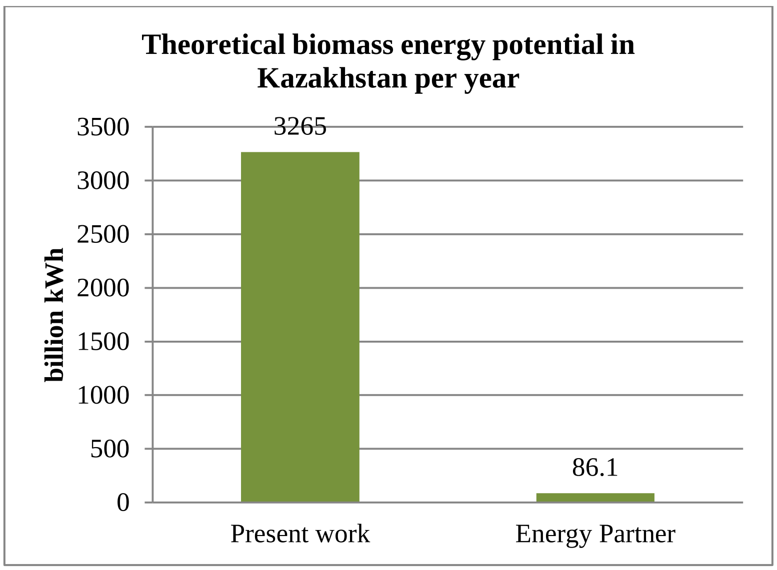

Figure 24. Comparison of biomass energy potentials in Kazakhstan (own graphics)

It is hard to validate final results with findings of previously published works, due to lack of information specifically for Kazakhstan. Only solar energy potential estimate can be proved to be within reasonable range since it is similar to the NREL results. I assume that more sophisticated approaches which include economic constraints and actual electricity and road networks approximation factors can output more reliable estimates. However, for the evaluation on a country scale, technical potential can help in delineating promising areas and finding regions where additional renewable energy can cover electricity and heating needs.

4.4. WEB MAP APPLICATION

The developed web map application is an interactive map where users have options to visualize three types of renewable energy potentials in Kazakhstan. A user interface is illustrated in Figure 25 and Figure 26. Depending on the level of detail the first form of data representation is raster map showing estimates per grid cell. The other one is vector map, where the cell-based potential values are aggregated for every administrative region in Kazakhstan. The user may check a description box for the region and see the information about energy potentials, existing energy production, and consumption values.

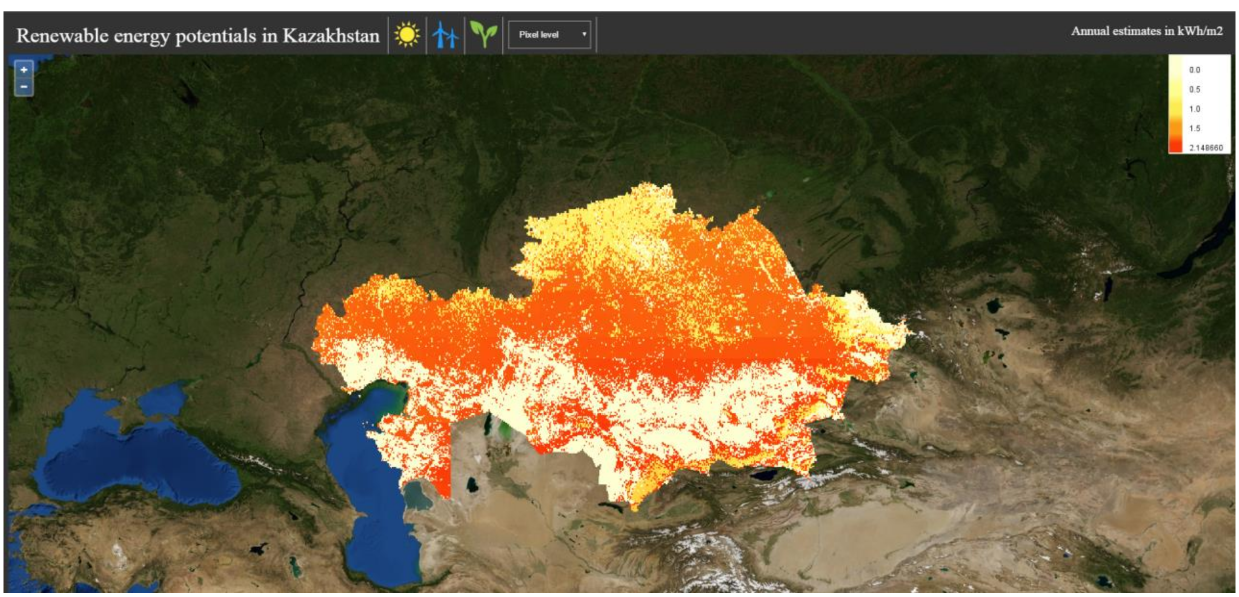

Figure 25. User interface of interactive map of renewable energy potentials in Kazakhstan, pixel level (own graphics)

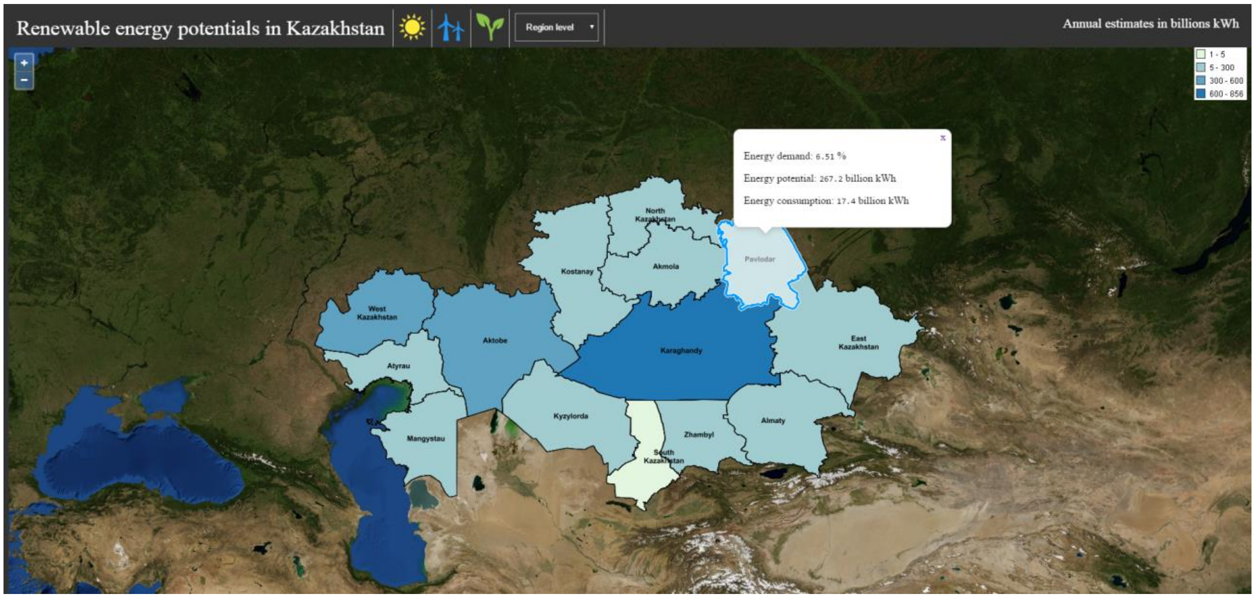

Figure 26. User interface of interactive map of renewable energy potentials in Kazakhstan, regional level (own graphics)

5. CONCLUSION

This work evaluated renewable energy potentials for Kazakhstan and compared the results with existing values of energy demand and supply. Kazakhstan retains the potential energy of all three types in different amounts. Solar energy is the most promising resource for electricity generation. Its highest values are located on the land with bare ground in the southern regions. Wind energy potential is characterized as being moderate up to 0.5 kWh/m^2, with peaks in the adjacent regions near the Caspian see. Theoretical potential of bioenergy is wide-spread all over the country and around 93.9 % of the entire area is suitable for the harvest of biomass in order to produce heat and power.

These estimates calculated with the assistance of GIS technologies and visualized on an interactive map can spot most favorable locations for discussed alternative energy resources within existing energy system. They do not show the final amount of energy that can be used by consumers; however, on the scale of a country, they may suggest the ways of solving the problem of high demand and low production of electricity and heat. Solar and wind energy installations can be the alternative options to traditional power generation systems. Products of bioenergy industry can replace coal for power and heat production at already existing facilities. If considering demand – supply energy system, the potential areas for renewable energy development can be shifted to the areas with the deficit of energy production. For example, spotted regions like Aktobe and Karaghandy suffer from deficit in energy production and at the same time they own the highest potentials of renewable energy.

As a subsequent step, the economic potential can be estimated based on the results of this research, which may precisely highlight the best areas to harvest any renewable energy without negative environmental impacts and considerable losses during their transportation. Economic potential may also distinguish ways of energy production with minimal costs to satisfy the increasing demand.

In general, I noticed drawbacks in a variety of methodologies, which differ in assumptions, leading to diverse results. The reason of this circumstance may be a relatively recent start of exploring alternative energy sources and the lack of data. It is also difficult to take into account constraints that may be specific to each region. For instance, land cover assumptions can have different values, as there are different laws and policies to land use from state to state. To find the most suitable approach to estimate energy of renewables specifically for Kazakhstan can provide more reliable information for planners and decision-makers.

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