Assessment of renewable energy potentials based on GIS. A case study in southwest region of Russia.

by

Alisa Melnikova (M. Sc., M. Sc.)

from Bendery, Moldova

Accepted Dissertation thesis for the partial fulfilment of the requirements for
a Doctor of Political Sciences (Dr. rer. pol.)
Fachbereich 7: Natur- und Umweltwissenschaften
University Koblenz-Landau

Thesis examiners:

Prof. Dr. Oliver Frör, Universität Koblenz-Landau, 1st examiner

Dr. Stefan Jergentz, Universität Koblenz-Landau, 2nd examiner

Date of the oral examination: 28.03.2018

Declaration

I hereby declare that I autonomously conducted the work presented in this PhD thesis entitled “Assessment of renewable energy potentials based on GIS. A case study in south-west region of Russia”. All used assistances and involved contributors are clearly declared. This thesis has never been submitted elsewhere for an exam, as a thesis or for evaluation in a similar context to any department of this University or any scientific institution. I am aware that a violation of the aforementioned conditions can have legal consequences.

Landau in der Pfalz, 10.04.2018

Place, date Signature

Acknowledgements

Foremost, I would like to gratefully acknowledge my supervisor Prof. Dr. Oliver Frör for providing me a chance to pursue a doctoral degree at the University of Koblenz-Landau. He has given me valuable comments on my study and supervised this PhD thesis. I am sincerely grateful for his patience, motivation and immense knowledge.

Furthermore, I am also very thankful to Dr. Stefan Jergentz for his support and valuable suggestions on my final thesis and being second examiner.

I gratefully acknowledge the scholarships, which gave me the financial support for 3 years of my PhD thesis, the DAAD (Deutscher Akademischer Austauschdienst) for the first scholarship from October 2014 to July 2015 and an additional scholarship from August 2017 to October 2017 as well as Lotto Rheinland-Pfalz – Stiftung Sozial-Stipendien for providing a 2-years scholarship from July 2015 to July 2017.

I would like to thank the project NAWI (Förderung für Nachwuchswissenschaftlerinnen) from IPZ (Interdisziplinäres Promotionszentrum der Universität Koblenz-Landau) for supporting me during the preparation and conducting my doctoral study with useful workshops, networking measures and funding for scientific activities: visiting conferences and summer schools.

Moreover, I acknowledge all my colleagues from the University of Koblenz-Landau, (particularly Dr. D. Elsaesser and A. Ampofo), from Karlsruhe Institute of Technology (K. Mainzer) and from the Moscow State University (especially J. Rafikova and Dr. S. Kiseleva), who gave me valuable comments and ideas during my PhD study.

Furthermore, I thank the partners from the industry and commerce brache: 1) SOWITEC group GmbH for the regular informational support and advices since October 2016 and 2) PFI (Prüf- und Forschungsinstitut Pirmasens e.V.) for the valuable support and information.

I am also very grateful for the administrative staff, in the first place Franziska Wollnik and Jone Kammerer.

Finally, I will forever be thankful to my family and friends, for providing support, understanding and friendship that I needed. I truly thank my mom and dad for sticking by my

side during all the times. Finally, the unique thanks should belong to my husband, making my study and life filled with great meaning and love.

Table of Content

List of Tables

Chapter 3

Chapter 4

Appendix

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Appendix

List of Abbreviations

ANP	Analytic Network Process
CHP	Combined Heat Power
CI	Consistency Index
CPS	Concentrated Photovoltaic Systems
CR	Consistency Ratio
CSP	Concentrated Solar Power
DB	Data Base
DSS	Decision Support Systems
EIA	Energy Information Administration
FIT	Feed-in-Tariff
GIS	Geographical Information System
GMS5	Geostationary Meteorological Satellite
GPP	Gross Primary Productivity
HPP	Hydropower Plant
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
MCDM	Multi-Criteria Decision Methods
METEOSAT	Meteorological Satellite
NPP	Net Primary Productivity
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RS	Renewable Energy Sources
RS	Remote Sensing
SWOT	Strengths Weaknesses Opportunities and Threats
TM	Landsat Thematic Mapper
UNEP	United Nations Environment Programme
VAT	Value Added Tax
WRF	Weather Research and Forecasting

Abstract

The continuous increase in energy demand and the related negative impact on the environment through fossil fuels has raised serious challenges. The renewable energy sources (RES) are increasingly considered as potential solution for a sustainable energy production and reduction of negative environmental impact. In the Russian Federation, the exploration and of RES potentials and the implementation of RES facilities is underdeveloped and requires research that is more active. Furthermore, the country is the fourth largest emitter of CO2 since the predominant share of the energy production is generated from fossil fuels.

The main barriers for the deployment of RES facilities in the Russian Federation are the lack of political, legislative and regulatory support, low prices for electricity and heat generated from fossil fuels, lack of information for decision makers (e.g. data from research projects) as well as the preference for centralized energy supply schemes. These barriers are contributing to an inadequate investment climate for the implementation of RES facilities. Nevertheless, in some regions of the Russian federation with a potential of RES and a comparatively low degree of economic centralization the situation is different.

In the present thesis, the initial conditions for the development of RES potentials for the production of wind, solar and biomass energy in the Krasnodar region (southwestern region of the Russian Federation) are examined using a multi-criteria assessment methodology. For the assessment of the RES potentials at regional scale, the prosed multi-criteria methodology based on the geographic information systems (GIS) and has been complemented by the evaluation and analysis of primary and secondary data as well as economic calculations relevant related to economic feasibility of RES projects. The Krasnodar region has been chosen as model region for other regions in the Russian Federation, Eastern Europe and the former Soviet Union that have unexplored RES potentials but lack sufficient data for the assessment of RES potentials in GIS. An innovative element of the proposed multi-criteria methodology is the combined assessment of the maximum available factors relevant for the economically feasible exploration of RES potentials. These factors included the energy status with the specific features of the energy infrastructure, the energy policy relevant for RES along with the market and economic conditions of the region.

The main objectives of the assessment of the RES potentials in the Krasnodar region were

1. to examine and present the energy status and the market conditions in GIS map as the essential conditions for an implementation of GIS facilities;
2. to calculate and present the available yield of wind, solar and biomass energy output through consideration of environmental and land-use restrictions reducing the theoretical resource potential, to the technologically and eventually the economically exploitable share of the initial resource potential;
3. to model energy scenarios and develop specific recommendations for and improved planning of future projects on RES in the study region.

The assessment of the theoretical and technological wind energy potential utilized GIS models on extrapolation of wind speed, on suitability class (optimal locations for installation of RES facilities), on wind power density and wind energy estimation. For the assessment of the theoretic and technological solar energy potential, the kriging model, the suitability class model as well as the solar energy estimation model were applied in GIS. The assessment of the biomass energy potential utilized net primary productivity (NPP) and statistic data on organic wastes organic and animal manure using the GIS generic model. Optimal locations for the installation of biomass power plants were identified using network analysis tools in QGIS.

The assessment of the technical wind energy potential in the Krasnodar region yielded an electricity production of 23 GWh year^{-1}. Taking into account all the environmental and infrastructural restrictions as well as the current market conditions, the technical energy potential was subjected to reduction to an economically viable share of 0.8 GWh year^{-1}. The total technical solar energy potential amounts to 24 GWh year^{-1}. However, the economically viable share of the solar electricity is 4.5 GWh year^{-1} due to economic restrictions. The assessment of the biomass energy potential yielded an electricity production from biomass residues of 25 GWh year^{-1}, which, however, was subjected to reduction to 4.7 GWh year^{-1} due to specific restrictions.

The calculated unit (kWh) generation prices for hypothetical energy production facilities in both rural and urban areas of the Krasnodar region were €0.15 (urban-utility scale) and €0.20 (rural-utility scale) for wind electricity, €0.16 (urban PV installations of up to 2 MW) and €0.25 (rural PV installations of up to 1 kW) for solar electricity, and €0.12

(rural-utility scale) and €0.14 (urban-utility scale) for biomass electricity. Compared to the current mean unit generation prices for electricity from conventional energy sources of €0.06 per kWh, the RES electricity prices are not competitive under the current regional and governmental energy policy. The recommendations provided in this thesis aim to highlight relevant support and measures to enable further development of RES potentials in the Krasnodar region.

Thus, due to the application of an integrative multifactorial GIS-analysis it was possible to comprehensively estimate the RES potentials in the present work. Detailed and step-by-step analysis of constraints, the energy situation, and the market climate made an in-depth feasibility assessement of potential RES projects in the study region. Thus, it was possible to answer the question why, despite the great potential of RES, there are no successful projects in the study region. As a result, reliable information about the RES potential in the region was provided, minimizing risks for investors and policy makers.

For other regions, the proposed multi-criteria methodology provides a multi-purpose approach for a complex exploration of RES potentials and their exploitation under specific environmental and economic conditions.

1. Introduction

Mitigation of climate change as well as meeting an ever-increasing energy demand of the global population are one of the most important challenges the world is facing today (Lindlein et al., 2005; Popel et al., 2010). The 1973 global oil crisis has revealed a vulnerability of the economy based on the fossil fuels extraction and has stimulated the research on renewable energy sources (RES) in its turn. The disasters at the Chernobyl nuclear power plant (NPP) in Ukraine in 1986 and the Fukushima Daiichi NPP in Japan in 2011 have set policy-makers from many countries thinking of energy and environmental security of current and future generations. Following these events, the inter-related issues on energy generation, ecology and economy are more actively discussed internationally. The resolution of these issues has been left to ecologically clean and cost-effective energy production technologies.

Renewable energy (RE) is receiving increasing attention for its clean, green, and safe characteristics. It drives the energy structure towards a sustainable level by providing a sustainable approach to energy generation (Elliot, 2000; Vera et al., 2007), and contributing to mitigation of the climate change in the long term. It also plays a vital role in the overall sustainable development strategy (Dincer, 2000). Geographic and topographic factors such as altitude, climate, and terrain conditions strongly affect spatial distribution of RES (Vettorato et al., 2011). Therefore, the exploration and supply of RE take place at local or regional levels (Sarafidis et al., 2009; Voivoitas et al., 1998). These features also shape RE supply networks to be distributed in decentralized forms making the planning of RE facilities a highly detailed issue.

Geographic Information Systems (GIS) have proved to be a useful tool for regional RE potential estimation (Gil et al., 2011; Arnette et al., 2013; Hoesen et al., 2010) and support for decision making in energy planning (Domigues et al., 2007; Voivoitas et al., 1998; Clarke et al., 1996). This is due to their flexible data management and spatial-temporal analysis capability (Figure 1.1). Furthermore, the visualization function of GIS can connect statistical analysis with visualized spatial data in the integrated RE planning approach. Visualization maps facilitate the understanding and decision making of policy makers, private investors and citizens. Besides that, web-based GIS application provide public platforms for information sharing and planning participation (Simao et al., 2009; Energy-Atlas Bayern, 2014).

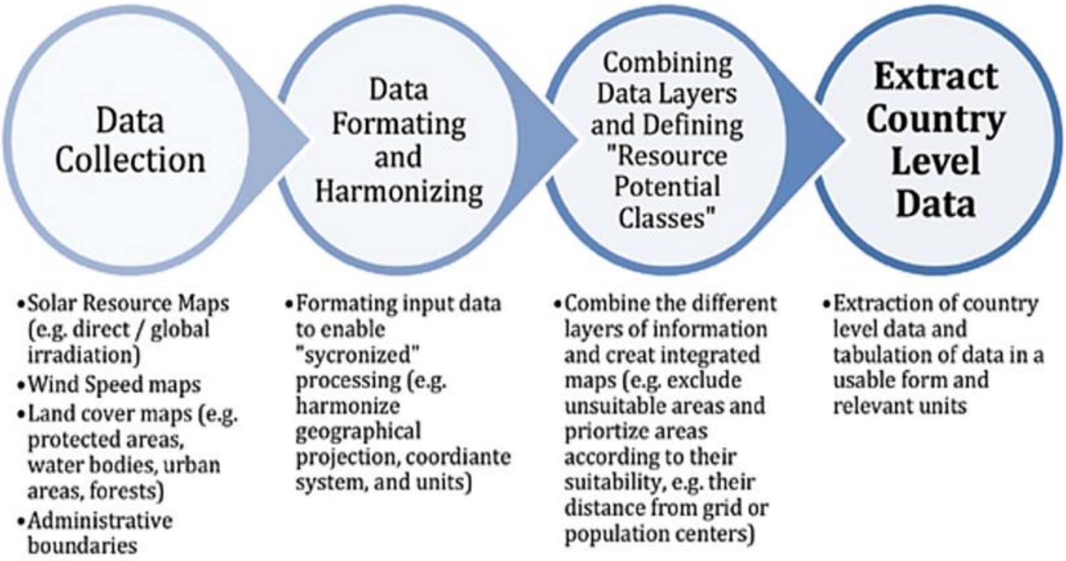

Figure 1.1 General structure of GIS data collection and management
According to International Renewable Energy Agency, IRENA and Sweden's Royal Institute of Technology (2016)

RES represent a wide range of resources and technologies for producing and converting energy into electricity, heat and fuel. Most of RES such as solar radiation, wind, biomass energy, hydraulic energy of rivers and ocean energy are of solar origin, while geothermal energy, tides, waste heat of anthropogenic origin etc. belong to "non-solar" RES. According to United Nations Environment Programme (UNEP), all the resources mentioned above may currently claim for an efficient application in various economic sectors (UNEP, 2004).

An effective development of RES is complex and requires a long-term strategy. Many studies rated the positive environmental effect from the implementation of RE technologies as the most significant among others (Şenkal and Kuleli, 2009; Qin et al., 2011; Miller, 2008). Besides the positive impact on the environment, using RES can satisfy ever increasing energy demand on both international and national level (Yue and Wang, 2006). Following global problems are the main incentives for exploring and developing RES worldwide (UNEP, 2004):

- **Energy safety**. The dependence of exporting countries on the level of extraction/consumption of fossil fuels as well as unstable cost of energy sources for exporting countries are key factors that may provoke economic crises.

- **Ecological equilibrium**. The global production and consumption of energy from hydrocarbon material is responsible for 50 % of all hazardous anthropogenic discharges into the environment including greenhouse gases.
- **Sustainable development strategy**. According to the forecasts, the global energy demand will increase more than one and a half times by 2025 mainly due to growth of in developing countries. In this case, an introduction of RES, which are able to self-restore may be the most effective solution in the context of the concern for future generations.

The RE industry employ ~7.7 million people worldwide (IRENA, 2015). The solar photovoltaic (PV) energy is the leader among RE industries by jobs (~2.5 million) while the People's Republic of China is leading among countries (~ 3.4 million) by the same indicator (Wang et al., 2014). In the U.S., wind and solar energy have become the most economical way of producing electricity (Lazard investment Bank, 2013). Only gas-based cogeneration could compete with them. The levelized cost of energy (LCOE) in wind energy has amounted to $32 – 77/MWh excluding subsidies in wind energy to $50 – 70/MWh and to $52 – 78/MWh in gas-vapor generation, while LCOE for gas turbine power plants ranges from $68 – 101/MWh.

The leading countries in energy generation using RES are Iceland (25% of RES in the energy balance; primary geothermal energy), Denmark (20.6%; primary tidal energy, wind and solar energy), Spain (17.7%; primary solar energy) and New Zealand (15.1%; primary geothermal and wind energy). In 2014, new investments in RES amounted to $270.2 billion being 17% greater than in 2013 (REN21, 2015). The People's Republic of China, the U.S., Japan, Great Britain, and Germany were the leaders by investment volumes.

According to the sources mentioned above, the ecologically clean energy market has been rap-idly developing, although it may be just a small share of the desired rate of development, which would mitigate climate change and offer equivalent replenishment of the energy demand. The given data may particularly fall short of such large countries as India, Russia, Canada, Kazakhstan and others. These economies are of chief interest since they require detailed and realistic study of the RE potentials from the level of technical evaluation to the economic efficiency, which could be rather difficult for a variety of the following reasons (Lazard investment Bank, 2013):

- The lack of sufficient technological, economic and energy predicted data to justify fundamentally the necessity of transition to RES;
- An inactivity of state and regional authorities, business community and population to implement technologies and advantages of using RES actively.

Thus, despite all obvious advantages, RES have not been evenly developed yet to compete with conventional energy sources to the utmost. There are many specific barriers (Figure 1.2) appearing already at the design stage and during the assessment of RE potentials. Hence, the risks of RE projects may be significantly underestimated without a high-quality RE potential assessment. The resource assessment should be available on a site-specific basis such as wind or solar atlases for an extended period (at least one year of reliable and verifiable data). Even then, risks of generation capacities and related revenues that are less than expected may remain.

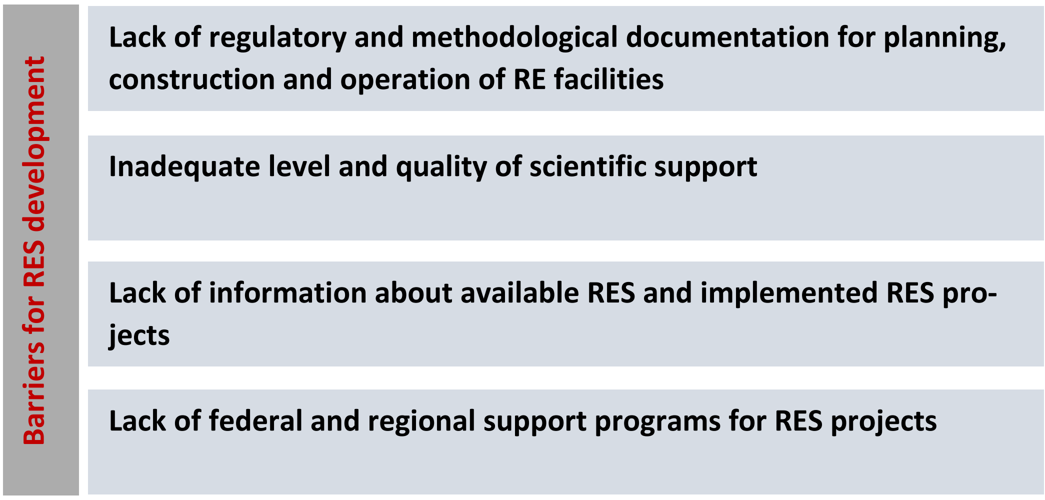

Figure 1.2 Main barriers for a successful RES development
Author’s compilation

As a result, only very little potential has been developed so far although many countries claim they have significant RES available. Despite extensive databases for the assessment of RES, the worldwide environmental, infrastructural, technical, and economic conditions for RES can be estimated with a high degree of uncertainty. The uncertainty is most pronounced in countries with relatively low rates of RES introduction (Taysaeve et al., 2009). There may be a unique set of factors for every study country and region which could raise barriers (an imperfection of the legal framework) on the one hand as well as offer prospects of innovative improvement of an energy system with the secondary power based on RES (decentralized energy supply) on the other (Buflasa et al., 2008).

The complex agenda of a study may set a thorough prerequisite for employing a multi-criteria assessment approach. Correspondently, the approach should evaluate prospects and possible scenarios for RE introduction starting from the engineering infrastructure stage until the commercial one. Integration of spatial data using GIS may be the prime advantage of a multi-criteria assessment, which could be particularly beneficial for the distance assessment of RES potentials of other countries. This may allow keeping the research at the desired level whatever the region for RE potential assessment would be as well as may save on expensive field measurements thus reducing risks for investors interested in reducing uncertainties by means of an integrated assessment of the potential for introducing new energy sources.

The selection of a model region is a necessary criterion for employing such a multi-criteria assessment approach. The model region should be located in a country where the issues of RES introduction have not been explored well yet, and so the possibility may exist of conducting an integrated analysis in the RES establishing region.

For years the RE sector has been developed poorly in some countries losing leadership positions in a number of directions. The development of an integrated methodological approach for the assessment of RES potentials assessment in particular regions of countries with insufficient initial data as well as its adaptability to specific conditions of the preselected territory may offer a promising potential for developing this research area. This may also allow representing the analytical tool useful for policy-makers, investors, developing companies and other interested parties in an accessible way.

Outline of the thesis

This consists of five chapters.

Chapter 1 (**Introduction**) describes the motivation of the thesis, the concept of the RE potential as well as the current global introduction of new RES capacities. Furthermore, the chapter gives a brief outlook of the RES development situation and energy policy in the energy sector.

Chapter 2 (**State of the art of using GIS for the assessment of RES potentials**) gives a review on the ongoing research on RES development along with GIS methods for the assessment of wind, solar and biomass energy potential. Furthermore, an introduction of the selected study region and the research questions addressed are given. The chapter introduces the Krasnodar region (Southern Federal District of the Russian Federation) as the model region for employing the proposed multi-criteria assessment approach on evaluation of RES potentials. The Krasnodar region is a popular tourist and recreational area. Having a rapid infrastructure and economic development, the region has the largest shortage of electricity in the country. To satisfy the ever-growing energy demand, RE technologies receive much attention.

Chapter 3 (**Methodology**) describes the multi-criteria assessment methodology proposed to answer the research questions of the thesis. The following assessment steps represent the sequential order for the evaluation of wind, solar and biomass potential as **theoretically**, **technically**, and **economically exploitable**:

(1) Assessment of the energy situation in the study region;
(2) Assessment of limitations and buffer zones restricting RES introduction;
(3) Evaluation of the available technical potential of RES;
(4) Evaluation of the economic and market potential of RES introduction;
(5) Modelling of development scenarios of RES introduction in the study region.

This thesis, thus, presents a multi-source approach in support of spatial planning for RE exploitation at the regional level. It aims to establish an elaborate informative procedure, as well as integrated quantification and visualization via GIS maps, to support decision-making.

Chapter 4 (**Results and discussion**) presents the main results of the multi-criteria assessment of available RES and the potential for their exploitation in the study region. A sensitive suitability analysis for identification of land-use classes appropriate for RES development demonstrates potential location for installation of RES facilities. Furthermore, the energy situation in terms of energy production and consumption for the years 2014 – 2017 as wells as the energy infrastructure is presented. The multi-criteria assessment approach, thus, takes a step further from the previous research in RES that focused on GIS-based identification of a realistic potential based on static mapping of RES in GIS.

The proposed methodology provides an approach that facilitate establishing local GIS databases and handle efficiently heterogeneous open data. The results of the multi-criteria assessment energy actor with information that determine the existing opportunities and support RE planning process. This is through the provision of quantification and visualization of information on regional potentials and restrictions, to different energy stakeholders such as the energy policy makers, investors and local authorities. Moreover, the approach presented in this thesis can serve as an example applicable in other regions to help in building a safer and sustainable energy system.

In this chapter three energy scenarios will be given demonstrating possible pathways of RES development and recommendations, which will propose concrete measures towards RES implementation in the energy system of the Krasnodar region.

2. State of the art of using GIS for the assessment of RES potentials

GIS are currently being broadly used to analyse the potential for RE as a source for producing electricity and heat (Droege, 2006). Many GIS models are being developed to facilitate planning of renewable technology to replace or complement existing fuel sources or to be introduced in rural areas without any electrical infrastructure (Clarke et al., 2006). There are analytical tools advantageous for use by policy-makers, utility companies, planning commissions as well as environmental, economic and energy technology researchers. It should be noted that the assessment of RES potentials generally leads to a systematic reduction of initial values of the theoretic potential to eventually calculate technical, economic and market potential values (Figure 2.1).

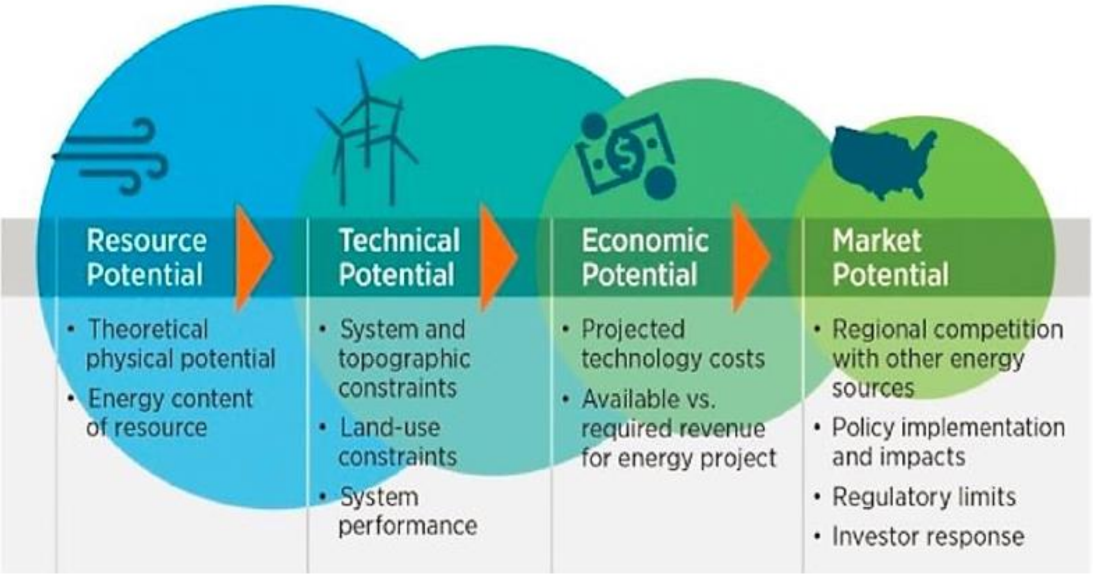

Figure 2.1 Decrease the initial potential of RES by every assessment stage
NASA, NREL (2015)

At the regional level, several traditional techniques have been applied in RE planning. These include Multiple-Criteria Decision Analysis (MCDA) (Pohekar et al., 2004; Beccali et al., 2003; Tsoutsos et al., 2009; Loken, 2007; Terrados et al., 2009), Delphi surveys (Celiktas et al,. 2010; Shiftan et al., 2006), and participatory approach (Neudoerffer et al., 2001).

There are also a few methodologies and empirical studies on RE planning in literature. Terra-dos et al. (2009) proposed a combined methodology for RE planning; a hybrid composed of Strengths Weaknesses Opportunities and Threats (SWOT) analysis, MCDA, and Delphi methods. Sarafidis et al. (1999) established a planning approach for RE that compared energy demand estimation and RES potential estimation to identify the most effective exploitation of RES in the study regions. Droege (2006) introduced a framework and several tools to help in building a renewable energy system at the city scale. In planning practice, an aim to achieve 100% energy self-sufficiency through RE supply has been a common trend among European municipalities (REN21, 2015). Some of them such as Mauenheim (Germany) and Gussing (Austria) have achieved or will achieve energy autonomy in the coming decade (Takigawa et al., 2012). Nevertheless, RE planning application has often been limited to district, community, or city scale (Stremke et al., 2010). Previous research has focused on estimation (Hoesen et al., 2010; Yue et al., 2066) and mapping (Ramachandra et al., 2007) of RES, whereas energy self-sufficiency analysis based on demand-supply prediction at the regional level has been lacking.

It is obvious on the one hand that mass data covering natural resources of the territories as well as economic characteristics of the region (energy infrastructure; energy balances; power lines; the presence of timber, woodworking, food and other industries enterprises; agricultural industry characteristics etc.) may be necessary for the regional level approach. On the other hand, it may be necessary to invoke those analytical tools that would allow collecting, promptly updating and mapping this mass data as well as displaying it; obtaining meaningful estimates on their basis and making calculations by means of an integrated analysis.

An important point is that an end user may be more interested in integrated assessments by different energy sources. The use of hybrid power plants or development of several facilities (plants) based on different types of energy could be the most effective in specific regions. A further challenge is the incorporation of the spatial nature of energy systems, considering not only energy-related parameters, but also geographic and economic ones. This requires the integration of energy system models in GIS. However, this integration is not trivial for several reasons:

(1) Modeling of energy systems and geospatial analysis processes is highly complex in terms of the combination of numerous model parameters to approximate the model to the real world without too much simplification (Van Hoesen et al., 2010);

(2) Computational requirements for integrating the geospatial dimension into energy system models are enormous, due to increasing complexity of models and high

amount of datasets necessary for fine-grained results (Droege, 2006). However, geospatially and temporally fine-grained analysis results may constitute the major advancement over previous approaches that mostly either operated on a regional resolution or just examined a small area of interest;

(3) Integration of a variety of heterogeneous data structures and formats poses a major challenge in integrating energy system models and GIS (Schoof et al., 2013).

Thus, this chapter analyses previous research efforts in the area of RE system modeling and planning with GIS-based approaches.

2.1 Geospatial data selection

Spatial analysis with GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task. A thematic map has a table of contents that allows the reader to add layers of information to a base map of real-world locations. Maps can be divided into one-component (only one type of RES is considered: sun, or wind, or biomass etc.) and multicomponent (containing several RES) by themes (Szentimrey et al., 2007; Höhn et al., 2014). The initial data used for RE projects can be divided as follows:

- The long-term performance of RES (e.g. meteorological and actinometrical[1] data; a description of water wells with data on physical and chemical characteristics of geothermal fields; hydrologic data; data on industrial and human wastes, population etc.).
- Technical characteristics of facilities based on RES (to calculate the estimated electricity production).
- Economic aspects (price for the energy from conventional and non-conventional sources (for comparison); energy balances of the regions; enterprises and manufacturing power plants based on RES; investments in this sector, tax privileges on the use of RES, employee salaries at facilities based on RES, etc.);

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[1] Actinometrical data - a data of several radiometric instruments, such as a pyrheliometer, which used chiefly for meteorological measurements of terrestrial and solar radiation (Kalitin, 1978).

- Social aspects (the employment rate and jobs available due to the construction of facilities based on RES; a relation between new jobs and the predicted amount of the produced energy; reduction of negative factors affecting a population health by the reduction of pollutant emissions; an aesthetic acceptance of new energy sources in the landscape etc.);
- Environmental aspects (the pollutant reduction value when RES are used: reduction of soil and water contamination as well as radiation level etc.) (Szentimrey et al., 2007).

Thus, the availability of baseline geographic information in the form of prepared atlases or separate raster layers for further processing and analysis may be the basic problems faced by the researchers while using GIS in RES potential assessment. We shall consider in detail geo-spatial data resources used as an initial basis by many research and design organizations.

International Databases (DB) covering territories of different scales (NASA, WRDC, SOLARGIS, PVGIS and METEONORM) developed in the last two decades could be considered as products performing functions similar to GIS but providing mainly just an information basis for further analysis. Some of them are available via the Internet while the others may be commercial products. The mentioned DB, being in essence climate databases, offer initial mass data which may allow conducting quantitative assessments (or qualitative characteristic) mainly of solar and wind energy sources as well as modelling the functioning of proper plants and systems. Surface measurements data as well as the results of the satellite monitoring and modelling (models of general atmospheric circulation and solar radiation propagation in the atmosphere) may form the information basis for them. A number of BD contains terrain relief and site maps.

The open GIS Database 3TIER Renewable Energy provides the FirstLook service of initial potential assessment of three RES: wind, solar and water flow. It may allow making some conclusions on performance potential of this software. Wind energy sources assessment is based on observation data and numerical modelling of atmospheric circulation considering the terrain relief and surface properties. Spatial resolution of the model may amount to 5 km. Data for the model calculation may be taken from open meteorological information sources. The difference between surface measurements and model forecasts for wind energy assessment may be less than 0.5 m/s at 50% of observation stations and less than 1 m/s at 78% of stations.

Solar energy sources potential assessment may be carried out on the basis of the results of satellite monitoring and modeling. Similar approaches have been taken while evaluating incident solar radiation in NASA SSE Database which is the most in-demand both amongst some users and RE software. The user is not furnished with information on initial data to construct models of water energy resource endowment.

The National Renewable Energy Laboratory (NREL), a division of the U.S. Department of Energy has many objectives. They have the mission to develop technology associated with renewable energy, advance the related science and engineering, and transfer knowledge into innovations that can address the country's energy goals. While they are involved in many different areas of renewable energy and even help manage projects around the world, they also research and produce GIS data to be used by other investigators. This free GIS-ready data describes the potentials for solar, wind, biomass, and hydrogen production around the country. These maps are all completed and in raster format for the western part of the U.S. now with the goal of having the entire country finished soon (NREL, 2013). They also provide GIS data about the emergency management system and the existing infrastructure of the electrical grid. To go along with this data, NREL provides a free downloadable GIS Toolkit that provides many analytical tools specifically designed for energy production analysis.

Since 2011, free downloadable GIS Toolkits have been available at NREL official site not only for USA, but for Afghanistan, Bangladesh, Bhutan, Brazil, China, Salvador, Ghana, Guatemala, Honduras, India, Nepal, Nicaragua, Pakistan, Shri-Lanka and Turkey as well. There may be an insufficient number of GIS analogues on RE in CIS countries including Russia. However, GIS projects on water resources for several regions, the Atlas of solar energy sources in the territory of Russia and climate databases from observation stations have started a work along this line (Gridasov et al., 2011).

For instance, the Russian Wind Atlas based on surface meteorological observations was released in 2000 by the Russian-Danish joint team of authors (Starkov et al., 2000). The issue contains rather lengthy statement of methods for wind energy sources assessment developed by Risø National Laboratory for Sustainable Energy (Technical University of

Denmark), a Danish scientific organization, and considered de facto to be the commonly accepted (but not indisputable) calculation tool in wind energy.

However, the issue cannot be considered as a rigorous atlas since it does not contain any map of wind speed distribution nor other wind regime parameters. The set of qualitative and numerical characteristics, which could allow determining wind energy characteristics at weather stations sites is given for each of the selected weather stations in the territory of Russia:
(1) Location of the station,
(2) Rate and specific power of air flow (Wm^{-2}) at different heights (10, 50, 100, 200 m)
(3) Repeatability of wind speed from various directions,
(4) Total wind repeatability as well as a wind rose,
(5) Surface characteristics (e.g. roughness factor, characteristic roughness height).

Current projects describing RES potential characteristics may be distinguished by the considerable map generalization, often due to a small scale. Hence, they may provide just a limited capacity to estimate solar, wind and other energy sources. Such parameters as non-uniform distribution and poor accuracy of data may deteriorate the value of the presented maps in the context of further resource potential assessment. It is of importance that a number of maps have been constructed on the basis of observation sites distant from each other, which could raise difficulties during further analysis. The uncertainty of a result unknown in advance could particularly complicate the analytical process in this instance. No robust qualitative model can be constructed on the basis of such data, and so no rather specific forecasts on RES potential can be made.

2.2 Multi-layer approach

At present, interactive maps based on Google Maps depicting energy source potential of various RES for several countries have been constructed. However, most of the maps represented today may not contain all the assessment stages in totality (e.g. RES infrastructure, economic and market potential), which could render it difficult to assess risks for investors as well as create some degree of uncertainty for RE development. This may be probably due to the fact that scientific organizations from different countries are involved in the project carrying out the development at the individual regional level without

RES integrated assessment. Thus, a scheme which can allow processing mass data as well as selecting step-by-step the required study regions may become a necessity for GIS multi-criteria analysis. Such scheme may contain several map layers and process mass data in steps (Figure 2.2).

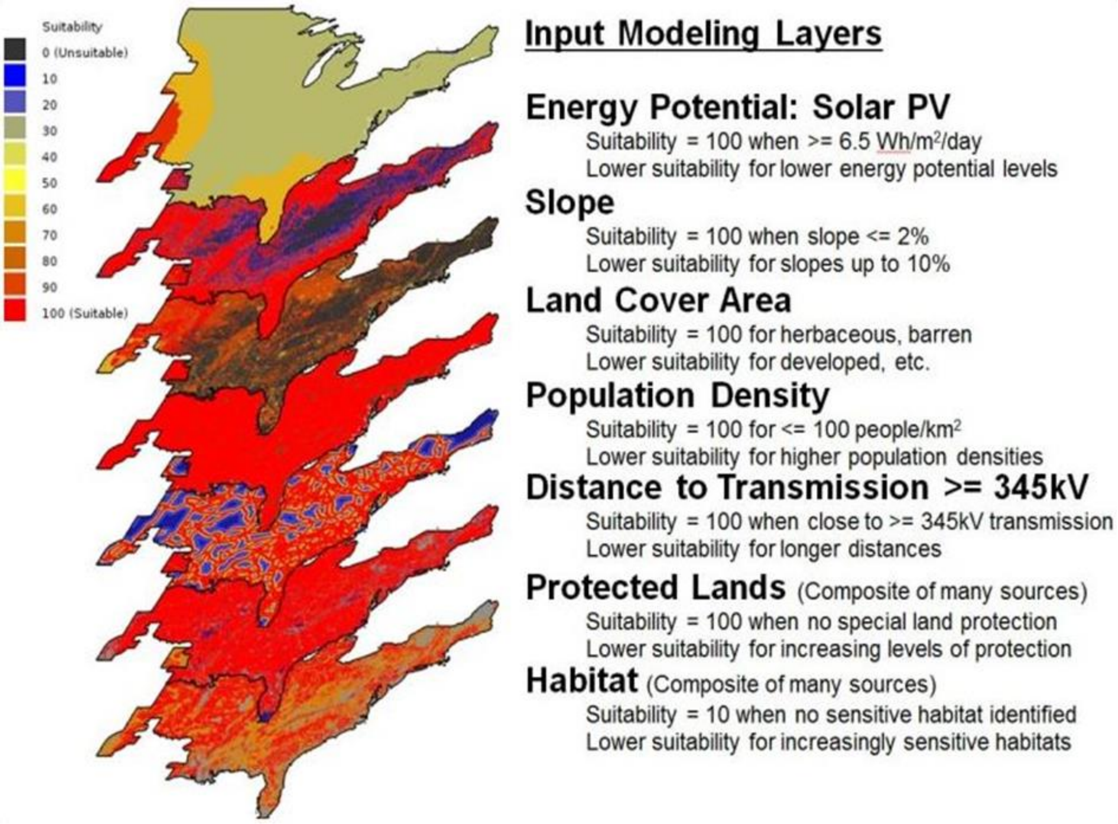


Figure 2.2 Sample model input layers and screening criteria for utility-scale solar photo-voltaic power suitability model
Argonne National Laboratory, (2014)

There are numerous examples where GIS have been used to support the planning process of renewable energy infrastructure. Especially, the identification of suitable locations for wind and solar farms, pump storage hydroelectricity (Blarke and Lund, 2008; Connolly et al., 2010), as well as the mapping of renewable energy resources, including solar photovoltaic, wind, geo-thermal, biomass and hydro-electricity (Sliz-Szkliniarz et al., 2011; Van Haaren et al., 2011; Schardinger et al., 2012), have lately been widely explored. These studies employ geospatial data on land use, elevation, buildings and infrastructure.

Aydin et al. (2005) introduced a methodology based on GIS, fuzzy set theory and multi-criteria decision making for finding the optimal placement of a hybrid wind-solar-photo-voltaic (PV) RE system, which can potentially reduce the need for energy storage. The main argument of the authors is that, depending on weather and climate conditions, one renewable energy source is complementing the other.

However, this methodology may only be applicable if enough space for power plants is available, which is hardly the case, for instance, in densely built-up urban environments. An additional limiting factor is that parcel or building owners can decide individually whether and how to use renewable energy. Thus, the individual use of renewable energy sources is oftentimes predetermined in that possible locations for setting up renewable energy power plants are rare in dense urban areas. In a similar way, Omitaomu et al. (2005) describe an adapted GIS-based multi-criteria decision analysis approach to determine the suitability for new power generating sites. The methodology considers environmental, geological and socio-economic aspects, amongst others. Although this GIS-based approach is designed to work at large scales, it is spatially explicit in that it divides the entire area of the USA into millions of 100 m by 100 m cells and computes the suitability of each cell for new power generation sites. Significant drawbacks of approaches like (Gret-Regamey et al., 2011) include the lack of ability to consider more dynamic spatio-temporal aspects across different spatial and temporal scales, or the lack of inerrability of topological aspects of the underlying energy network as regards the balancing of extraordinary peaks in energy load shifts across spatially explicit cells.

The International Renewable Energy Agency (IRENA) has been developing the Global Atlas for Renewable Energy since 2013. Regional mapping of the wind, solar, geothermal, tidal and biomass energy potential is one of the main objectives of the project. The addition of new layers such as economic and potential as well as buffer zones (restrictions) is being initiated gradually. Such criteria as market potential or energy infrastructure assessment cannot be observed there due to the large scale of the project. Such data may require very detailed regional information.

The innovative approach in the present work is that accounting of market conditions together with the energy situation assessment produce a correct description of implementation conditions thereby minimizing risks associated with RE projects. Recent studies (Omitaomu et al., 2005; Van Haaren et al., 2011; IRENA, 2013) have confirmed, that results of the above mentioned approach are mandatory for a correct assessment of the real implementation potential of RES. Nevertheless, none of the represented researches or atlases may allow conducting integrated analysis of the territory from the perspective of technical and ecological potentials as well as in the context of economic and market criteria in total. These objectives may remain vitally important despite the developed cartographic materials to date.

2.3 Scale determination

Data development as well as database nomenclature select and initial data resources analysis may be one of the first objectives while developing GIS. It is advantageous to select the correct scale due to the resource heterogeneity and the necessity to map their characteristics with various densities (Figure 2.3). Modeling an energy system requires a high variety of different base data (Gret-Regamey et al., 2011; Gormally et al., 2012). For many regions, datasets like energy production, installed PV power plants or population densities are available on a community level (Adams et al., 2006; Ostergaard et al., 2011). Depending on the data provider and the original usage and purpose of the data, a broad variety in the scale can be expected. For in-stance, data at the level of individual buildings have a high accuracy. A disadvantage at this scale, however, is that the data tend to be commercial and costly.

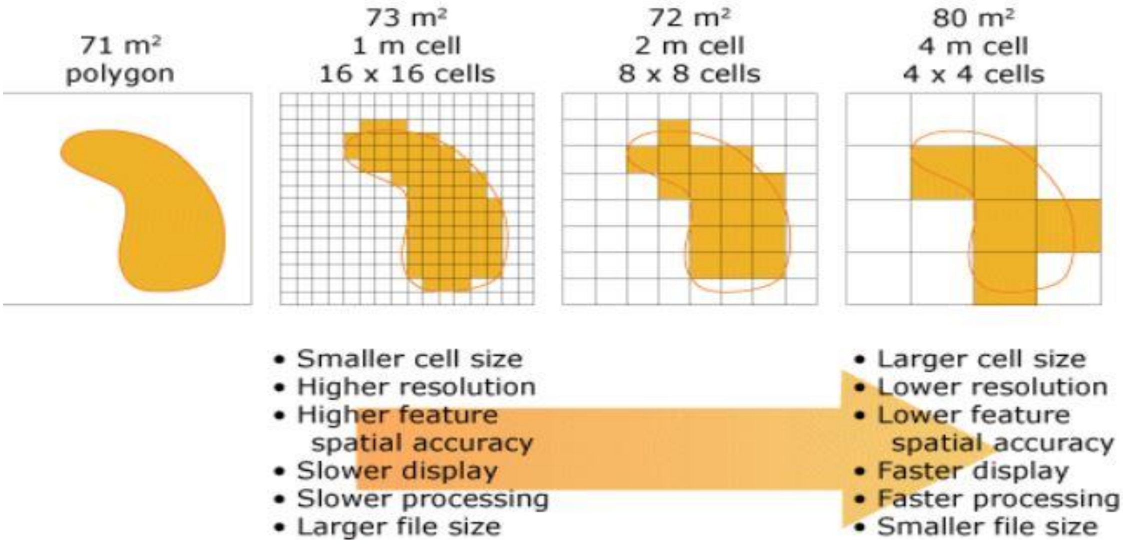


Figure 2.3 Comparison of small and large cell sizes
ArcGIS tutorial (2009)

Furthermore, some of the desired attributes might only be partly available. At this level, privacy issues are often of concern. When moving towards the block and postal code level, a loss in geospatial accuracy is expected (Hargreaves et al., 2012). Depending on the purpose of the study (e.g., a general estimation of the heat demand for a possible expansion of the district heating grid), this level may still be appropriate. For other purposes (e.g., a more exact positioning of decentralized energy storage facilities), this scale may be too coarse. As a consequence, when coupling energy planning and GIS, there are at least three reasons why one would have to work on different spatial scales and to aggregate or disaggregate the data:

(1) Common scale (e.g., building level or district level) for all data is required for the analysis or validation of the results;
(2) Faster computing time is desired;
(3) Consideration of data privacy aspects are required.

Hence, it is essential to apply methods that can store and process data at different scales. One option is to apply a geospatial database having a hierarchical structure in which the smaller units all are part of larger units as demonstrated by Tenerelli and Carver (2012). The data of the smaller units (e.g., districts) could then be aggregated to larger units (e.g., states) based on SQL queries. The same principle can also be applied to scales of finer resolution, including city district, housing block, street sections and individual buildings, among others. Another option for aggregation is to apply a regular grid on a lower resolution than the original data, e.g. 100 m x 100 m for the modeling and visualizing of energy demand (Fernández-Jiménez et al., 2002).

Nevertheless, scale selection may be difficult in some instances due to data heterogeneity and, more precisely, to the significant difference in their mapping accuracies. This problem is especially typical for describing RE potentials of entire countries since different regions may have split-level initial data (Fortov and Popel, 2015). For example, if the level of detail in one region could attain accuracy of the energy consumption at the level of individual building, then it would be the whole city without further differentiation by districts or industrial areas in another region. Thus, it may be particularly significant to make sure before starting RES potential analysis that the same scale could be kept within one assessment stage at least, e.g. energy infrastructure (Latinopoulos et al., 2015).

2.4 Energy situation and energy infrastructure assessment

The value of using GIS-based approaches for solving questions in the renewable energy domain have been proven in a number of research projects, including technical potential assessment (Grassi et al., 2012), energy consumption modeling (Rodríguez-Hidalgo et al., 2012), planning of specific energy infrastructure projects (Zhou et al., 2013) and site planning for renewable energy power plants (Van Hoesen et al., 2010).

Medrano et al. (2008) already stated that, with respect to sustainable energy infrastructure planning, standardized interfaces and GIS enable interoperable data exchange among specifically designed energy models, thereby fostering GIS as being an integral component rather than a spatially-aware add-on. Currently, one of today's essential overarching problems in using GIS in renewable energy infrastructure planning projects is the lack of relevant geodata or deficient data quality. The lack of geodata is primarily rooted in three main reasons.

- Valuable datasets, such as energy and heat demands, energy production, types of home heating systems, line network structures or energy and heat grid topologies, are mostly owned by energy providers and distribution network operators, who are often not willing to provide these data to external institutions;
- Many energy datasets, such as network topologies, have no explicit geospatial reference;
- The inhomogeneity in the levels of detail and the non-area-wide availability of specific energy-relevant parameters are a central challenge in the context of the geospatial analysis of energy systems. For instance, the number of floors in buildings is hardly available for all buildings within a study area, although it would be significant for the energy demand calculation of individual buildings. This is specifically true if the study area crosses several administrative borders involving different public institutions providing the data (Frid et al., 2011).

However, highly informative analysis requires more data and more advanced analysis methods. For instance, Kucuksari et al. (2014) propose a framework that incorporates GIS, mathematical optimization and simulation in order to find the optimal size and the optimal location of photovoltaic plants for campus environment. The GIS module serves for identifying appropriate rooftops and their photovoltaic panel capacity. However, this approach is purely based on static geodata (in this case, light detection and ranging (LiDAR) data) and does not account for dynamic geographical variables, such as weather conditions, in general, or solar radiation and wind meteorological data particular.

Coupling GIS with energy system modeling is also applied in the field of hydrogen supply, demands and infrastructures. Strachan et al. (2009) present an example of such an approach that is anchored within an economy-wide energy systems model of the U.K. For the German hydrogen economy, Ball et al. (2007) introduce an optimization approach for accessing the geographic and temporal aspects of a hydrogen transport infrastructure configuration. The outcomes of both studies reveal that the use of GIS is crucial when exploring the impact of the geospatial dimension of hydrogen networks and the increasing changes in energy generation mix on future energy system infrastructure and supply chains.

Sorensen et al. (2008) describe the process of measuring the potential of renewable energy production by solar, wind, and biomass in Denmark. The authors used the UN population data to determine the population and renewable energy potential in each of 0.5 km x 0.5 km latitude/longitude grid cells. This was done including topographical features, annual rainfall, and the demand of energy. All of these factors can be analysed together in GIS with the same geographic location in common to determine the best energy source for each energy project in question. The authors attempted to use current energy standards to determine energy demand for 2050 to see if renewable energy would be sufficient or if other sources would be necessary to satisfy the demand. The results of this analysis were not advanced enough to answer the proposed questions, but provided a start to the data collection and theoretical work necessary to answer it.

Computer aided analysis of integration of renewable energy systems in remote areas has been proposed by Muselli et al. (1999). In the proposed methodology a different perspective was taken to create data layers for electricity grid set-up, potential for solar energy, and topographical features on the ground surface. The authors used this information to analyze the most cost effective means of providing electricity to Corsica farmers that are currently lacking either existing infrastructure or decentralized electric production. For domestic use of less than 10 kWh per day and night, it was determined that decentralized power generation using a combination of photovoltaic cells and batteries was a more cost-effective solution than extension of the grid network to these houses (Muselli et al., 1999).

Spatial Analysis of Rural Energy System was investigated by Pokharel and Shaligram (2012). The authors created a GIS based model that would allow determination of energy surplus potentials, energy deficits, and energy balanced areas within a given village development as well as determine energy demands. Pokharel and Shaligram (2012) created a spatial energy information system (SEIS) addressed the above stated factors by assessing the production ability of either biomass (fuelwood, charcoal, crop residues, animal manure, and biogas) or non-biomass (solar, hydro, and wind) sources. The authors used this model to assess the RES potential in rural areas of Nepal and demonstrated SEIS to be a valid method for developing a location specific energy resource and consumption profile.

Amador and Dominguez (2014) attempted to test the reliability of GIS results when GIS analysis was used to estimate information about the use of RES and proposed projects. The authors performed a spatial sensitivity analysis on the study area. The spatial behavior of the variables was studied to determine the robustness of the results. Amador and Dominguez concluded that variables with the greatest influence on the outcome of analysis were energy demand, storage life, photovoltaic system investment costs, fuel prices, and solar radiation. These factors should be measured more carefully. Since they have the ability to cause the most uncertainty in the analysis of deciding where and what type of RES to rely on.

It may be concluded based on the considered research that the sequential and unified analysis, which could be reproduced and approved in other model regions, has not been conducted yet. Verification of these methods would further require quantitative iteration of the techniques in various regions, which could involve difficulties since data on which each of represented re-search is based may differ in scale and accessibility.

Thus, the methods considering and making a corner stone of such concepts as ‘usability’ and ‘integrability’ for other study regions may become a necessity. Specific flexibility in the methodological approach, namely adaptability in case of the lack of initial data or its deviation from data initially required for calculations, may be also important. Therefore, it was actively used in this work, particularly for georeferencing. Such an analysis can receive wide acceptance from countries having similar preliminary energy and infrastructure conditions.

2.5 Impact of environmental effects, buffer zones and other limitations

At present, not only the determination of a wide range of technical characteristics and energy potentials of RE facilities, but also the environmental assessment may remain important re-search trends. Such data is particularly important as it may allow analysing spatial distribution of natural limiting factors while accomplishing strategic objectives of RES introduction.

For example, the WindScape software allowing regional wind resource potential mapping has been developed at the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia (Coppin et al., 2003). The use of data on land cover, protected natural are-as and bird migration as a limiting factor for installation of wind turbines may be a characteristic property of this database. Data contains natural areas of preferential protection where construction is restricted at the legislative level. Another project, EnerGEO aims to provide a versatile modeling platform that will enable planners, environmentalists and governments to calculate, forecast and monitor the environmental impact of changes in the energy mix on local, regional and global scales. Even though EnerGEO seems to be a thorough approach for integrating GIS and energy system models, clear and exploitable results are still missing. The existing energy potential mapping method (EPM) developed at the TU Delft allows assessing possibilities for increasing energy efficiency at the municipal and regional levels. However, this method is difficult to implement, and it considers technical and socio-political limitations only but disregards the environmental impact of energy facilities (Coppin et al., 2003).

Special attention has been paid recently to criteria for sustainable development of territories in projects on RES mapping. Thus, the GIS software for the “Potential of Clean and Renewable Energy on Contaminated Lands” project has been developed in the USA. The use of lands after mining as well as other environmentally neglected zones appeared due to human industrial activities has been suggested in the project. The presence of power lines, infrastructure and road network may be considered as positive factors for RES development in such territories, which could simplify and cheapen the construction significantly. There may be also an economic benefit since contaminated lands are of little promise in terms of investment due to heavy costs of their cleanup and reclamation.

The method for RES mapping on contaminated lands based on the natural resources potential (average wind speeds, solar radiation, biomass potential), the area of projected facilities, the remoteness from power lines and the remoteness from roads has been developed in the course of the project. Thus, the development of “clean” energy facilities on obviously contaminated lands may be considered one of the promising ways of sustainable development of territories.

The methodology employed in the present work can be used to identify feasible areas for RES installations based on the land suitability analysis. Results of the suitability analysis can define different parameters (such as restricted areas and energy incentive policy) to analyse their effects on power generation from RES. This is a powerful tool for developing a spatial decision support system for private or public facilities planning. Simultaneously with the fact that the restrictions can reduce the potential, they can also increase it by making more effective use of the provided territory. This leads to the rational use of land, recreational and other types of resources.

At present, just a limited number of studies on environmental risk assessment are carried out on a regular basis, which could further result in environmental hazards to endangered species or a change in microclimatic characteristics of the territories (Baban and Parry, 2011). RES technologies would be not so clean, non-waste and harmless or so called “green”, if not considering these factors. Incorporating this stage in the methods may be one of the most important tasks of the qualitative multi-criteria analysis, the more so there is enough georeferenced information on environmental characteristics in GIS DB in many countries.

2.6 Economic and market potential

Renewable energy decision making is considered a multiple-criteria decision making problem because of the increasing complexity of the related social, technological, environmental and economic factors, and traditional single criterion decision-making approaches cannot manage the complexity of current systems in addressing this problem (Abu-Taha, 2013). Additional aspects that influence the growth of renewable energy utilization are market and policy factors that play significant roles in the promoting the development of renewable energy projects (Madlener and Stagl, 2005). While the economic and market potential is one of the most complicated stages of the potential assessment of

RES introduction, there may be a number of studies setting themselves this complicated task.

Voivontas et al. (1998) claim that RES reduce energy loss, improve the reliability and stability of the energy system, and minimize environmental impact during the generation of electricity. Within their proposed framework, GIS were linked with a decision support system (GIS-DSS) to measure theoretical, available, technological, and economic exploitability of RES in a given area. The framework proposed the minimization of social and environmental impacts by considering the location of housings and the location of difficult or sensitive areas based on local knowledge. The framework can be used by policy makers and utilities to maximize the RES potential, but still does not provide enough information for investors (e.g. time of return on investment, the cost-supply curve).

The supply-cost curve of renewable energy sources is an essential tool for synthesizing and analyzing large-scale energy policy scenarios, both in the short and long terms (Izquierdo et al., 2010). It is often used in global, regional or country analyses of energy-policy scenarios. For instance, a report from NREL “Village Power Program Flowers” came out of a 1998 conference to discuss the findings of pilot projects in 12 countries around the world that NREL managed and provided technical assistance. The findings were based on NREL employee feedback and included lessons about institutional aspects, lessons learned from the characteristics of the pilot projects, lessons about implementation, operational issues, and technology needs. Overall, the projects indicated the system to be functional, sustainable, and economically reliable. In above mentioned study, the supply-cost curve was employed as an essential tool in the analysis of economic potential.

To demonstrate the spatial distribution of RE generation costs and draw the geospatial supply curve, unit RE electricity costs in the study area have to be calculated. For instance, the total production cost of solar PV energy comprises initial investment cost as well as operation and maintenance costs. According to Hoogwijk (2004), the total initial investment cost is the sum of PV system costs and construction costs, and the annual operation and maintenance costs are considered constant and defined as a fraction (3%) of investment cost. The transmission cost and the lifetime of the system has been neglected, which is in the opinion of the author of the present work a difficult but necessary task for the future analysis. Such a comprehensive analysis is on a great demand for investors and policymakers as well (Sun et al., 2013).

For policymakers, Yue, Cheng-Dar and Wang, Shi-Sian (2014) were attempting to evaluate the best use of renewable energy for a particular location of 12,560 ha in the Chigua area, South China. This area is unique in that the government has already shown significant interest in converting the outdated fish farm area to renewable energy farms (consisting of solar, wind, and/or biomass from sugar cane). The area currently contains a section of agricultural land to preserve with the renewable energy system set-up. Besides that, the migratory route of the endangered Black-Faced Spoonbill (*Platalea minor*) bird crosses the area. Based on the analysis, the near shore area was demonstrated to benefit most from using wind turbines and that sugar cane biomass used for ethanol fuel production and solar power would be a good complement to wind farms. Nevertheless, no conversion of biomass energy (e.g. to ethanol) has been proposed, which indicates the incompleteness of the idea of complementarity of such a RE system.

A regional scale GIS-based modeling system for evaluating the potential costs and supplies of biomass was carried out by Graham et al. (2005). The authors presented a GIS model to calculate the amount of a biomass crop that could be produced and converted into ethanol fuel in a state. The model was based on calculating the amount of land use in the state dedicated to a primary (cash crop) or conversely a secondary crop. This allows the investigators to provide two different predictions according to the market value of the biomass crop. The model also incorporates soil quality, climate, current land use, and road network information. This in con-junction with economic, transportation, and environmental models allows the researchers to accurately describe the potential costs and benefits of biomass production in a given state.

Many applications working with RE facilities were carried out to test the calculation of leveling electric costs (LEC) of renewable energy production such as wind or solar vs. traditional energy production. Systems of disperse production and concentrated production were assessed based on medium and low voltage loads on the existing network. Finally, Amador and Dominguez (2005) were able to make modifications to the GIS platform to automate the calculation of accumulation, remove gasoline as a source material in analysis and allow user access to all GIS required parameters for a better economic and market potential estimations.

Nevertheless, the previously mentioned power market assessment is static and does not ac-count all necessary dynamic factors of the energy market (e.g. growth of energy consumption or economic imbalances). Based on this, Samsonov (2010) defined five principles for energy market analysis including dynamic factors:

(1) Subsidiarity (delegation of responsibilities between network levels),
(2) Flexibility as an economic good (a good with spatial and temporal reference),
(3) Adequacy in installation and retrofitting of the energy infrastructure (regarding costs, risks, utility, and limitations),
(4) Cost equity (equitable distribution of costs of the energy system to originators and users),
(5) Incentives for innovation and investments. Even though all of these principles have an inherent geospatial reference, consequently, a GIS-supported method for a new power market designs has not been defined yet.

Thus, it could be seen that despite the presence of various studies on economic and market aspects, the efficient scheme describing step-by-step methods applicable for various regions with their specific conditions has not been developed yet. Therefore, careful studies in this area should be continued.

In the present work, economic and market indicators were yielded for the first time in detail within the framework of an individual assessment stage. Furthermore, the unit generation cost is considered the most important criterion because it defines the feasibility of RES electricity production and integrates regional market conditions. This paired approach (economic and market parameters) allows to create a complementary evaluation principle, where each parameter being studied complements or clarifies the other to obtain the most realistic result.

2.7 Conclusions and central research questions

It could be stated in this chapter that the energy sector has not been enough penetrated by geospatial data storage and modeling concepts in many countries, except USA, Germany and some others. Thus, raising the awareness of GIS-based methods effective data exchange as well as implementing the decision support system for RES would become future challenges. However, RES geospatial mapping is widely demanded due to RE development worldwide. At the same time, there may be a lack of information on RES characteristics as well as of a verity of software products allowing processing and analysing this data in every country or region of the world. RES mapping may have some features related to insufficiently uniform spatial and time data distribution required for their assessment. The development of methods for such data interpolation and verification may be of current interest today.

The unified data model needs to allow integration of a variety of different base data sources, including: renewable energy technical potentials, line network topologies, meteorological data, statistical data (e.g., population density), building properties, 3D building models, digital sur-face models, energy storage facilities, power plants and energy converters, satellite imagery and amongst numerous others. Consequently, the data model needs to be able to handle variety of datasets, which is still a prevailing factor in the sector of geographic information studies. However, results from previous research projects have shown that a common agreement on a core data profile for energy-related data is hard to achieve (Sun et al., 2013; Gastli and Charabi, 2010).

Another strategy to cope with the problem of the availability of highly heterogeneous datasets is the integration of pre-processed data into the data model rather than all the raw datasets, depending on the inputs required for a specific analysis task. For instance, if an energy system model requires building outlines to compute the passive solar energy potential of single buildings, one would not store the original LiDAR point cloud in the database, but rather store the building outlines derived from the LiDAR data. First, this saves memory space in the database (Nguyen, 2012), and second, it allows for enough flexibility in adapting the database contents to the input parameters required by the energy system model (Gagnon, 2016; Boz et al., 2015).

An additional challenge that comes along with limited data availability is the inhomogeneity in the level of granularity with respect to both the geospatial and the attribute dimension. For instance, building-specific parameters, such as the number of floors, may be accessible in one administrative region, but not in another, whereas the number of households is not available in one region, but accessible at the block-level in another. Thus, in order to find a common de-nominator in terms of a harmonized geospatial and attributive level of granularity, innovative vertical and horizontal aggregation and disaggregation mechanisms need to be developed.

The seemingly most essential shortcoming in current energy systems research, which is based on topological system models, is the lacking bridge to geospatial planning activities. In other words, energy system models are largely decoupled from the real world (in a geographical sense) as they mostly only consider topological relationships within the network, disregarding the actual topographic and geographic relationships. The analysis of atlases and reference media on RES potential conducted internationally has revealed that the materials developed earlier may represent either a schematic map or an illustrative material or a text document devoid of any cartographic representation. Current projects could be often characterized by gaps in methodological bases of resource potential mapping and by an insufficient consideration of factors effecting the RE development in studies at the regional scale.

Thus, the purpose of this work is to develop and approve the multi-criteria analysis of RES potentials by GIS, which is based on following criteria: 1) assessment of the energy situation; 2) analysis of initial (i.e. natural) RES potential and its constraints; 3) calculation of the technical potential on various types of RES; 4) the economic and market analysis for RES projects introduction. This approach should solve some scientific research problems that neither have been sufficiently advanced nor practiced judging from the literature review:

(1) The development of the integrated methodological approach for RES potential assessment including step-by-step analysis of the following factors: technical, energy infrastructure, environmental and economic potential in GIS software;

(2) Integration of spatially separated and heterogeneous initial data by qualitative non-georeferenced data conversion into georeferenced one, or to put it another way, filling the gaps under the circumstances of the lack of required data;

(3) Adaptability of the suggested methodological scheme to the specificity of the study region due to several alternative calculations of the processed mass data;

(4) Verification of the methods in the chosen model region.

The study is based on fundamental works in geoinformation as well as investigations on RE potentials. The following methods will be applied in this work: geoinformational, mathematical, cartographical modelling, programming, statistical and forecasting. The applied methodology of the present work constitutes the newly developed implementation order of the above stated methods.

The implementation order is specific for each of the energy sources (solar and wind energy, biomass), but also contains general criteria common for every particular energy source (e.g. the assessment of energy infrastructure, energy situation of the investigated region, etc.). The methodology itself and the implementation order of analytical tools used for analysis will be described in detail in Chapter 3. The thesis has several main statements, which may serve thorough prerequisites for advantageously applying the suggested methods in practice:

(1) Applying multi-criteria methods for the integrated analysis at the RE development stage may play a distinctive role. RE can be introduced while building the information base for long-term development planning of the energy sector as well as for developing standards for execution of designing works when installing and constructing RES facilities;
(2) Authenticity and accuracy of results can be obtained by selecting important factors affecting RES installation and exploitation. Thus, this approach aims to consider as much as possible criteria and limitations for developing and representing several model scenarios for the study region including worst case and best case ones;
(3) Reducing risks for potential investors by the in-depth study of the energy balance as well as the efficiency forecast with allowance for weather conditions of the region along with economic factors affecting the success of RE introduction.

An integrated methodological approach including mapping of potentials ranging from engineering to economic stages has not been employed at the regional level yet. Thus, this work can bring together separate mass data and approaches for its processing as well as adapt to the specificity and deficiency of initial data for the specific territory and so represent realistic values of RE introduction. The relevance of the work may be also determined by the necessity to develop unified methods for RES potential assessment with allowance for the broad range of prerequisites and limitations. The study will be of considerable practical importance because GIS and databases may be an important tool for the performance analysis and making in-formed engineering, design and management decisions on RES introduction into regional energy systems.

2.8 Study country

RES have been already playing an important role in energy balances of developed as well as developing countries. Moreover, the transition from fossil fuels to RES would become more important globally, as oil and gas along with coal resources are depleted, new hotbeds of geo-political tension are emerging, and various environmental problems are stored up on the one hand as well as RE competitiveness is growing on the other (Rafikova et al., 2014). According to IRENA (2015) and IFC (2015) forecasts, the process of piecemeal replacement of some portion of conventional energy consumption by RE would continue in the next several decades worldwide. As regard to developing countries, drastic changes in energy consumption structure have not been forecasted yet, though some authors even now are developing plans for total or almost total transition to RES for big cities, regions and even entire countries. Such transformation could take more than one decade though it is technically feasible already.

At present, RES may remain noncompetitive in many countries since the conditions for RE project implementation turn out to be unfavorable for a number of reasons. For example, it may be very difficult for RES technologies to find its niche in the energy market of CIS countries due to considerable fossil fuel subsidies. Such favorable territorial and climatic opportunities in transition economy countries such as Kazakhstan, Ukraine, Moldova and Russia could not affect the fast transition to RE (Popel and Fortov, 2015). Implementation of RES projects should be based on serious economic concerns and prospects for further development, sceptics from the mentioned countries say. Nevertheless, each country has their own energy efficiency and RE implementation strategies up to a certain level.

An active investigation and analysis of various RES potential with allowance for the specificity of all implementation stages should be started on order to take efficient actions in

RE sector. This work focuses on revealing the importance of the accurate initial assessment of the potential ranging from engineering to economic stages by the example of the country where RES development is still at a relatively low level as compared to Germany, Denmark, China, and USA taking the lead. An application of the multi-criteria analysis may be based on suggesting a number of scenarios for implementing new ecologically clean energy capacities in a country having little experience in RES development.

As noted in Chapter 1, some countries, such as Kazakhstan, Russia, Belarus and Ukraine may arouse a particular interest among many others for the energy sector development. They have many common problems and challenges in the context of RES investigation, so the multi-factor analysis applied for one of them could be a model example for others. This approach could allow carrying out a comprehensive overview of risks and benefits of RE projects for the model region. Thus, it may make sense to apply these methods in the country having initial regional diversity and accessible initial data. This work deals with the Russian Federation, which meets the criteria mentioned above. It should be noted that the selection of the model region in the territory of the country with different weather conditions and possibilities of RE introduction might be also a crucial stage of the multi-criteria methodological approach.

2.8.1 Russia in the context of international and national energy transition

Despite the global trends, renewable energy is still in a primitive state of development in Russia. Russia may seemingly have an excess of conventional energy resources in terms of national measures. According to IRENA (2016), Russia is ranked 1st in the world by gas reserves (32% of global reserves), the 2nd by coal reserves (19% of global reserves) and the 5th-7th by oil reserves (4-5% of global reserves).However, easy-to-reach deposits of relatively cheap energy sources are exhausted while the exploration and development of new fields may be very ex-pensive. It is apparent that the policy of the country may require a significant correction to-wards a more careful use of energy resources just in the nearest future.

It may be economically justified to extract and use fossil energy resources due to large-scale state subsidies which amount to $10 million per minute (or $5.3 trillion in 2015) worldwide according to an estimate by International Monetary Fund (IMF). These vast sums of money are spent to maintain a reasonable level of field exploration and development, to eliminate negative effects on environment and to develop the cumbersome infrastructure.

The affirmed Energy Strategy of Russia for the period up to 2035 provides in fact for just a slight relative decrease in export of energy sources. The export orientation is determined in many instances by the fact that the Russian oil and gas industry provides about 17% of GDP and more than 40% of the consolidated budget income, while it may be rather difficult to give up such earnings. However, timely development of RES industry may have a positive effect on the Russian economy.

Exploration costs and investments in the equipment manufacturing for RE as well as investments directly in electric power plants producing electricity by means of RES could positively stimulate Russian economy and increase the innovation activity of Russian companies. The currency crisis (since 2014) may be the time to increase the efficiency and to correct strategies. Russian companies have been examining RES more carefully since 2014. For example, Rosatom State Atomic Energy Corporation plans to build wind power plants and invest RUB 83 billion (€1.1 billion) in this sector in 2018-2020 (Figure 2.4).

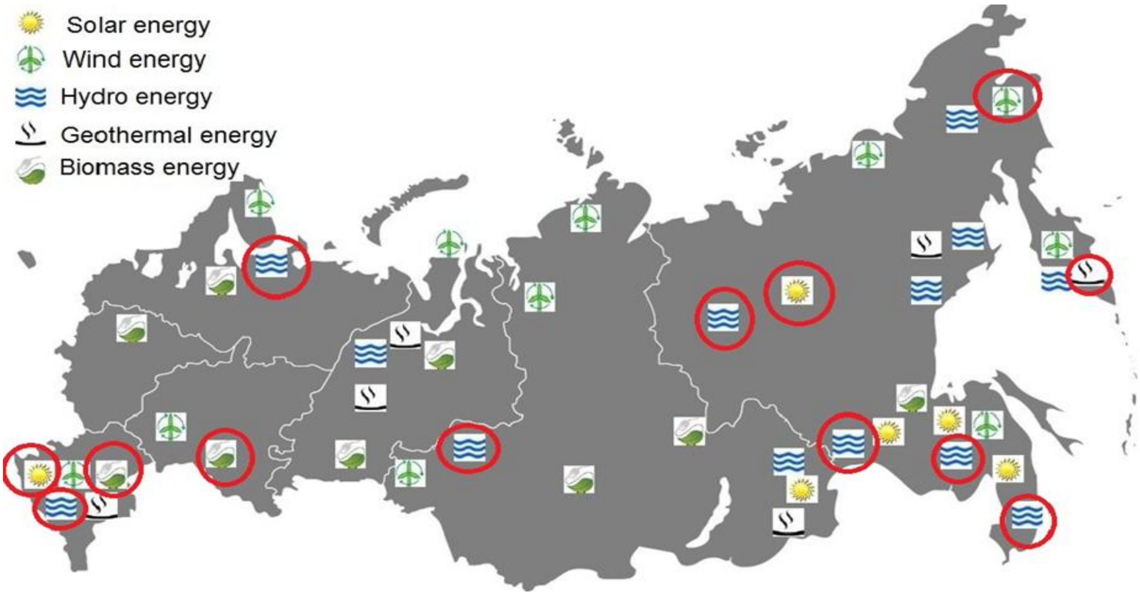


Figure 2.4 RES potential distribution in Russian Federation
Rosatom (2015). Red ovals indicate already existing RE power plants

Today, 124 large-scale power generation facilities operate on the basis of RES in Russia. Their total capacity amounts to 2.3GW, i.e. about 1% of global electric energy production (Popel, 2015). Here, local electric power plants including those supplying small human settlements and facilities are not considered. There are entire regions having a unique combination of available RES which could complete the deficiency of energy supply at times or even provide full autonomy in case of well-thought-out systems for excess energy storage. Thus, new businesses and jobs as well as new possibilities for the development of human settlements located on the territories isolated from the centralized energy supply could be created due to RES (Popel, 2016).

The energy complex plays a dominant role in the Russian economy being its strategic industry, so its innovation-based development along with diversification may be of particular importance for the entire country. Russia may run the risk of losing positions in the global energy sector while its income from the energy industry, being extremely volatile and dependent on a wide range of external factors, could decrease significantly (as it already happened in 2014 – 2015) in the next decades or even years without the development of new technologies in the energy industry including RES technologies. Localization of manufacturing as well as expansion of technological capabilities in RE sector may be the prime object of the alternative energy support in Russia (Amerkhanov et al., 2015). The development of RE sector may be favored by the cooperation with IRENA which member Russia became in July 2015.

The slump in production in 1999 – 2000 has resulted in almost 40% reduction of CO_2 emissions in the atmosphere. However, according to the World Bank Statistical database (WBSd, 2015), the Russian economy stays about two and half times less energy efficient and more carbon intensive than other comparable modern countries (e.g. Canada, Germany, Japan, USA). According to the Russian Statistical Annual (RSA, 2016) losses and leaks occur at every segment in the energy supply chain. The emission of GHG due to that losses and technological processes was more than 22% of all emissions of fossil fuels usage. Losses in electrical grids were 10% of all electrical power consumption, which is more than the total consumption in the transport and communication sector alone.

Estimates show that by 2030 the amount of carbon emissions would not reach the level of 1990 even without special precautions taken, so there is no need to express a considerable concern over this problem. The given data may seemingly play into the hands of pessimists as renewables appear to be unimportant for Russia via macroeconomic analysis, however it may not agree with objectives of the Russian government which begins to create the legal framework for RE introduction (Ratner et al., 2014).

2.8.2 The legal national framework for energy use and efficiency

According to data as at early 2016, total installed generating capacity in Russia may amount to 225GW of which only 1% is RES including 0.6% for biomass, 0.3% for small hydropower plants, 0.1% for wind and solar energy along with geothermal sources. At the same time, Decree No. 861-r issued by the Russian government on 28 May 2013 provides that the share of green energy in the wholesale market should amount to 2.5% or about 6GW by 2020. RES support system has been developed in the Russian wholesale energy market to attain these values, so wind and solar power plants as well as small hydropower plants which could enter power delivery contracts guaranteeing the return on investments at the expense of increased consumer payments are selected annually (SOWITEC Group, 2015).

The Federal Law of 26.03.2003 No. 35-FZ “On Electric Power Industry” defines renewable energy sources, empowers state authorities in regulating and supporting the use of RES and gives some mechanisms of government regulation demonstrated in Figure 2.5. Additionally, the Russian government has created new policies and legislation in order to develop and implement a successful energy savings strategy. In November 2009, Federal Law No. 261 “On Saving Energy and Increasing Energy Efficiency, and on Amendments to Certain Legislative Acts of the Russian Federation,” (“Law 261-FZ”) established a framework for how Russia will direct energy efficiency reform. However, the problems in this area are complex and require, for the most part, long-term structural solutions.

Figure 2.5 Legal mechanisms to support renewable energy in Russia
Author’s compilation

Programme on Energy Efficiency and Energy Development” including the sub-program “Renewable Energy Sources Development”. It aims at stimulating the development of the use of RES in subjects (regions) of the Russian Federation, attracting extra-budgetary funds to develop the use of RES as well as creating infrastructure conditions for developing the use of RES. So far, in Russia RES is supported by three ministries (Figure 2.6) participating in developing the Energy Strategy of Russia. There are also some specific proposals from them.

Figure 2.6 Governmental support of RES
Author’s compilation

The New Energy Strategy of Russia for the period up to 2035 provides for the gradual growth of RE share in the total energy balance of the country as well as for the active attraction of foreign investments in RES projects development. However, there may be a lack of specificity and strategic consistent actions of the state in the sphere of RES in contrast to many other countries. Political declarations on the importance of RES have not been supported by the necessary set of legislative acts stimulating the use of RES as well as framing “the rules of the game” for investors and “green energy” consumers yet.

The government made also provisions for supporting RES in the wholesale market in early 2015. Thus, network companies were obliged to purchase their electricity, but not more than 5% of daily grid losses. The support mechanism covers energy facilities using biogas, biomass, landfill gas, solar, and wind energy as well as small hydropower. However, we shall look at Russia from a little bit another standpoint that is from standpoints of the regions of the country and particular energy consumers.

2.9 Selection of a suitable model/study region

The growing interest of many Russian regions to RE projects due to the necessity of stable energy supply at reasonable cost could be observed in the last several years. For example, about 8 – 10 GW of power coming from renewables have been targeted at the regional level by 2024. In 2015, seven new solar power plants with installed capacity of 1 – 25 MW were brought into operation in all regions participating in RE programs.

The extensiveness of the territory outside the centralized energy supply system makes the situation in Russia rather particular in terms of the energy supply. The centralized energy sup-ply covers only 1/3 of the territory while 70% of the territory with population of about 20 million of people is powered primary by autonomous power plants running on imported fuel. Renewable energy in these regions could be represented by autonomous facilities and hybrid power plants based on RES as well as standby diesel (gasoline) generators (Frid, 2014). Technical and economic assessments reveal that just the regions with the decentralized and autonomous energy supply may be most attractive for the effective use of RE. Moreover, many regions may be affected by increasing ecological problems which solution could be contributed by renewables significantly.

More than 50% of Russian regions are energy-deficient and forced to supply energy sources from other regions (Popel at al., 2016). The construction of hydro and coal-fired power plants meets strict environmental requirements. In consequence, the focus on local energy sources as well as everywhere accessible different RES included may become more relevant. The rise in prices for all types of fuel and electricity as well as the existence of restrictions on connection to grid and gas-distributing system in many regions of the country have resulted in the spontaneous development of small energy in recent years.

Whereas commissioning of large-scale power plants has amounted to 9.7 GW only, introduction of small power plants has been 13.4 GW over the period 2001 – 2007. In such a way, the market may respond to a change in price factors and the occurrence of infrastructure limitations. Consumers may use small generation units on the basis of expensive liquid fuels in the absence of competitive technologies using RES in the domestic market. Import of these units may increase at a quickened pace at that. The share (by capacity) of the introduced Russian-made small generation units has decreased from 80% in 2001 down to 28% in 2007. Financial losses of commodity producers may be estimated at hundreds of millions of dollars.

As a result, the united power grid, which has been the basis of the power supply reliability in the country in its time guaranteeing low electricity cost due to the scale effect, may be in a very profound strategic crisis so far. This situation has been reflected by the fact that consumers of small and medium capacities (from 1MW) spontaneously refuse, partially or completely, to use services provided by the centralized energy supply in favor of their own generation units. A demand for non-network generation may start increasing spontaneously after the price level of 3 – 4 rubles (€ 0.05 – 0.07) per kWh has been overcome.

The situation is exacerbated by the network access problem on the part of the enterprises being constructed. For example, companies face problems of high grid connection costs in Moscow, St. Petersburg and Krasnodar as well as in a number of other energy-deficient regions. About 30% of grid connection requests may be not granted on the average, while deadlines of many requests could be extended. A satisfactory experience in the use of wind power may be observed in Chukotka and Kaliningrad region as well as that of mini and micro hydropower plants may be the characteristic of Bashkiria, Dagestan and Tyva, while solar energy is effectively used for hot water supply of sanatorium-resort complex facilities in Krasnodar region, apartment houses and industrial enterprises in Buryatia and the high-altitude astrophysical observatory in Karachay-Cherkessia.

There may be good prospects for the effective use of RES in special tourism and recreation areas which development has been already decided in different regions of the country. The use of latest energy-saving and environmentally friendly energy technologies during the construction of Olympic facilities in Sochi may be an example to that. The attractiveness of these facilities for the effective extensive use of RES may be determined not only by economic causes but by strict environmental requirements as well. Primary investigations have revealed high efficiency of the combined use of solar, wind and geothermal energy as well as micro hydropower plants in the territory of recreation areas in the Pribaikalsky National Park, in the North Caucasus (Sochi, Kabardino-Balkaria and Karachay-Cherkessia) along with Primorski region.

An increasing interest of Russian and foreign energy companies in developing a number of geothermal power plants, wind farms and mini hydropower plants in the territory of Russia may be encouraging. Thus, the regions having potential for RES introduction should possess the following factors:

(1) Availability of appropriate environmental conditions;

(2) Imbalances in the energy management (e.g. energy deficiencies);

(3) Availability of basic geo-referenced data in open sources;

(4) Investments in RES sector and successful pilot projects.

The important point is that the model region on which basis the multi-criteria scheme of the analysis for countries and/or regions having similar initial conditions such as brief experience in RES development and lack/incompleteness of initial data could be tested and implemented is taken as the base. Thus, the methodology could be used in a number of countries where risk and RES introduction potential assessment may be rendered difficult and the investment activity may be low as a consequence. So far, the Krasnodar region (Figure 2.7) has been selected to meet all characteristics mentioned above.

Figure 2.7 Location of the Krasnodar region
RosStat (2012)

Besides that, it may be critical to define the range of RES for consideration. Since the list of RES types may be rather broad and polytypic, solar, wind and biomass energy sources have been selected for a detailed consideration. These resources could represent the scheme for RE introduction in the study region more visually and versatilely due to the greater abundance, state of exploration as well as complementarity.

2.9.1 Krasnodar region: geographical, economic and energy description

The Krasnodar region (also called Krasnodar krai or Kuban) is the most southern Russian region located between Georgia and Ukraine. Its administrative center is the city of Krasnodar. The region is sometimes referred to as Kuban, a term describing a historical region of southern Russia. In 1991, the Adygea Autonomous Oblast abandoned the region's structure and was reorganized into the Adyghe Republic with Maikop as its capital. Nowadays, the region occupies an area of 76,000 km^2 and is divided into 38 administrative districts (Figure 2.8).

Figure 2.8 Districts of the Krasnodar region
Administration of the Krasnodar region (2014)

According to regional statistic agency KrasnodarStat (2016) more than 5.5 million people live in the region including about 53% – in the cities and 47% – in the rural area. Average population density amounts to 67.2 persons per km^2. The population of Krasnodar region is concentrated in the Kuban River drainage basin, which has used to be traditional Cossack land (OSSFD, 2016). The region is located in the south-west part of the Northern Caucasus, and the 45th parallel splits it up in approximately two equal parts. In the north-east, the region borders on the Rostov Oblast, on the east — on the Stavropol Region. The territory is washed by the Azov and the Black Seas in the northwest and southwest.

The total extent of the borders of the region is 1,540 km including 800 km overland and 740 km on the sea (KrasnodarStat, 2016).

The territory is divided into two extremely different parts: the northern – plain and the south – mountain. The plain zone – the Prikubanskaya lowland – covers two third of the territory being the most developed part in terms of economics. The southern zone is formed by systems of ridges of the Western Caucasus, the foothill belt and a narrow line of the Black Sea coast adjacent to it. Being situated at the border of moderate and subtropical latitudes as well as at the junction of plains and mountains, the region is distinguished for the variability in weather conditions (KrasnodarMeteo, 2014. The most part of the territory has temperate continental climate, while the Black Sea coast is characterized by the subtropical one. The average temperature in January on the plain is minus 3 – 5 °C, in July – plus 22 – 24 °C (Figure 2.9).

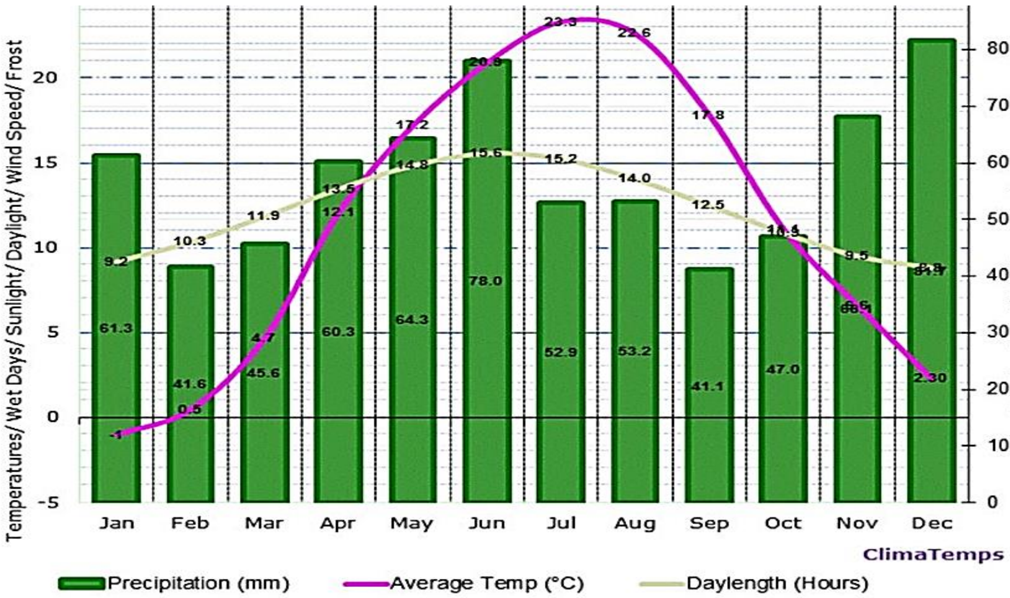


Figure 2.9 Average climate graph of the study region
KubanMeteo (2016)

The Krasnodar region is the warmest region of the country having 2,300 sunny hours per year (Butuzov, 2012). According to KrasnodarMeteo (2014), forests covering a total of more than 1.8 million hectares are one of the most important natural resources in study region. Among the riches of Kuban, forest takes the most important place since it is of great environmental significance and is the main source of valuable kinds of wood in

Russia. The total area of forests in the Krasnodar region amounts to more than 1.8 million hectares. The oak and beech forests, having an industrial value, occupy 49 and 19% of total forest area available in the region respectively.

The Krasnodar region is characterized by industrial, agrarian and recreational type of the development. According to Amerkhanov et al. (2015) basis of the economic structure of the Krasnodar region is formed by industrial, construction, fuel and energy complexes as well as information and communication technologies along with agrarian, industrial, transport, resort-recreational and tourist complexes.

The last three lines of activity (agro industrial, transport, sanatorium-resort, and tourist complexes) correspond to the priorities of social, ecological and economic development of Russia and determine a special status of the Krasnodar region in the national economy. Thus, this may result in the fact that the region is one of the first subjects of the Russian Federation, which get the financing from the federal budget for developing renewable energy programs (SOWITEC GmbH, 2015).

The rating of the Krasnodar region in the global business community is rather high: the Standard & Poor's has assigned a BB rating (a "positive" outlook) to the region. Moreover, the region enters top seven Russian regions with the lowest investment risks and holds the second place in the rating of Russian regions classified by a legislative activity in the sphere of investments (CUBE GmbH Report, 2012). So far, a lot of work is being done on implementing electric vehicles and public transport on biofuel in resort areas (Grigorash, 2014). There are some pilot projects by now providing free car battery charging in special parking zones in Sochi, Anapa and other large resort towns of the regions (RIA News, 2014).

Unique climate and environmental conditions of the Krasnodar region as well as the availability of advanced medical facilities and technologies along with historical sites may establish the potential for the development of tourist and recreational complex meeting the growth of population and energy demand. According to Russian’s state Statistic (Rosstat) (2016) the domestic tourist flow amounts to 33 million of persons per year in Russia. One third of them visit resorts of the Krasnodar region. The growth in tourist flow in the region may be evidenced over the last decades, while it has attained 13 million visitors by 2016. Kuban has about half a thousand tourist attractions including caves, canyons, waterfalls and dolmens.

According to KrasnodarStat (2015), the energy complex of the Krasnodar region is represented by more than 300 enterprises with different types of ownership having about 60,000 employees and producing more than 25% of region's industrial output as well as providing over 10% of total tax revenues to the regional budget. The structure of the system comprises the following industries: electric power industry, heat power industry, gas industry, pipeline transport, oil and gas extraction industry, oil refining and petroleum products industries.

The energy safety and efficiency as well as budget efficiency and environmental safety of the regional fuel and energy complex are strategic directions of the long-term energy policy of the region. Considering the system of goals, objectives and targets of the Government of Russia in compliance with the Energy Strategy of Russia for the period up to 2035 and the program of socio-economic development of the Krasnodar region for the period up to 2020 (RSA, 2011), the strategic objectives of the fuel and energy complex of the Krasnodar region may be stated as follows:

- A reliable and balanced supply of fuel and energy resources (FER) for economic sectors and social sphere of the Krasnodar region;
- Ensuring a faster growth rate of capacities for electricity and gas supply in order to implement the long-term and higher-priority investment projects in the region;
- Increasing the energy efficiency of the regional economy;
- Meeting energy demands under constantly increasing energy consumption;
- Increasing electricity generation from 40 to 60% of the required amount in the region.

The energy system is pushed nearer to its limits while having a limited transfer capacity of the existing infrastructure so far. According to official federal statistic data (2015), deterioration of the energy networks may come up to 75%. Besides, heat and electric energy is transferred via outdated distribution schemes. Therefore, rather heavy losses may occur for this as well as for a variety of other reasons. All of this may surely reflect on power tariffs as well. On the other hand, the energy consumption growth in the region may increase the load on the entire infra-structure additionally (Butuzov et al., 2013).

Basic production assets of the Kuban energy sector being rather worn out to date were produced several decades ago. The wear and tear of the existing power generation equipment of JSC Kubanenergo may amount to about 70% on the average as compared to 52%

of the Russian average. Every year there is an increase in the number of worn-out equipment, buildings and constructions to be replaced, reconstructed and technically re-equipped since electric power substations, electric networks and heating systems have not been essentially modernized in the last 7 – 10 years (Rosstat Annual Report, 2015).

According to KubanEnergo (2014), the overall technical condition of the investigated electric networks and heating systems is close to critical, and the situation would worsen in the future at current re-equipment rates since only 50 – 80% of capital construction and reconstruction programs are implemented. The planned increase in energy consumption due to 2014 Olympics and further active use of Olympic facilities as well as to the industrial production growth along with the development of agricultural production and processing amounts to 5.5% per year.

Even now, the residents complain of poor quality of energy supply in agricultural areas of the region in particular (main voltage is 140 – 180V, lack of power). This is due to the fact that the industry has not kept pace of modernization with the rates determined by the economic development (RIA News, 2016). Therefore, these items are considered as prior strategic objectives of the Krasnodar region so far. It is imperative to develop and optimize distribution networks, introduce additional RES at autonomous generation in particular and strive for improvement in quality of the energy supply at the expense of environmentally friendly energy sources to solve these problems.

Today, the use factor for RES in the energy balance of the region may not exceed 1.7% revealing a great potential for increasing the share of such power generation facilities (Frid et. al., 2014). Thus, the advisability of developing the Kuban energy sector on the basis of RES is based on a great number of fundamentals, and the region has all prerequisites for gaining the lead in RE sector at that. As a consequence, the Krasnodar region could be a model for regions and countries with similar problems and initial conditions showing an example of effective introduction of new energy sources.

Methodology

3.1 Significance of a comprehensive RES potential assessment

As demonstrated, a multifactorial GIS approach can have a significant contribution in identifying environmentally feasible locations for RES, which require management and analysis of wide range of spatial data types (Loken, 2007). Current developments in the field of spatial multi-criteria analysis (SMCA) (Terrados et al., 2009) are characterized by gaps in the availability of adaptation schemes for the integration of non-georeferenced data into GIS. Many current approaches (Czaplicka-Kolarz et al., 2009; Celiktas et al., 2010; Takigawa et al., 2012) do not include digitalization of large sets of non-georeferenced data thus preventing themselves from finding and selecting essential and sometimes critical characteristics of RES potentials. This information is often available in reporting and other non-georeferenced data.

Consideration of such information is crucial for the success of RES introduction. Risks of incorrect evaluation are acute if this data is not addressed from the analysis in project studies. This situation may challenge realization of the project and increase initial capital expenditures connected with further correction of unaccounted criteria. Thus, an elaborated set of methods may allow reducing risks of insufficient initial data. Digitalization and spatial referencing of crucial factors for the RES potential assessment is an innovation of the methodological approach proposed in this thesis. Another distinct feature is that the proposed evaluation stages have been considered in an overall workflow for the first time. So far, major research on RES studied by the author focused on several evaluation stages (cf. Chapter 2) having considerable gaps in methodological approaches. The results of such studies have require significant improvements and unaccounted parameters to be included.

The development and implementation of this methodological approach may have a favorable effect on regions and countries where comprehensive assessment of RE potential as well as sufficient GIS data is unavailable. These areas may often have huge unexplored RES potential. Therefore, they should be studied with the same accuracy as the regions with sufficient initial information in such countries as Germany, Denmark, USA and others. However, even these leaders may lack some free accessible data, which impedes the assessment and poses barriers to researchers and potential map users.

The proposed multi-criteria assessment methodology combined various parameters (e.g. RES potential and specific characteristics of the Krasnodar region) in one workflow. Some of these parameters will change only slowly in time saving the obtained results for 5-10 years. For instance, the results on the assessment of the theoretical solar energy potential may not change for decades (in case of initially robust estimation). The stable solar energy potential may be explained by constant natural climatic characteristics of the study region (Kowalski et al., 2009). The technical potential characteristics are more dependent on technological progress in their turn, e.g. the applied power system generations (wind turbines, solar panels). Therefore, the rate of change of the available technical potential is related to the degree of introduction of innovations into the market. Although a variety of improved and updated technologies are known, there are classical models of RES facilities considered reliable and being in steady demand for more than 5 years today (Greene et al., 2010).

The economic potential is mostly dependent on and determined by two previous parameters combined. The economic potential is more flexible among all other parameters. This is because it is based on the price movement referred to design, manufacturing, installation, logistics and other costs of RES standard projects (Tenerelli and Carver, 2012). For instance, solar energy may become cheaper with the passage of time, while wind turbines and biogas facilities of medium power (2 – 15 MW) have remained at the same costs over the past 5 years (IRENA Global Report, 2016).

A key feature of the proposed methodological approach is that initial data and calculation model may vary for each type of RE. Specific features according to characteristics of a particular type of RE may be considered in this manner. For instance, consideration of one types of limiting factors (e.g. bird migration routes, proximity to an airport) may be required for wind, while that of others (e.g. shadiness of the area, slope angle) would be essential for solar energy. Thus, there is a good reason to present the extended scheme for the data used and the processing procedure for particular energy sources, namely wind, sun and biomass, in the next section of the study.

3.2 The multi-criteria assessment methodology for the evaluation of RES potentials in the Krasnodar region

Georeferenced mapping of RES is widely demanded due to the development of RE worldwide. However, there may be a lack of baseline information on characteristics of the territories for the proposed RES introduction.

Mapping of wind, solar and other kinds of RE may have a number of features related to non-uniform spatial and temporal data distribution required for their comprehensive assessment and obtaining realistic results. Therefore, the development of an integrated framework of interpolation methods for such data to evaluate RES potentials is relevant for research on RES. DB verification as well as the use of additional sources (statistical, cadastral and reporting) for adapting and mapping various RES characteristics may be required additionally.

To facilitate a comprehensive exploration of RES potentials in cases of insufficient baseline data, this thesis proposes a multi-criteria assessment methodology (Figure 3.1) consisting of a sequence of steps that allow for the evaluation of wind, solar and biomass potential as **theoretically**, **technologically**, and **economically exploitable**. In this thesis, the proposed methodology is used to explore the exploitable potential of wind, solar and biomass energy resources in the Krasnodar region (Russian Federation). The multi-criteria assessment methodology consists of three stages of evaluation, which represent sets of restrictions on the exploitation of the RES potential (Figure 3.1). First, the theoretical potential is assessed (**Stage 1**), and then the technological potential is evaluated (**Stage 2**). Finally, the economic potential is evaluated on the basis of appropriate financial indices (**Stage 3**). For each assessment stage, thematic digital maps present the evaluation of the theoretical, technological and economic potential for the three RES.

The proposed assessment methodology follows two analytical lines, herein the middle represents the resource parameters of the three RES (such as wind speed, irradiation, etc.) derived from appropriate data sources (left part), while the right represents specific local characteristics of the Krasnodar region that may limit the exploitation of the RES potential. Two types of data provided the empirical basis for the assessment of the RES potential in the Krasnodar region, namely georeferenced data and non-georeferenced data. The latter originated from statistical surveys, reports of public authorities and private investors etc. and were converted (i.e. digitized) into an appropriate form for GIS analysis. The process of converting various non-georeferenced data into location-based GIS data is termed as **adaptation** in this thesis. The incorporation of the different types of data aimed at the evaluation of the maximum number of factors that may affect the exploitation of RES potentials in the Krasnodar region.

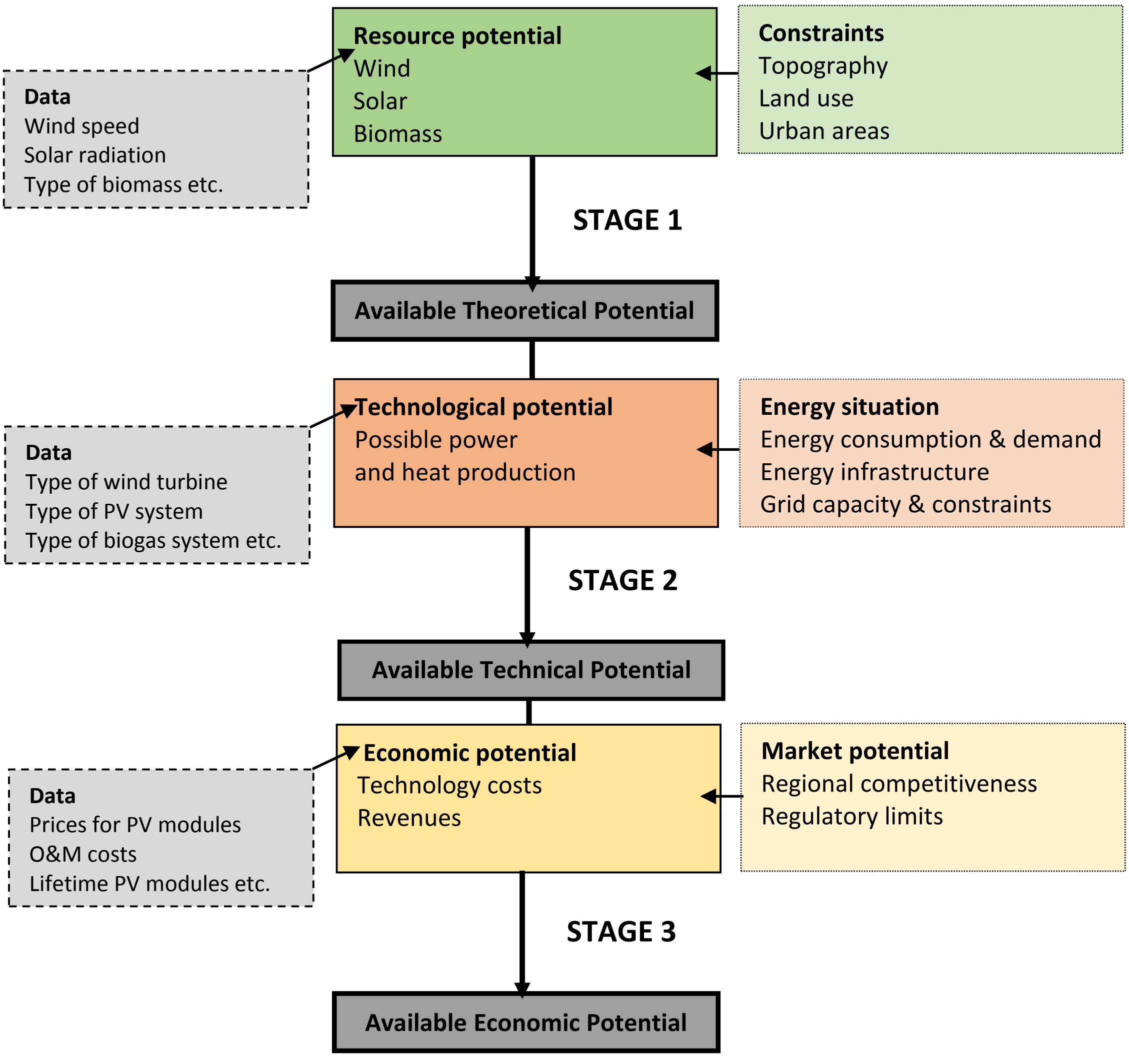


Figure 3.1 Workflow of the multi-criteria assessment methodology

3.3 Data sources relevant for the assessment of RES potentials in Krasnodar region

Two types of data provided the empirical basis for the assessment of the RES potential in the Krasnodar region, namely georeferenced data and non-georeferenced data. Large georeferenced data sets originated from the NASA Surface meteorology and Solar Energy (NASA SSE) and OpenStreetMap (OSM). For parameterization of NASA SSE models, constantly updated satellite data on radiative balance on the upper boundary of the atmosphere, earth albedo, cloud cover, concentration of aerosols etc. is used. The NASA SSE has been verified for Russian environment (Kiseleva et al., 2013; Rafikova et al., 2015) using surface measurement data including that of Russian weather stations (Meteocenter DB, 2013-2017). However, the NASA SSE may not display microclimate of certain areas, and so great may be the importance of valid surface measurements and georeferenced databases such as OSM. The OSM is a free map of the world with many thematic digital layers.

The non-georeferenced data originated from statistical surveys, reports of public authorities and private investors etc. and were initially converted (i.e. digitized) into an appropriate form for GIS analysis. An example of georeferencing is given in Appendix 3.1.

3.4 Theoretical resource potential

3.4.1 Onshore wind energy

The assessment of the theoretical onshore wind potential was performed using the workflow depicted in Figure 3.2, which is the wind-specific component of the multi-criteria assessment methodology. Input data used for the assessment of the theoretical onshore wind potential is shown in Table 3.1. A detailed presentation of data input, data processing and cartographical output is given in Appendix 3.3.

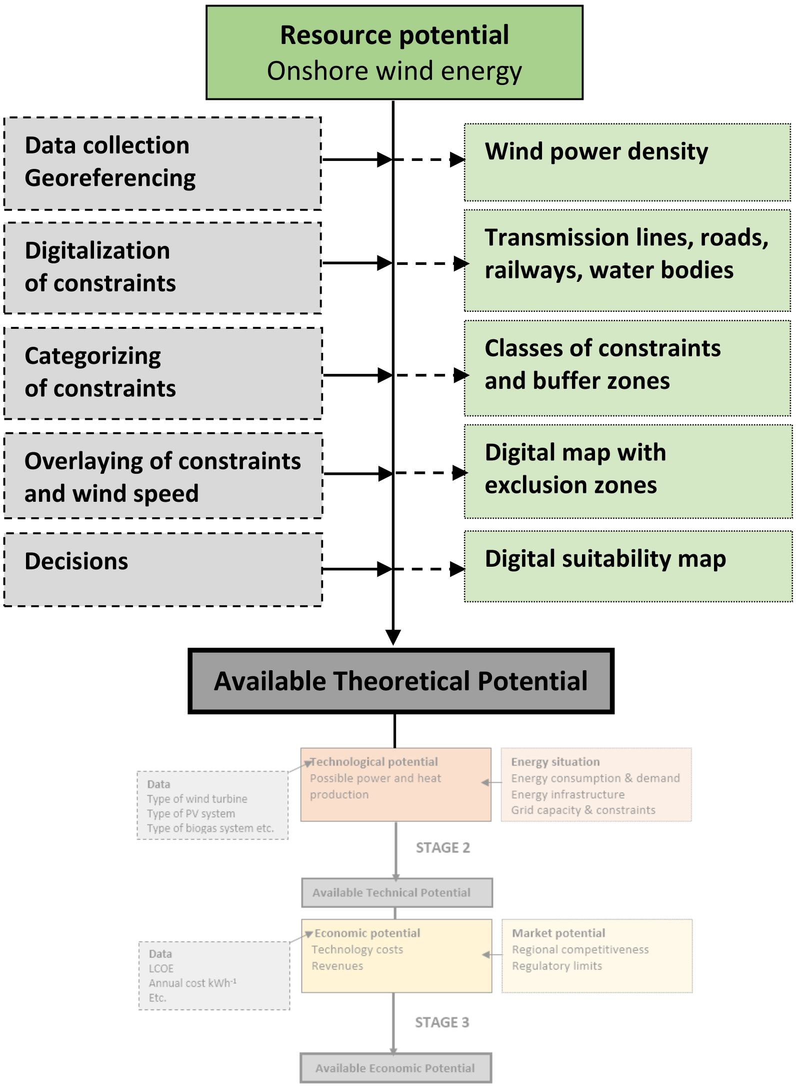


Figure 3.2 Workflow of the theoretical onshore wind energy potential

Table 3.1 Data used for the assessment of the theoretical onshore wind potential

Parameter	Information	Main reference
Wind speed	Empirical data (climate normal) from 45 meteorological stations of the Krasnodar region	KubanMeteo, (1,2)
Surface roughness	Map of 44 land use classes in Europe (resolution, 250 x 250 m);	CORINE Land Cover (1)
	Empirical roughness values for the land use classes	Roger and Brode, 2007
Slope	Slope of the topography is the critical characteristic for installation of wind turbines and constructing works	Digital elevation model (DEM), ASTER GDEM, (1)
Constraints	Minimum wind speed and distances to objects prohibiting installation of wind farms;	Vogt et al. (2012), Table 3.2
	Land use classes prohibiting wind farm installations	OpenStreetMap (OSM) (1) KubanCadaster (2)

(1): georeferenced data; (2) non-georeferenced data (official reports, statistics, etc.)

First, data on wind speed collected from 45 meteorological stations of the Krasnodar region were extrapolated to the height of wind turbines (i.e. 80 m above ground) and georeferenced. The extrapolation was performed using the modified power law (Akpinar et al., 2003) or 1/7 power law for the energy output variation (Patel, 2006) defined by equation [1]:

$$\frac{\mathbf{V_2}}{\boldsymbol{V_1}} = \left(\frac{\boldsymbol{Z_2}}{\boldsymbol{Z_1}}\right) \boldsymbol{a_m} \qquad [1]$$

V_1: average annual wind speed at a height Z_1;

V_2: average wind speed at the height of extrapolation;

Z_1: height of wind speed measurements at meteorological stations;

Z_2: height of wind turbines;

a_m: value dependent on the roughness of the physical surface defined empirically.

The surface roughness, which is the determinant for variable wind speed was accounted by using the CORINE Land Cover data and the empirical roughness values (cf. Table 3.1). The process of extrapolation and correction of initial wind speed data yielded average annual wind speed at a reference height of 80 m above ground level, with a horizontal spatial resolution of 2.5 km.

As physical, planning, economic, etc. constraints may limit the available area for installation of wind farms and thus reduce the theoretical wind energy potential, a set of constraints (Table 3.2) was considered in the assessment of the theoretical potential. Besides the environmental constraints such as water bodies and areas of ecological value, digital topographical maps of elevation, slope and curvature with a spatial resolution of 30 m were derived using DEM (Table 3.1). Areas with slopes > 20% were excluded due to high costs of installing works and safety risks during erection of wind turbines and boring works for construction of foundations.

Table 3.2 Constraints prohibiting the installation of wind farms

Criteria		**Constraint factor**	**Consideration**
1	Avoidance of summits of large hills	Topography	Physical
2	Maximum slope 10%	Topography	Physical
3	Westerly orientation	Wind direction	Planning
4	Minimum wind speed 5 ms^{-1}	Wind speed	Planning
5	Minimum distance to woodland 500 m	Land use/cover	Environmental
6	Minimum distance to large settlements 10,000 m	Population	Planning
7	Minimum distance to dwellings 500 m	Population	Planning
8	Maximum distance from roads 10,000 m	Access	Economic
9	Maximum distance from the National Grid 10,000 m	Economy	Economic
10	Minimum distance to water bodies 400 m	Hydrology	Environmental
11	Minimum distance to areas of ecological values/ special scientific interest	Ecology	Environmental
12	Minimum distance to historic sites 1,000 m	Historical/cultural resource	Resource
13	Minimum distance to airports, 2,000 m	Land use	Infrastructure

Author’s compilation after Vogt et al., 2012

Taking into account limiting factors and restrictions, which act as exclusion criteria eliminated areas of the Krasnodar region with characteristics prohibiting the exploitation of wind energy and yielded the available theoretical onshore wind energy potential.

Next, a land suitability analysis was conducted to find the most suitable areas for the installation of wind turbines. Mendoza (1997) defined land use suitability as a generic term associating a combination of factors and their effects with respect to potential land uses. The generic model of land suitability can be formulated according to formula [2].

$$\boldsymbol{S} = \boldsymbol{f}(\mathbf{i_1}, \mathbf{i_2}, \dots\ \mathbf{i_n}) \qquad [2]$$

S: suitability measure (class in the present work);
i_1, i_2, i_n: indicators affecting the suitability of the land.

Wind speed is the most influential criterion in determining the suitability of land for wind turbines. Ideally, wind farm sites should be close to roads and the existing power grid systems. Moreover, several geographic criteria must be taken into account. Areas with lower slopes are more suitable for wind turbines than areas with steep slopes, as construction is significantly easier and costs lower where the ground is flat. Finally, economic factors including distance to roads, urban areas and transmission lines should be considered. However, economic factors are less restrictive for the theoretical wind potential, but may become more important for the calculation of the available economic potential since they may increase the overall costs due to the extension of the power grid.

In the present work, suitability of areas for wind turbine installations was distinguished using five suitability classes (Table 3.3) applying pairwise comparison of criteria to offer a ratio scale. The weight of each criterion was derived, by directly comparing the importance of one criterion to another (Saaty, 1980). The criteria are ordered according to their degree of importance and normalized on a scale of 1 to 5, where 1 is the highest value and 5 is the lowest for the current assessment stage.

Table 3.3 Suitability classes for the assessment of areas for the installation of wind turbines.

Criteria	Importance	Indicators	Suitability class
Wind speed	**1**	> 9 m s^{-1}	High
		$7 - 8$ m s^{-1}	Good
		$6 - 7$ m s^{-1}	Medium
		$5 - 6$ m s^{-1}	Bad
		< 4 m s^{-1}	Not suitable
Slope	**2**	<1%	High
		1 - 2.5%	Good
		2.5 - 5%	Medium
		5 - 10%	Bad
		> 10%	Not suitable
Distance to urban area	**3**	<5 km	High
		5 - 10 km	Good
		10 - 15 km	Medium
		15 - 20 km	Bad
		>20 km	Not suitable
Distance to power grids	**4**	<5 km	High
		5 - 10 km	Good
		10 - 15 km	Medium
		15 - 20 km	Bad
		>20 km	Not suitable
Distance to road	**5**	<2 km	High
		2 - 5 km	Good
		5 - 10 km	Medium
		10 - 20 km	Bad
		>20 km	Not suitable

3.4.2 Solar energy

The assessment of the theoretical solar energy potential using a similar workflow (Figure 3.3) as for the assessment of the theoretical onshore wind energy potential, except for the initial data, which is shown in Table 3.4. A detailed presentation of data input, data processing and cartographical output is given in Appendix 3.3.

First, empirical data (climate normals) on wind collected from 45 meteorological stations of the Krasnodar region as well as data on surface albedo and cloudiness were georeferenced and transferred into the *r.sun* model of the open source GIS environment GRASS GIS for integration.

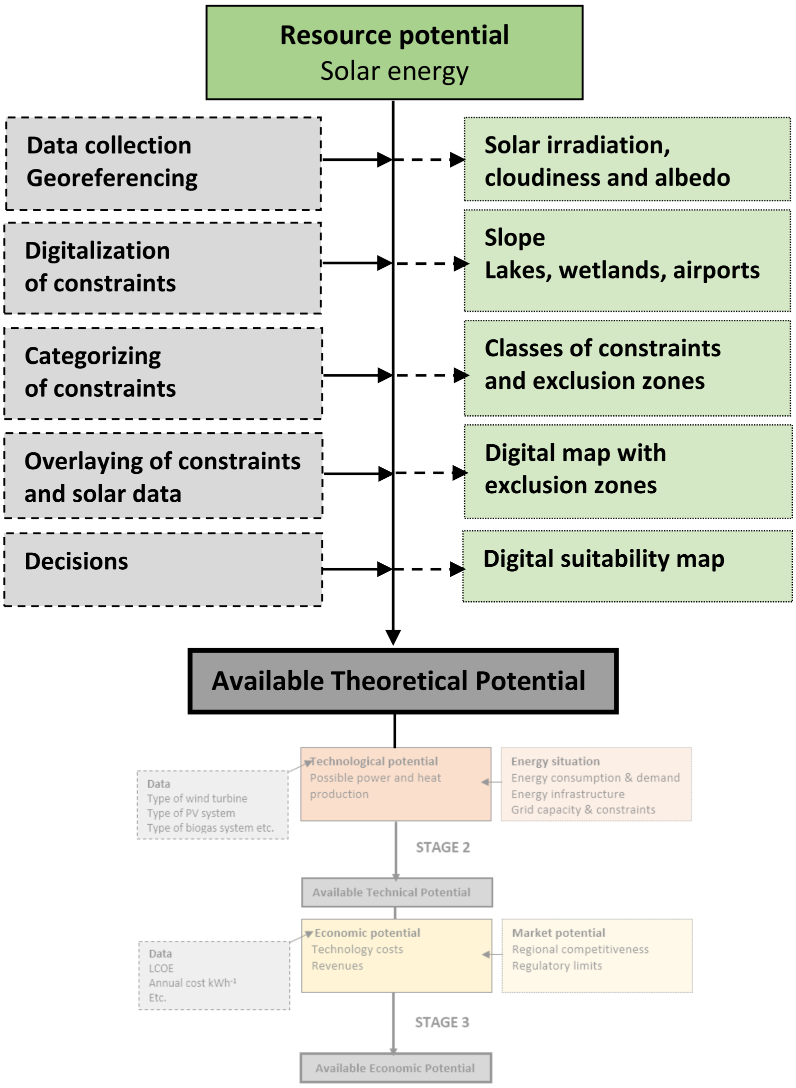


Figure 3.3 Workflow of the theoretical solar energy potential

Table 3.4 Data used for the assessment of the theoretical solar potential

Parameter	**Information**	**Main reference**
Irradiation	Generalized data for the Krasnodar region; Empirical data (climate normal) from 45 meteorological stations of the Krasnodar region	PVGIS (1), KubanMeteo (2) KrasnodarStat,(2)
Albedo	Reflectance of a specific surface	KubanMeteo (2014)
Cloudiness	Atmospheric factor affecting solar irradiation	KubanMeteo (2014)
Constraints	Types of objects prohibiting installation of PV modules;	KubanCadaster (2), Table 3.2
	Land use classes prohibiting installation of PV modules	OSM (2016) (1)

PVGIS: Photovoltaic Geographical Information System;
(1): georeferenced data; (2) non-georeferenced data (official reports, statistics, etc.)

The *r.sun* model already contains georeferenced data on irradiation. However, due to the generalized characteristic of these data, it was corrected using empirical data from the meteorological stations of the Krasnodar region, which cover more evenly the 38 districts of the region. A further detailed description of the implementation of the *r.sun* model for the assessment of the theoretical solar energy potential is given in Appendix 3.2

Limiting factors and objects prohibiting the installation of PV modules (Table 3.5) were excluded by eliminating of these areas from the theoretically available area for exploitation of solar energy. In contrast to the onshore wind energy, the limitation criteria of exclusion objects and buffer zones is less restrictive, resulting in a preferential use of PV systems in the Krasnodar region.

The consideration of the set of limiting factors and object resulted in a reduced available theoretical solar energy potential presented as a thematic digital map pointing out the areas with:

(1) Daily amounts of the total solar radiation on a sloped surface (kWhm^{-2}),
(2) Daily amounts of solar radiation falling on the optimally oriented surface (kWhm^{-2}).

Table 3.5 Constraints prohibiting the installation of PV systems

Impacts due to facility construction and decommissioning	**Impacts due to facility presence, operation, and maintenance**
Destruction and modification of wildlife habitat	Habitat fragmentation and barriers for gene flow
Direct mortality of wildlife	Electromagnetic field effects
Dust and dust-suppression effects	Microclimate effects
Road effects	Fire effects
Off-site impacts	Water consumption effects
	Light pollution effects, including polarized light

Author's compilation according to Hernandez et al., 2015

Solar radiation is considered the most influential criterion in determining the suitability of land for solar farms. The sites of PV farms should avoid mountain summits and steep slopes, as the complex terrain makes the installation of PV modules and the construction of other infrastructure difficult. Moreover, PV module installation requires a large area, unlike wind turbines, and land cover type is an important indicator. Barren land is considered the most desirable; forest and farmland are less suitable. Ideally, solar farm sites should be close to roads, the existing power grid system and urban areas. Energy demand in urban areas is significantly higher than in rural areas, and locating solar farms near urban areas reduces loss during energy transmission. As multiple factors influence the suitability of an area or the establishment of a solar farm, the multi-criteria method is appropriate for land suitability analysis. The methodology is identical to that used in land suitability analysis for wind farms. The weight of each criterion was derived using the proposed classification, by directly comparing the importance of one criterion to another (Table 3.6).

Table 3.6 Suitability classes for the assessment of areas for the installation of PV modules

Criteria	Importance	Indicators	Suitability class
Solar radiation	**1**	> 1500 kWhm^{-2}	High
		1400 - 1500 kWhm^{-2}	Good
		1300 - 1400 kWhm^{-2}	Medium
		1300 - 1200 kWhm^{-2}	Bad
		< 1200 kWhm^{-2}	Not suitable
Land cover	**2**	Barren land	High
		Grassland	Good
		Scrub	Medium
		Farmland and forest	Bad
		Water body, wetland, natural reserve	Not suitable
Slope	**3**	<1%	High
		1 - 2.5%	Good
		2.5 - 5%	Medium
		5 - 10%	Bad
		> 10%	Not suitable
Distance to urban area	**4**	<5 km	High
		5 - 10 km	Good
		10 - 15 km	Medium
		15 - 20 km	Bad
		>20 km	Not suitable
Distance to power grids	**5**	<5 km	High
		5 - 10 km	Good
		10 - 15 km	Medium
		15 - 20 km	Bad
		>20 km	Not suitable
Distance to road	**6**	<2 km	High
		2 - 5 km	Good
		5 - 10 km	Medium
		10 - 20 km	Bad
		>20 km	Not suitable

3.4.3 Biomass energy

The workflow used for assessment of the theoretical biomass energy potential (Figure 3.4 and Table 3.7) is similar to that used for the assessment of the theoretical potential of the other two RES. The basis for the exploitation of biomass energy are agricultural and forestry residues, waster from intensive livestock industry farm and urban solid organic waste of the Krasnodar region. Initially, the empirical data on cultivated areas and types of cultures among the 38 districts of the region is georeferenced. A detailed presentation of data input, data processing and cartographical output is given in Appendix 3.3.

Table 3.7 Data used for the assessment of the theoretical biomass energy potential

Parameter	Information	Main reference
Cultivated areas **Types of cultures**	Empirical statistical data on agricultural and forestry residues	KubanCadaster (2), Ministry of agriculture and processing industry (2)
Constraints	Minimum distances to objects prohibiting installation of wind farms; Land use classes prohibiting installation of biomass plants	Voivontas, (2001); Perpina et al. (2009); Table 3.7 OSM (1)

OSM: OpenStreetMap;
(1): georeferenced data; (2) non-georeferenced data (official reports, statistics, etc.)

It is assumed that the biomass residue is uniformly spread over the entire area of the study area and is expressed in terms of energy per unit area (km^2). The application of constraints (Table 3.8) such natural reserves and wetlands, water bodies etc. and their specific buffer zones in GIS excludes areas prohibiting collection of biomass for conversion into electricity and yields the available area for biomass exploitation. A digital thematic map presents the total available area pointing out the areas excluded from the theoretic biomass potential due to their restrictive characteristic.

Table 3.8 Constraints for the installation of biomass power plants

Criteria		Constraint factor	Consideration
1	Minimum distance to wetlands and lakes, 100 m	Hydrology	Environmental
2	Minimum distance to lakes, 100 m	Hydrology	Environmental
3	Minimum distance to protected areas, 500 m	Ecology	Environmental
4	Minimum distance to airports, 500 m	Land use	Infrastructure
5	Maximum slope 15%	Topography	Physical
6	Minimum distance to residential area, 500 m	Population	Planning

Author’s compilation according to Voivontas, 2001 and Perpina et al., 2009

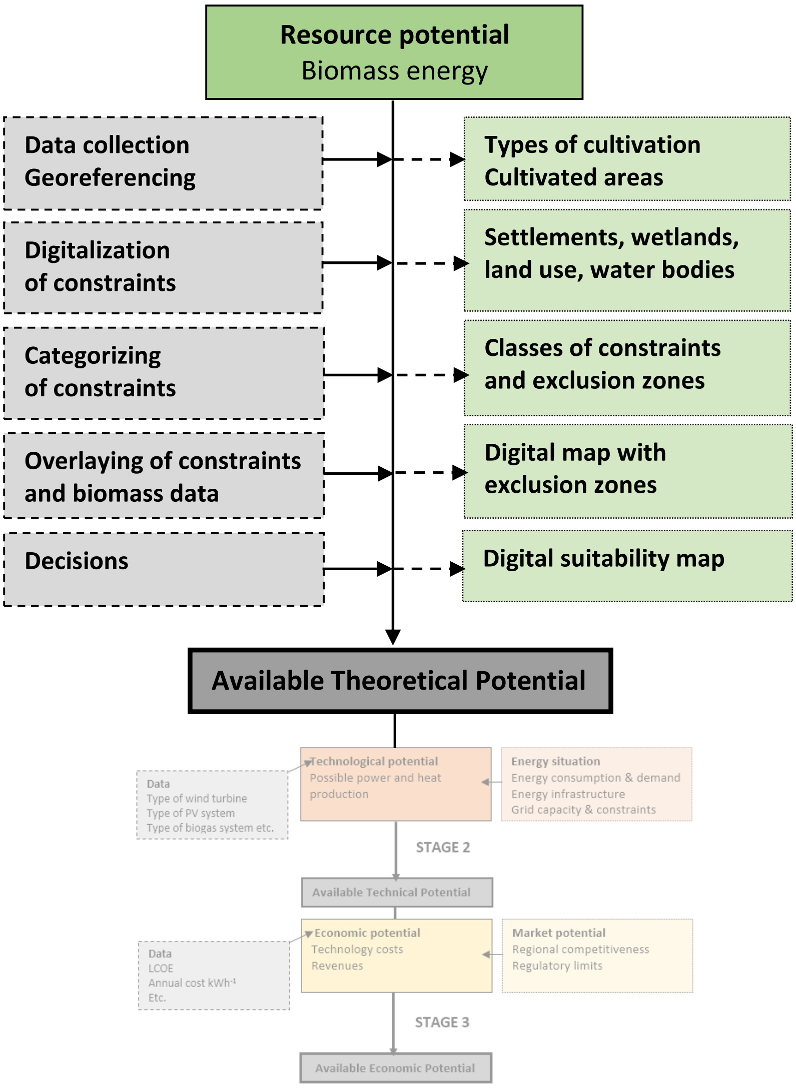


Figure 3.4 Workflow of the theoretical biomass energy potential

Once constraints are excluded, selection of optimal sites biomass power plant is performed. The techniques used to optimize the locations for plants include location-allocation modelling and supply area modelling. Location-allocation modeling optimizes plant locations based on all usable biomass in the area, even if some biomass locations are beyond the reasonable transportation distance to the plant locations.

Environmental and social constrains must be considered when planning a site for a biomass power plant. Factors that affect location include bad smells, existence of protected areas, distance to crop production or farmlands and others (Ma et al. 2005). Based on studies by Voivontas (2001) and Perpiñá et al. (2009), the criteria in Table 3.9 were simplified and applied to site biomass power plants in the present work. Hence, the classification has two ranges and includes suitable and non-suitable class.

Table 3.9 Suitability classes for the assessment of areas for the installation of biomass power plants

Criteria	Importance	Indicators	Suitability class
Biomass production	**1**	> 600 tons km^{-2}	Suitable
		< 600 tons km^{-2}	Not suitable
Distance to protected areas	**2**	> 500 m	Suitable
		< 500 m	Not suitable
Slope	**3**	< 15%	Suitable
		> 15%	Not suitable
Distance to urban area	**4**	> 500 m	Suitable
		< 500 m	Not suitable
Distance to power grids	**5**	<5 km	Suitable
		> 5 km	Not suitable
Distance to road	**6**	< 100 m	Suitable
		> 100 m	Not suitable

Author`s compilation according to Ma et al. 2005; Voivontas (2001) and Perpiñá et al. (2009)

3.5 Technical potential

3.5.1 Onshore wind energy

The input data for the assessment of the technical potential is the yield of available theoretical potential (i.e. available areas with distinctive wind speed), which was estimated in 3.2.1 after the application of the restrictions characteristic for the Krasnodar region. The calculation of the wind energy output on available areas was performed using equation [3]:

$$Q_{\max}\ (\mathrm{Wm}^{-2}) = T \times W_{\max} \qquad [3]$$

T: number of hours during the time frame under consideration (a year, most often);

W: wind turbine capacity.

When calculating maximum wind energy output for a selected wind turbine type, it is assumed that the wind turbine is operating at maximum capacity throughout the year. However, wind turbine cannot use 100% of this power due to the Berz limit. The wind power available according to the previous equation can be rewritten by adding a coefficient, C_p, which defines the maximum efficiency of the Betz limit (0.593) (Lima & Filho, 2012).

For the calculation of the energy output, the wind turbine Vestas V80 (rated 2 MW) with rotor diameter of 82 m and swept area of 5281 m^2 was selected. The Vestas V80 operates at cut-in and cut-off wind speeds of approximately 4.5 ms^{-1} and 25 ms^{-1} respectively. The V80 is an extremely competitive turbine in areas with annually medium wind speed. It is optimised for sites with an average wind speed of 6 m/s at hub height, while a breeze of as little as 3.5 ms^{-1} is all that is needed to start production.

Currently, the average capacity factor (W) for wind turbines used in the European Union reaches maximum levels of 25%. The capacity factor of 20% is considered high and acceptable to use wind power at the current level of development, for instance for Russian Federation. The available technical wind energy potential of the Krasnodar region is presented as a digital thematic map pointing out areas with varying produced energy density for the selected wind turbine.

3.5.2 Solar energy

For the assessment of the technical solar energy potential, several assumptions were introduced that further reduced the potential areas for the exploitation of the available theoretical solar energy potential. First, it was assumed that not all the available sites may be fully exploited by grid-connected PV systems. Especially the remotest sites where the grid cannot penetrate are considered economically unfeasible due to high investment costs for the construction of roads up to the PV facilities and for the connection to the electricity network.

Exploratory analysis on the energy infrastructure of the Krasnodar region showed that the central electricity network is susceptible to disruption due to windstorms and overloads. Off-grid PV systems operate more autonomously. Thus, stand-alone isolated systems that produce electricity independently of the grid are economically more attractive on the consumers' side. Stand-alone off-grid systems are a cost-effective choice also for rural applications remote from the utility grid. In this regards, the technical potential was further restricted to the rooftops of the residential and tourism and services sector. Given this rooftop area and the available theoretical solar energy potential estimated in 3.2.2, the technologically available electric power generation per year was calculated using equation [4]:

$$\boldsymbol{E_i = G_i} \text{ x } \boldsymbol{A} \text{ x } \boldsymbol{\eta} \qquad [4]$$

E_i: electric power generation per year (kWh year^{-1}),

G_i: annual solar radiation received per unit horizontal area (kWhm^{-2} year^{-1}),

A: calculated total area of suitable rooftops,

η: efficiency with which the solar system converts solar irradiation into electricity.

Conversion efficiency varies with PV cells. Based on the current report from the Fraunhofer Institution (2016), the highest conversion efficiency is between 36 and 41.1% using high-efficiency tandem cells. The efficiency of mainly c-Si cells is between 20 and 24%, and the conversion efficiency of simple c-Si cells is 14 to 18%. With thin film cell technology, efficiency is only 6 to 11%. Considering the technologies used in existing PV projects, efficiency falls between 11 and 15%. Thus, based on existing research conducted by Hoogwijk (2004) and Stoddard (2006), η is taken as 14.3% in this study.

3.5.3 Biomass energy

The technical biomass energy potential was estimated in two steps (Figure 3.5). First, the usable biomass power potential was estimated by calculating total quantity of residues from crops and forestry derived from the annual Net Primary Productivity (NPP). The NPP is defined as the net flux of carbon from the atmosphere into green plants per unit time (Zhang et al., 2014). The spatial distribution of total annual waste residues was estimated for the 38 districts of the Krasnodar regional using as well as non-georeferenced empirical data (Table 3.10).

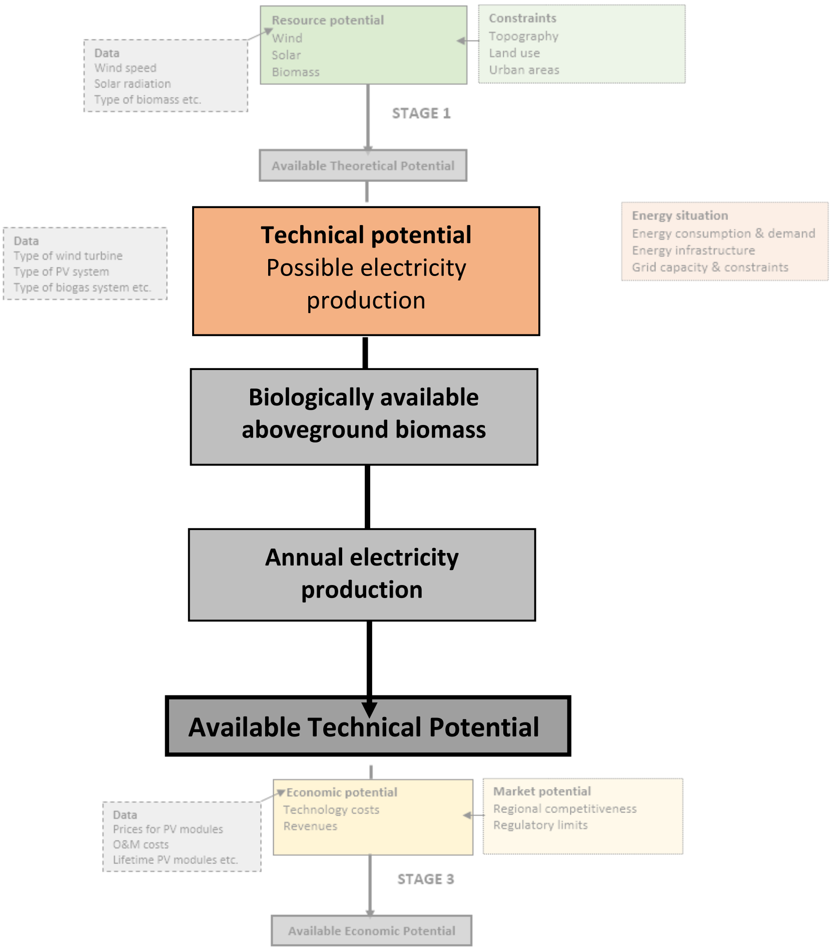


Figure 3.5 Workflow of the technical biomass energy potential

Table 3.10 Data used for the assessment of the usable biomass energy potential

Parameter	Information	Main reference
Administrative boundaries	Distribution of biomass among 38 districts of the Krasnodar region	OSM (2016), (1)
Location of settlements	Distribution of urban organic solid waste	OSM (2016), (1)
Demographic data	Urban organic solid waste per capita and year	OSM (2016), (1); RosStat (2016), (2)
Usable biomass for power production	Types of biomass and energetic value	Ministry of agriculture and processing industry, Krasnodar region (2016) (2)

OSM: OpenStreetMap;
(1): georeferenced data; (2) non-georeferenced data (official reports, statistics, etc.)

The regional NPP at a spatial resolution of 1 km was extracted from the database MODIS. Since only the biologically aboveground biomass was used, the total NPP was converted using equation [5] according to Shi et al. (2008):

$$\boldsymbol{B = NPP} \text{ x } \boldsymbol{\alpha/\beta} \qquad [5]$$

B: biologically biomass;
α: proportion of above ground biomass in the total biomass;
β: carbon concentration in dry biomass.

For crops and grass, α is 0.8 and β is 0.45, while for forest and other woody vegetation, α is 0.5 and β is 0.5 (Shi et al., 2008).

Second, the technologically available annual electricity production was estimated for a combined heat and power technology using equation [6]. Thek (2004) demonstrated that the average efficiency for electricity from the heat value of biomass is 16.9%, and average efficiency for heat is 71%.

$$\boldsymbol{E_b = F} \text{ x } \boldsymbol{hv} \text{ x } \boldsymbol{e_p} \qquad [6]$$

E_b: annual production of electricity from biomass residue;
F: consumed biomass fuel;
hv: heat value;
e_p: transfer efficiency from heat value of fuel to electricity production.

3.6 Energy situation

The assessment of the energy situation in the Krasnodar region included the evaluation of the energy demand, supply and import as well as the evaluation of the characteristics of the energy infrastructure (Figure 3.6). The assessment of the energy situation is important, insofar it may reveal potential deficits in energy supply (Figure 3.7) due to seasonally or day-and-night fluctuations of energy demand. The assessment of the energy infrastructure is important for the estimation of the energy grid capacity and resilience to include electricity that may be produced from the technologically and economically exploitable potential of RES available in the Krasnodar region.

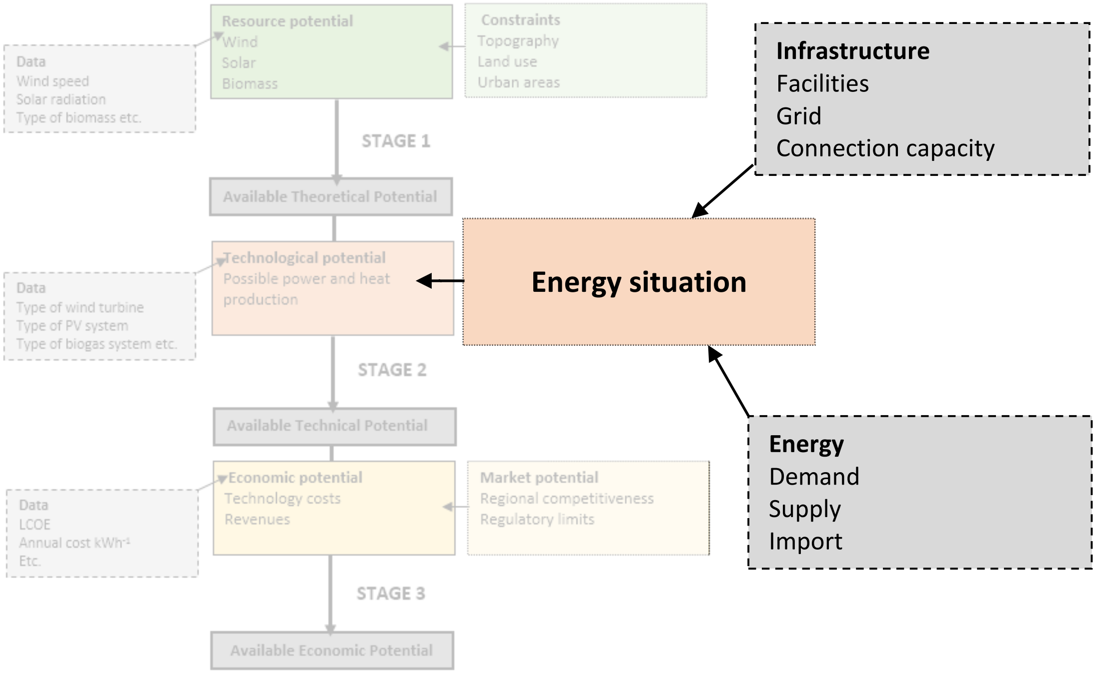


Figure 3.6 Workflow for the assessment of the energy situation

The energy balance accounts for major energy flows from the original supply sources through conversion processes to end-use demands and represents the current energy status of the region. The calculation of the electricity balance (as electric power in kWh) of the Krasnodar region was performed using equation [7] according to Frid (1980):

$$\Sigma(E_{kn} + E_{ad} + E_{im}) = \Sigma(E_j + E_{los} + E_{ex}) \qquad [7]$$

E_{kn}: energy generated by n power plants,

E_{im}: energy purchased and imported from neighboring regions,

E_{ad}: energy generated from non-conventional sources,

E_j: energy consumed by different consumers,

E_{los}: energy used to cover losses (e.g. during electricity transmission),

E_{ex}: energy used to cover needs of power stations and transmission devices.

In general, the total electricity produced by own power plants (E_{kn}) as well as electricity purchased and imported from neighboring regions (E_{im}) are the main positive energy flows accounting for the energy supply in the energy balance equation.

Table 3.11 summarizes the main references and type of data that were used to evaluate generation, supply and consumption of electricity in the Krasnodar region.

Table 3.11 Data used for the assessment of the energy situation and energy infrastructure in the Krasnodar region

Energy/Infrastructure parameter	Information	Main reference
Supply	Electricity generation capacity of power plants and companies in the Krasnodar region	CARMA, 2014(1); Rosstat, 2015-2016(2)
Overal consumption	Mean electricity consumption per capita population	KubanEnergo, 2015-2017 (2); RosStat 2015-2016((2)
Consumption by main sectors	Electricity consumption by **industry** (machine building, metal-working chemical, woodworking, and others); **agriculture** (i.e. food processing); **transport**; **tourism and service**	KubanEnergo, 2015-2017 (2); KrasnodarStat, 2015-2016 (2); Kirby, 2003 (2)
Grid capacity and disruption	Spatio-temporal distribution of **planned downtime** (maintenance work), **unplanned downtime** (no systematic disconnection; overload of the network) and **outages** in the electricity grid	KubanEnergo, 2015-2017 (2); KubanEnergo 2015-2016, Figure 3.7 (2)

CARMA: Carbon Monitoring for Action, provides an open-source DB containing information about the power generation capacity of over 60,000 power plants and 20,000 power companies worldwide;
(1): georeferenced data; (2) non-georeferenced data (official reports, statistics, etc.).

The calculation of electricity consumption (kWh) in the agricultural sector of the Krasnodar region was performed using equation [8] according to Frid (1980):

$$\boldsymbol{E_{ag} = E_{spec} \times E_{vil}} \qquad [8]$$

E_{ag}: energy consumption of the agricultural sector,

E_{spec}: specific power consumption per capita in the agricultural sector,

E_{vil}: number of rural residents (a share of population, specific to each region).

The estimation of electricity consumption of the touristic and service sector during the tourist season was performed using equation [9]:

$$\boldsymbol{E_{ser} = E_{spec} \times E_{tr}} \qquad [9]$$

E_{ser}: energy demand of the service sector (= touristic sector),

E_{spec}: specific power consumption per capita, e.g. tourists,

E_{tr}: number of tourist per year.

The estimation of electricity deficits (i.e. undelivered energy; kWh year^{-1}) that may arise when consumption exceeds electricity production was performed equation [10] according to Frid (1980):

$$\boldsymbol{E_{un} = E_{gen} - E_{del}} \qquad [10]$$

E_{un}: undelivered energy;

E_{gen}: total electric power fed into the electricity grid;

E_{del}: delivered energy.

Besides that, energy deficits are estimated from equation [6] that represents the overall energy balance of the Krasnodar region. Secondly, dominant factors affecting the energy demand on identified, e.g. seasonal fluctuations in energy consumption caused by touristic peaks or day-and-night fluctuations affected by differences in energy demand of private households and the industry.

The incorporation of electricity produced from RES requires a careful assessment of the energy infrastructure. The assessment of outages in the electricity infrastructure enables the evaluation of electricity grid resilience and capacity. The spatio-temporal distribution of outages, divided in five by causal classes (Table 3.12) was assessed, digitized and mapped in digital maps for the most severe and frequent events across the districts of the

Krasnodar region to demonstrate basic condition of the electricity grid. Besides that, the assessment aimed at identifying areas requiring energy inputs from additional sources that are not connected to the central energy grid to avoid overloads.

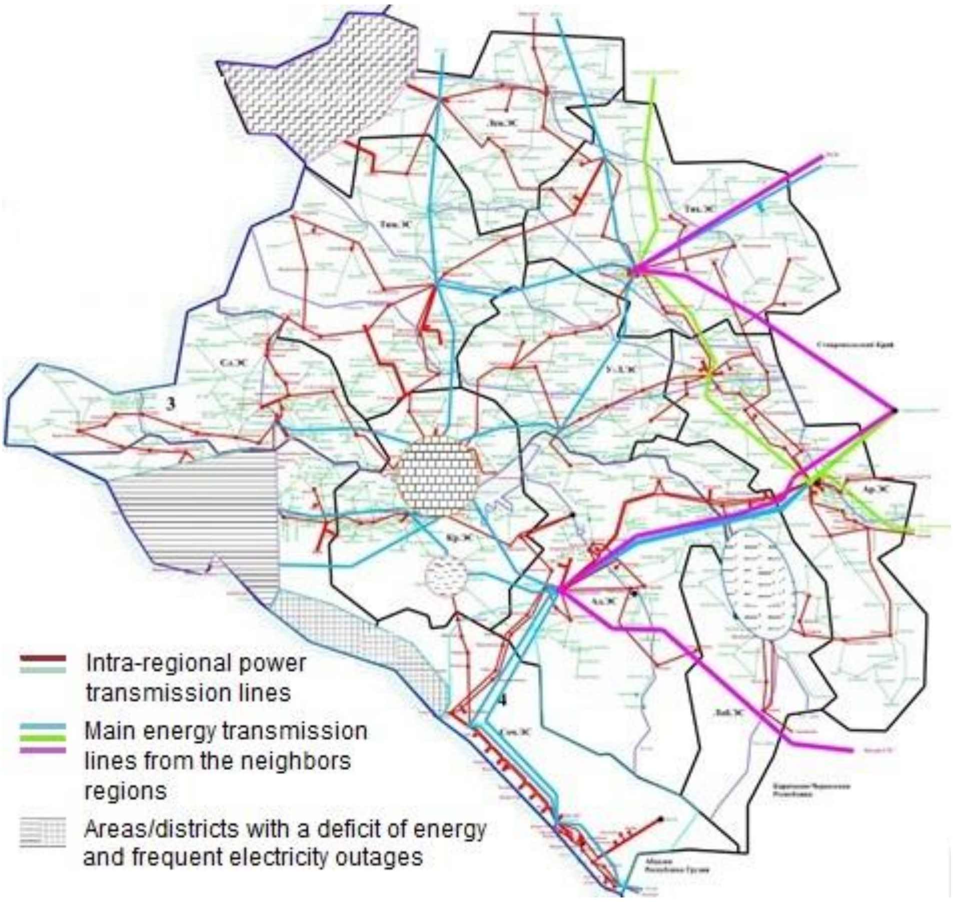


Figure 3.7 Map of the energy system of the Krasnodar region
KubanEnergo (2016)

Table 3.12 Classification of outages in the electricity grid of the Krasnodar region

Class	Cause	Features
1	Planning errors	Improper planning and architecture, high-density of buildings
2	Natural disasters	Floods, hurricanes, earthquakes, rapid weather changes
3	Outdated infrastructure	Closures, accidents in local segments of the net-work
4	Grid errors	Network errors in the distribution grid, deadlock threads in the power system
5	Insufficient capacity	Low resilience and reliability of network segments at peak load periods

Author’s compilation based on official reports of KubanEnergo, 2015

3.7 Economic potential

3.7.1 Onshore wind energy

In Russian Federation, the total amount earned by the producers of wind energy is composed of the market price of electricity and the government subsidy. The average annual cost per kWh of electricity generated by a wind turbine is derived from the sum of the total annual investment costs, operating costs and the turbine's annual energy yield. The transmission cost has been neglected. The unit cost of energy was calculated using equation [11]:

$$\boldsymbol{PC_i = \frac{C_{O\&M}+L}{E_i} \qquad L = I\,\frac{r(1+r)^n}{(1+r)^n-1}} \qquad [11]$$

PC_j: cost of 1 kWh of electricity;
$C_{o\&m}$: operation and maintenance costs, and is assumed to be a constant rate (0.03 of investment) over the life time cost (Hoogwijk, 2004);
E_j: annual energy yield in a grid;
L: annual loan payment, the total investment is obtained from loans;
I: initial investment cost, where turbine cost takes 80% of the investment;
r: interest rate (will be taken as 5%, according to calculations of Hoogwijk (2004));
n: life time of the system (25 years).

According to He et al. (2013) and to existing wind energy projects (Vestas, 2014) the costs of wind turbines account for 75 – 85% of the total investment expenses. The expenditure related to the auxiliary and road infrastructure as well as to grid connection may amount to up to 15% of the total costs. Of this share, the majority is the cost of connecting to existing transmission lines; this represents the 6 to 8% of the investment cost. Annual operation costs include debt service costs, insurance, property tax and lease of land, and expenditure on maintenance, and amount to 3% of the initial capital cost (Vestas, 2014).

The energy production cost for wind turbines was estimated on an example of a wind farm of 30 wind turbines situated in an area of the Krasnodar region where the highest energy production was estimated from the assessment of the technical wind potential. In the second step the assessment of the market potential for wind energy was performed on the basis of methods described in 3.6 (Market potential). It describes additional factors that influence the wind energy utilization. These factors include electricity tariffs, subsidies and administrative project-related policy.

3.7.2 Solar energy

The assessment of the economic solar energy potential was performed using equation [12], which is the modified form of equation [11] used for the calculation of the economic onshore wind energy potential in 3.5.1. The variable L, i.e. annual loan payment was not implemented in the calculation equation as it was assumed that the total investment for PV module for a private household would not be obtained from loans. Furthermore, there are no governmental subsidies for PV modules or for electricity produced from RES. Therefore, the average annual cost per kWh electricity was derived from the sum of the annual investment and operating costs and the annual energy yield from the total area of selected rooftops.

$$\boldsymbol{PC_i = \frac{C_{O\&M} + I}{E_i}} \qquad [12]$$

PC_j: cost of 1 kWh of electricity;

$C_{o\&m}$: operation and maintenance costs, and is assumed to be a constant rate (0.03 of investment) over the life time cost (Hoogwijk, 2004);

E_j: annual energy yield in a grid;

I: initial investment cost, where turbine cost takes 80% of the investment

Additional information on economic feasibility of PV development provides by the assessment of the market potential in 3.6, which is aimed to evaluate factors such administrative project-related policy of the Krasnodar region that may influence the introduction of PV systems.

3.7.3 Biomass energy

For the assessment of the biomass energy potential, it was assumed that installation of biomass power plants is economically feasible for sites, which are:

(1) Within a maximum allowable biomass collection distance,
(2) Have a good access to roads for collection and transportation of the usable biomass and
(3) Have an access to a grid network to feed the electricity produced.

The criterion (1) applying exclusion of sub-optimal sites according to following restrictions:

- A site is accepted when the available potential is higher than the required energy input and the biomass collection radius does not exceed the maximum allowable biomass collection distance;
- A site is rejected when the radius exceeds the maximum allowable distance and the available potential is lower than the required energy input for the operation of the biomass power plant;
- The available biomass potential of regions within an increasing radius is compared with the required energy input for the operation of the power plant.

The criteria (2) and (3) were assessed applying the road network and the energy infrastructure of the Krasnodar region (Table 3.13).

Table 3.13 Data used for the assessment of the economic biomass energy potential

Parameter	Information	Main reference
Roads	A good road network is important for access to the biomass and transportation to biomass power plants;	OSM (2016), (1)
Energy infrastructure	Access to local energy grid for feeding of produced electricity	KubanEnergo (2016), (2)

The unit cost of biomass energy was calculated using equation [13]:

$$\boldsymbol{PC_i = \frac{C_{O\&M}+L+T+G}{E_i} \qquad L = I\,\frac{r(1+r)^n}{(1+r)^n-1}} \qquad [13]$$

PC_j: cost of 1 kWh of electricity;
$C_{o\&m}$: operation and maintenance costs;
E_j: annual energy yield in a grid;

L: annual loan payment, the total investment is obtained from loans;
T: biomass transportation cost;
I: initial investment cost;
G: local grid connection cost;
r: interest rate (will be taken as 5%, according to calculations of Hoogwijk (2004));
n: life time of the system (15 years).

Each optimal site for the installation of a biomass power plant was set to be situated along the nearest road in order to avoid additional costs for road construction. The distance of the biomass power plant from the nearest high-voltage grid line was estimated using built-in GIS methods. The biomass transportation cost was estimated using quantity of biomass and the transportation distance.

3.8 Market potential

The assessment of the market potential entails a generic process involving two main criteria (Bazmi and Zahedi, 2011; Gosens, 2016):

1. Yield of a broad array of national and regional market conditions, drivers, trends;
2. Utility regulations and rules.

Input data can also include sales trends and projections, utility loads and supply including costs and prices, surveys, analysis of utility capital budget plans, detailed product cost estimations, forecasts, etc. The market potential assessment for exploitation of RES of the Krasnodar region was conducted on a combination of the following indicators:

1. Actual rules and regulations;
2. Market opportunities for RES electricity generation.

To provide a picture on the market potential in the region, available data from the Ministry of the Economy of the Krasnodar region and the Regional Energy Commission, Department of Prices and Tariffs of the Krasnodar Region were used. Besides that, relevant data (e.g. reports, tables, surveys and forecast models) from large investment, development and manufacturing companies with megawatt-class RE projects such as SOWITEC (wind energy), Hevel Solar (solar energy) and BioGazEnergoStroy (biomass energy) were included in the examination. To present the spatial distribution of the factors influencing the market potential of RES, the available data was initially generalized for the three types of RES and classified:

1. Good conditions: governmental subsidies have been provided to compensate electricity costs produced from RES;
2. Satisfactory conditions: regional decision makers require a full range of documentation for RE facilities to produce electricity autonomously;
3. Unsatisfactory conditions: transit areas of large energy mains coming from neighboring regions to supply energy to the Krasnodar region. Therefore, these territories are not included in the regional energy strategy as a priority area for the RE.

Due to the lack of initial information, it was not possible to account for the most of the major policy instruments such as feed-in-tariffs, investment tax credits, direct subsidies, and renewable energy portfolio standards (IRENA Global Report, 2016). For the same reason, the expected market potential for the technologically exploitable RES potentials of the Krasnodar region was evaluated without regard of storage costs.

3.9 Scenarios and recommendations on the development of RES

The practice of developing and using energy scenarios emerged as a way to give decision makers collaborative foresight that can underpin their strategy and policy in an uncertain circumstance. Energy scenarios need rigorous research and analysis to map out possible contrasting future worlds. They identify significant events, dominant actors, and their motivations, and they convey how those factors function all together.

Three scenarios for the development of wind, solar and biomass energy potential in the Krasnodar region are elaborated in this study, a best-case, worst-case and baseline scenario. Five factors that may influence the development of RES potentials were considered:

(1) Future energy demand;
(2) Support of new technologies;
(3) Environmental priorities;
(4) Government and investor relationships to RES.

Finally, a set of recommendations is provided for improved planning of feasible projects on RES in the Krasnodar region. The recommendations include specific measures proposed with regard to the achieved results of the assessment and the investigated specific features (e.g. energy status, market conditions, etc.).

4 Results and discussion

The assessment of RES potentials in the Krasnodar region revealed fundamental factors that influence all three types of RES in a similar way. These factors are:

(1) Energy status of the Krasnodar region,
(2) Constraints restricting the installation of RES facilities in the Krasnodar region,
(3) Market climate for RES in the Krasnodar region.

Since some of these factors apply equally to each of the investigated RES, their description will be provided prior to the individual results of the assessment of each RES potential. A brief introduction to the energy status of the Krasnodar region is considered first, inasmuch as it may be necessary to identify energy problems and to demonstrate the need for the exploitation of RES in the region. Second, the results of a suitability assessment is presented that identified territories where an introduction of RES facilities is legally prohibited or environmentally problematic. Third, a brief overview on the general market climate in the Krasnodar region is given.

This presentation of the results is aimed at deducing all results to the level, which would be regarded as a credible source of information for designing and introducing RES to produce electricity. To provide a critical assessment, the individual RES potentials as well as risks related to their exploration in the Krasnodar region have been addressed.

4.1 Energy status of the Krasnodar region

The Krasnodar region produces energy mainly from thermal fuel, with installed capacity of 1.158 GW, the largest installation being that of the Krasnodar Combined Heat and Power Plant (CHP) with 0.8 GW capacity fueled by natural gas (Figure 4.1). The share of the Hydropower Power Plant (HPP) stations is small and was not taken into account.

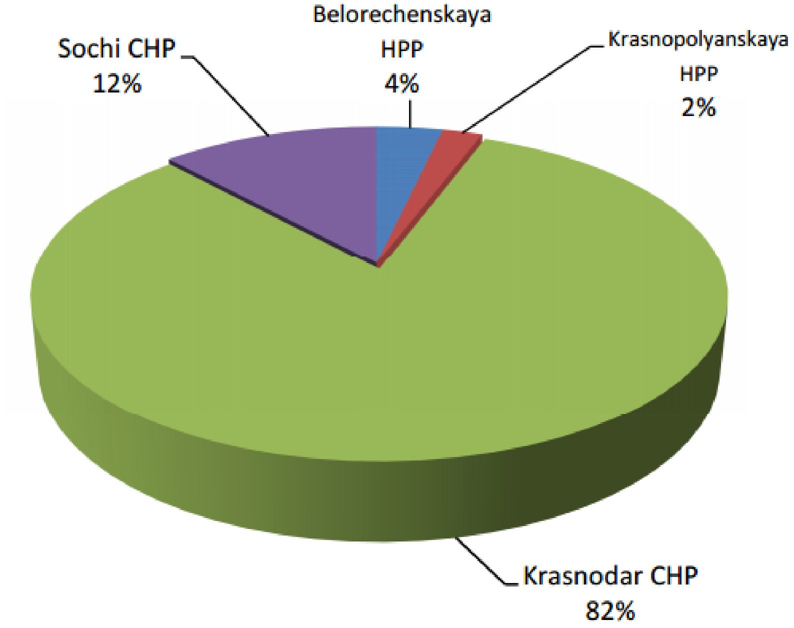


Figure 4.1 The structure of the Krasnodar region energy system in 2016
Author’s compilation according to official reports of KubanEnergo (2015)

In recent years, the Krasnodar region records a steady increase in energy demand (Amerkhanov et al., 2015). Because of fast economic development, the region has the comparably biggest shortage of electricity in the Russian Federation. On average, the region consumes 30 TWh of electricity annually while the production in the region amounts to 12 TWh (KubanEnergo, 2016). The rest of the energy comes from the power systems of neighboring regions: Rostov oblast (around 8 TWh) and Stavropol krai. (10 TWh). Thus, the current electricity production of the Krasnodar region amounts only to 40% of the total electricity demand (Butuzov et al., 2016).

At the same time, the region has very good natural conditions for the development of RE. Up to 22 GWh of thermal power and 13 GWh of electric power may substitute the equivalent energy quantities produced from hydrocarbon fuels (Kovalenko et al., 2012; IRENA

Global Report, 2014). However, the total installed capacity of RES facilities in the Krasnodar region is currently about 220 MWh (Grigorash et al., 2016).

In terms of energy consumption, as part of the energy balance of the Krasnodar region, the sectors industry, farming and agriculture (including food processing), transport, population (i.e. private households), services (including tourism) dominate the electricity consumption in the Krasnodar region (Figure 4.2). The share of the farming and agriculture sector in total electricity consumption is 33.3%; that of the population and the services sector amounts to 26.5%. The sectors transport and industry have a share of 26.5%. The the private household (population) and tourism electricity consumption amounts to 34.5% of the total electricity consumption in the region (KubanEnergo, 2016). On district scale, the highest average annual growth rates of electricity consumption were observed in the energy system of Sochi (19.4%), Yeysk (12.3%), Kuban (11.7%), Anapa (10.1%) and Tuapse (9.9%). The highest growth in energy consumption is in the Southern, Southwestern and Central energy districts as a whole.

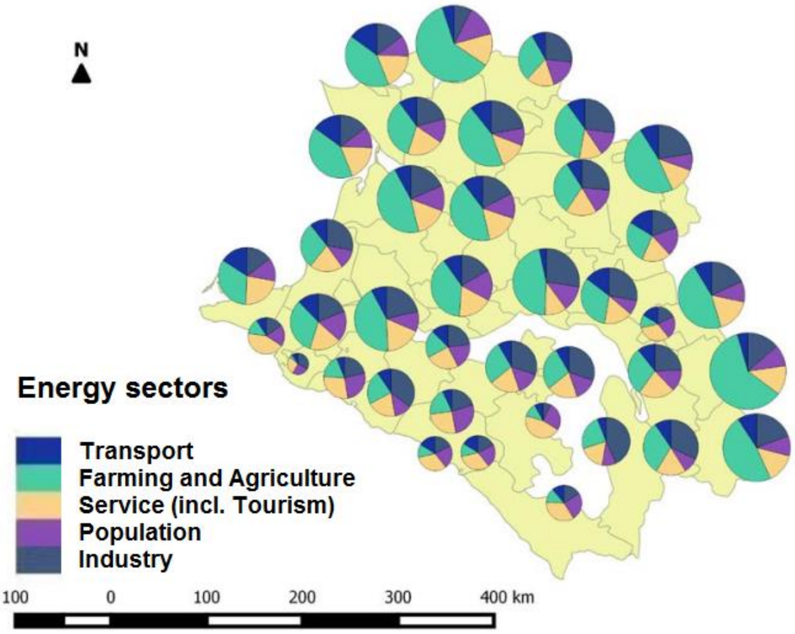


Figure 4.2 Energy consumption by sectors in the areas of Krasnodar region
Size of charts do not indicate different proportions of electricity consumption.

The large amount of electricity consumption in the above-mentioned sectors is explained by the fact that the Krasnodar region has the third largest population in Russian Federation. Furthermore, it has the heaviest volume of domestic tourists. At the same time, the Krasnodar region is the largest agriculture-oriented region of the Southern Federal District of Russian Federation (RosStat, 2016).

In recent years, the steady increase in electricity consumption took place in several successive steps:

(1) 2011: beginning trend of increasing electricity consumption as result of economic stabilization in the region,
(2) 2014: introduction of new facilities with additional electricity demand,
(3) 2014: Winter Olympics in Sochi,
(4) 2016-2017: large-scale modernization of the Taman Peninsula along with the construction of the bridge across the Kerch Strait.

In this period, the total electricity consumption of all districts of the Krasnodar region increased by 30% (Figure 4.3) from 21,960 to 31,103 million kWh. The total load on the energy system of the Krasnodar region is estimated to increase from 3,541 MW to 7,100 MW within the period from 2009 to 2020, i.e. more than twice (Regional Dispatching Office of the System Operator of the United Power System). For the period from 2013 – 2015, the critical electricity shortages amounted to 1,570 to 1,900 MWh per year and were covered by the Rostov and Stavropol energy systems. Thus, the Krasnodar region has an unbalanced energy status, which is characterized by a high percentage (50 – 60%) of electricity imports and frequent electricity shortages. Calculation of the regional energy balance demonstrate the average energy deficit amounts to 22 GWh year^{-1}.

Given these general dynamics of the energy consumption growth, districts of the Krasnodar region with available autonomous access to RE are considered as most promising for the introduction of new RES facilities.

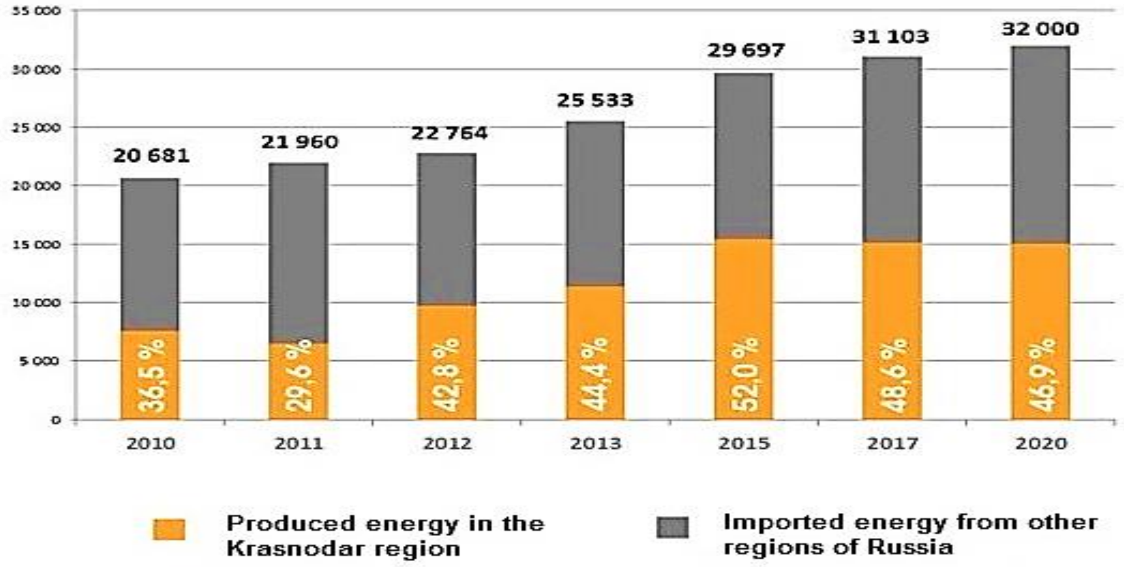


Figure 4.3 The total electricity consumption in the study region in million kWh
Author’s compilation according to KubanEnergo (2016). For the year 2020 an estimation of the electricity consumption is given.

Besides the data on energy production and consumption, data on underdelivery of energy for 2013 – 2016 were analysed to assess the status of the energy infrastructure of the Krasnodar region. For a vivid depiction of the energy infrastructure, all districts of the Krasnodar region were grouped on the basis of similar infrastructure characteristics into 11 energy polygons (Figure 4.4).

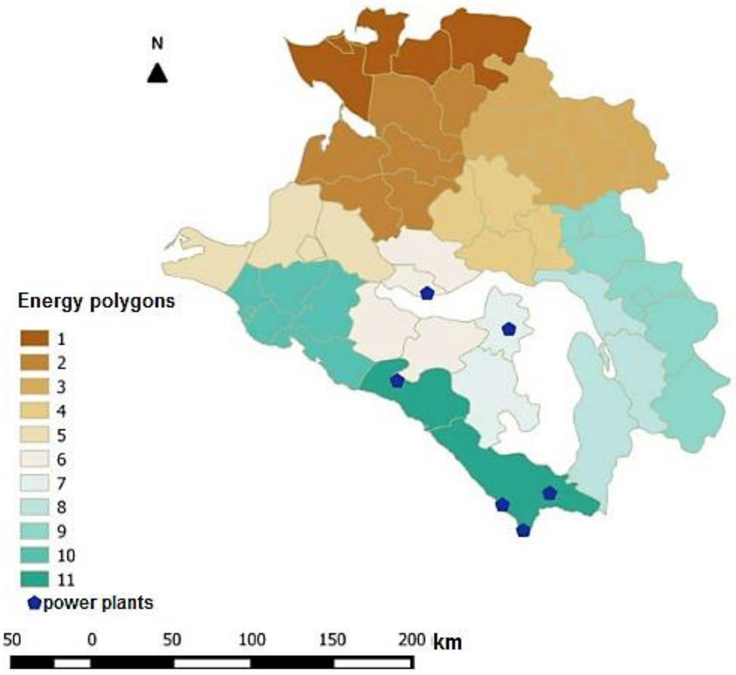


Figure 4.4 Spatial distribution of energy polygons and main power plants

The northern parts (polygon 1 – 3) of the Krasnodar region have a poor ma maneuverability of the energy infrastructure and a poor energy supply reliability since the distribution networks lack capacity for additional electricity in-feed as well as a frequent occurrence of dead-end feeders. In cases of network overloads dead-end parts of the network are completely shut down without a possibility to transfer electricity to consumers produced in other parts of the energy network.

For the western and southwestern parts (polygon 5, 7 and 8) of the region, typical characteristics of the energy infrastructure are overloads of the electric transit network and a low capacity of substations. For the central parts (polygon 4 and 6), it is not possible to develop additional distribution capacities due to dense construction of buildings. The south and southeastern parts (polygon 9 – 11) of the some of these problematic energy infrastructure features may have a significant impact on successful introduction of RES facilities. The following features are main risks and challenges in the infrastructure:

(1) Presence of isolated local energy systems operating on diesel generators;
(2) Intense development of the industrial and transport sector;
(3) Dead-end feeders of energy networks;
(4) Areas with strict environmental limitations for expanding energy networks;
(5) Frequent electricity network failures and repair of the outdated equipment.

The spatial distribution of these factors as well as of the main settlements with high population density of the Krasnodar region is depicted in Figure 4.5.

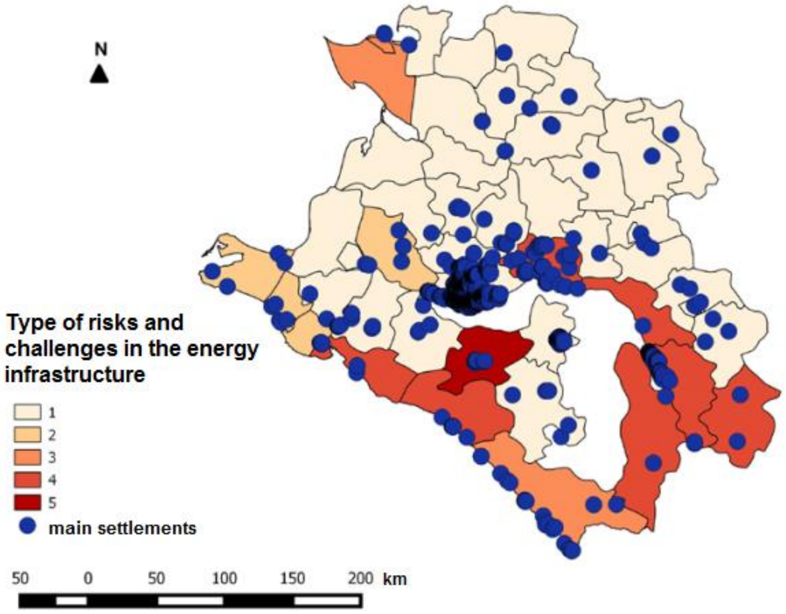


Figure 4.5 Spatial distribution of factors affecting the introduction of RES facilities

Figure 4.5 provides the distribution of areas in the Krasnodar region increasing level of energy consumption based on the density of the main settlements with high population numbers. RES facilities may provide an additional capacity for the main energy fund and, at least partially, cover the energy demands that are occurring periodically, for instance in sanatorium/resort facilities during high tourist seasons.

At present, more than 6,000 MW of turbine equipment of the regional thermal and hydro power plants has expired its economic life (Nikolayev, 2013). Replacement of turbines and other equipment may be required at power stations built 40 or more years ago. The introduction of new auxiliary electricity producing facilities may be currently possible based on autonomous RES projects without grid connection. As demonstrated earlier, the energy infrastructure of the Krasnodar region may not allow for connection of new RES facilities to the grid due to high risk of overloading of the existing loads in the energy system, due to a lack of a relevant distribution network and due to a low throughput capacity of the outdated equipment. For reasons, further calculations of the RES potentials for independent, off-grid RES facilities.

As demonstrated for the energy balance of the Krasnodar region, 40% of the regional electricity supply is provided by internal sources. Around 60% of electricity comes from neighboring regions. An integrated analysis of the energy infrastructure of the Krasnodar region has revealed further features of the energy situation:

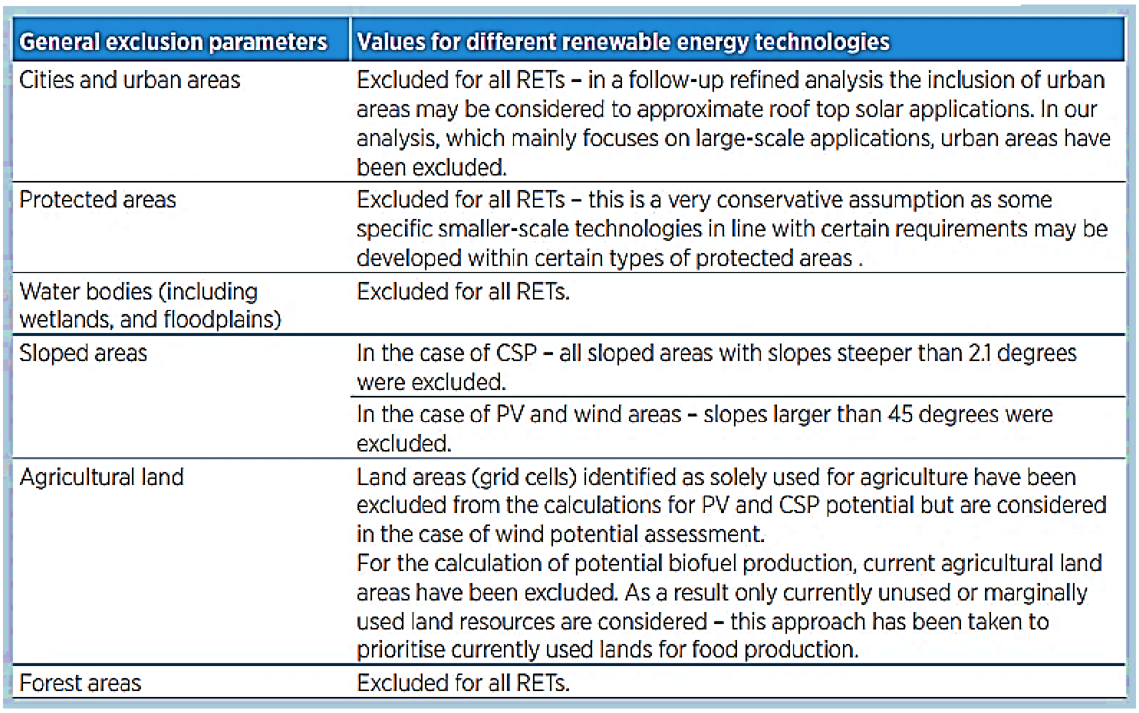
(1) Capacity deficiency persists along with high indicators of an energy underdelivery;
(2) High energy consumption growth in a number of districts of the Krasnodar region has aggravated the challenges of electric power;
(3) Depreciation and obsolescence of the equipment of electric power plants and electricity network facilities takes place;
(4) Autonomous facilities along with remote-area power supply are the most appropriate solution for using RES in the study region;

A comprehensive picture of the energy status of the Krasnodar region has been obtained. Hence, further stages of the analysis were performed with allowance for an optimal development scheme for RES facilities. The same calculation model could be used for the energy system assessment in other model regions.

4.2 Constraints restricting the installation of RES facilities

A set of screening parameters was used to develop digital exclusion maps in this thesis. While some of these parameters are similar for all types of RES examined, others may differ due to technical requirements with regard to terrain. In the case of the assessment of the biomass energy potential, estimation of the available biomass may only cover areas that are unused and may not interfere with the food production. Thus, forest areas and agricultural lands currently used are excluded from the estimation of the available biomass. There may be also some technical restrictions on the permissible noise level for wind turbines. The screening parameters similar for all types of RES (Table 4.1) were combined into an overall exclusion map. The total exclusion area was then subtracted from the territory of the Krasnodar region.

Table 4.1 General screening parameters used for arranging of exclusion zones



General exclusion parameters	Values for different renewable energy technologies
Cities and urban areas	Excluded for all RETs – in a follow-up refined analysis the inclusion of urban areas may be considered to approximate roof top solar applications. In our analysis, which mainly focuses on large-scale applications, urban areas have been excluded.
Protected areas	Excluded for all RETs – this is a very conservative assumption as some specific smaller-scale technologies in line with certain requirements may be developed within certain types of protected areas .
Water bodies (including wetlands, and floodplains)	Excluded for all RETs.
Sloped areas	In the case of CSP – all sloped areas with slopes steeper than 2.1 degrees were excluded.
	In the case of PV and wind areas – slopes larger than 45 degrees were excluded.
Agricultural land	Land areas (grid cells) identified as solely used for agriculture have been excluded from the calculations for PV and CSP potential but are considered in the case of wind potential assessment. For the calculation of potential biofuel production, current agricultural land areas have been excluded. As a result only currently unused or marginally used land resources are considered – this approach has been taken to prioritise currently used lands for food production.
Forest areas	Excluded for all RETs.

From IRENA (2014)

RET – renewable energy technologies; CSP - concentrated solar power systems

While considering the complete list of factors influencing RES development in the Krasnodar region, constraint factors were combined three categories indicating areas with different degree of limitation (Figure 4.6).

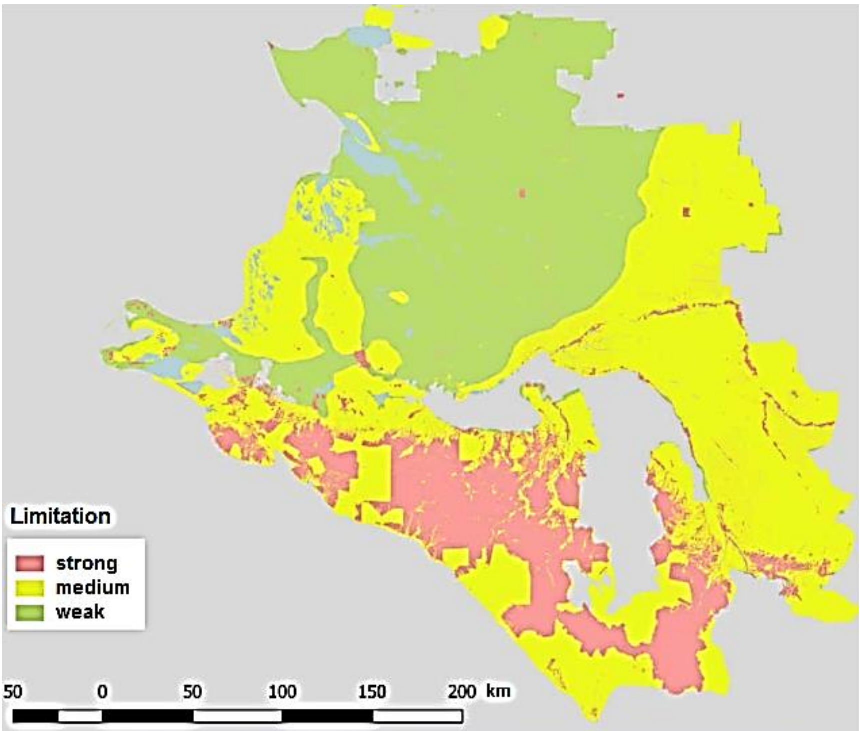


Figure 4.6 The suitability of the Krasnodar region for installation of RES facilities in terms of exclusion zones
The map is produced by author together with Rafikova Julie from Laboratory of renewable energy of the Moscow State University, Russia.

The constraint factors mentioned above originate from different “sources” and may be classified by following categories*:*

Terrain is the first significant limiting factor for the installation of RES facilities. An impact of this factor may become apparent through the amount of natural resources along with dangerous geotechnical processes and an aesthetic value of the area as well.

Hydrographic network is considered a strong limiting factor on RES maps. It should include the river net, channels, lakes, swamps, water storage basins and water protection areas corresponding to the scale and level of generalization. This thesis suggests that a water protection area (in addition to water bodies) should be considered a buffer zone which extent is determined by the Water Code of the Russian Federation and may amount to 5 – 200 m depending on the high-water line (Water Code of the Russian Federation ed. 43, 2016).

Dangerous geological processes may have the same impact on installation of RES facilities as on other engineering structures. The existing geotechnical zoning and cadastral data (KubanCadaster, 2016) was used in this thesis while conducting the evaluations of the geological framework of the Krasnodar region, soil analysis and monitoring of existing erosion processes. The following areas have been considered on the basis of geotechnical zoning data: karst and suffosion spreading zones; areas of possible underflooding; slope hazard areas; seismic extension areas; abrasion and erosion processes of river valleys; hurricane winds; sudden icing; subsidence of ash and loess etc.

Land use limitations for the installation RES facilities are especially urban settlements, airports etc.

Natural areas of preferential protection, which often have a considerable coverage, belong to environmental factors. For instance, the Caucasus Nature Reserve situated in the Krasnodar region covers total area of 2,848 km^2. However, such areas were recently used for RES projects trying to solve local energy supply problems (RIA News, 2015).

Ornithological areas were be selected on the basis of specific criteria developed by the BirdLife International requirements (BirdLife, 2016). Priority has been given to rare, decreasing in number or forming mass rookeries species of birds, whose migratory routes may be at risk due to RES installations.

Properties of historical and cultural heritage and *archaeological sites* may also limit potential locations for the installation of RES facilities. The aesthetic, tourism and recreation values are important to preserve especially in regions with unique natural and recreational resources.

According to the assessment of the limiting factors, areas having weak limitations amount to 34,819 km^2 or 50% of the total area of the Krasnodar region, indicating a comparably large area for the exploitation of various types of RES. Medium limited areas amount to 23,442 km^2 or 34% of the Krasnodar region. Around 9,600 km^2 or 14% of the Krasnodar region are not suitable for the installation of RES facilities and are excluded from further assessment. The remaining areas of 2% require a more detailed assessment in terms of the scope of the RES project and the related environmental impact.

The application of exclusion and buffer zones revealed that districts Bryukhovetsky, Vyselkovsky, Korenovsky, Krylovsky, Leningradsky, Pavlovsky, and Timashyovsky have maximum suitable locations for the installation of RES facilities in terms of the theoretical resource potential. In contrast, the most severe environment may characterize districts Apsheronsky, Mostovsky, Seversky, and Tuapsinsky. The remaining districts have a set of various limitations and require a more detailed assessment of the theoretical resource potential.

At the further assessment levels, the evaluation of RES potentials accounted for specific technological, infrastructural and economic requirements for the installation of RES facilities and included such factors as the distance to existing grid lines, market access, population density, etc. Digital layers with more specific limitation factors were combined with the theoretical natural resource potentials for all three types of RES and are shown in the sections 4.5 to 4.7.

4.3 Market climate for RES in the Krasnodar region

The spatial distribution of areas with different market conditions is depicted in Figure 4.7.

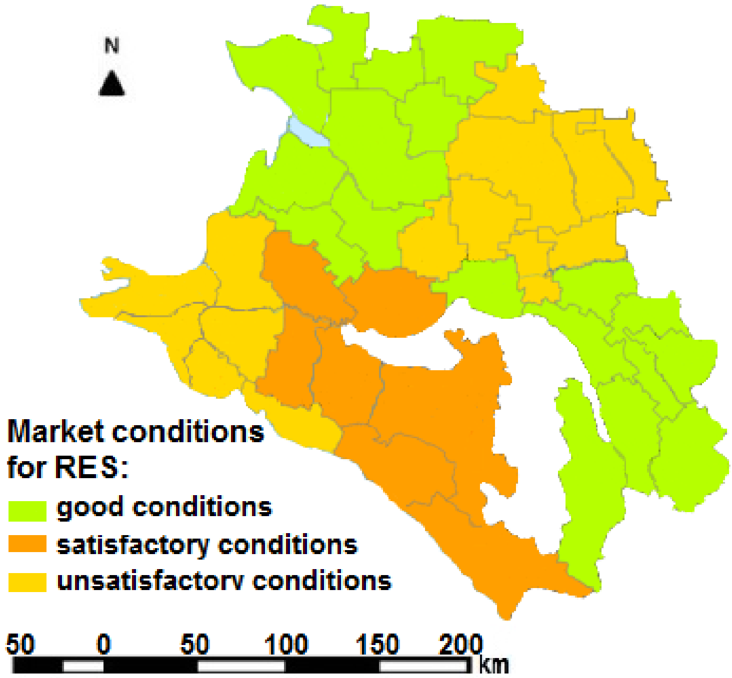


Figure 4.7 Spatial distribution of factors affecting market conditions for RES introduction in the Krasnodar region

Around 35% of the Krasnodar region has good conditions in terms of the market climate for the introduction of RES facilities. In this areas it may be necessary to finance such allied industries as research efforts in the field of alternative energy as well as manufacturing of the equipment necessary for constructing and completing electric power plants based of RE. These areas are well away from regional centers and thus may require a full range of documentation (due to the great bureaucracy procedures) to start to install RES facilities.

Areas with satisfactory conditions represent around 56% of the Krasnodar region. The rest of the area of 9% has satisfactory conditions. This parts of the Krasnodar region are transit areas of large energy mains coming from neighboring regions to supply energy to the Krasnodar region. Modernization along with the work on the energy supply in these parts of the region is suggested to concern only conventional energy. Therefore, these parts were initially excluded from programs for RES development in the Krasnodar region (KubanEnergo, 2016).

In the Krasnodar region, no subsidies have been provided to compensate electricity costs produced from RES. At this point, there may be many bureaucratic and financial (i.e. local) barriers for further development and successful implementation of RES projects. For instance, high costs for the connection of even small RES facilities to the main energy grid for cases of overproduction or many bureaucratic and institutional barriers for megawatt-class projects have a negative effect on the development of RES. This indicates the need of the region for the decentralized local RE stations of small and medium megawatt-class (up to 5 MW).

Nevertheless, amendments to the Federal Law № 35 were adopted in November 2015. They were first to establish the following basic provisions on legislative support for RES development in Russian Federation:

(1) Stimulation by the amount of the produced energy only;

(2) Fixed payment tariffs (Feed in Tariff (FIT));

(3) Flat-rate benefit to a market price;

(4) Development of a new executive order on numeric values of benefits.

However, these amendments are still very general and do not provide concrete reference values.

According to the Regional Energy Commission, issues related to subsidies for electric energy and energy efficient measures may be realized in 23.7% of regional target-oriented programs (Regional Energy report, 2014). This implies that there is still a substantial potential for the development with regard to financial support for introduction of energy efficient measures including RES. Attraction of more than ₽180 billion (€2,570 million) until 2035 is suggested within the implementation framework of the electricity development strategy of the Krasnodar region (Hevel solar systems, 2015).

Within the framework of the program Development of Renewable Energy Sources and Modernization of Electricity Industry of Russia for the period until 2020, investment projects for the construction and operation of wind power plants (total capacity, 400 MW) at Blagoveshenskaya, Gelendzhik, Anapa and Yeysk sites have been prepared (Popel et al, 2016). The following two investment projects are currently at the design stage: the construction of the modern wind power plant Blagoveshenskaya (the largest in Russia) with installed capacity of 120 MW on the outskirts of Anapa and the construction of the wind power plant Mirny with the planned capacity of 60 MW in Yeysk district. The scheduled implementation date for wind power plants is 2020 (SOWITEC GmbH, 2016). From 2020 on, it is planned to attract implementation of new projects on RES using the following measures:

(1) Attracting investments in RES projects to provide generating capacities in the most energy-deficient areas,

(2) Implementation of attractive investment programs for RES development companies.

Against this background, the Krasnodar region may be mainly interested in investing in reduction of energy deficits and the improvement of the energy supply at the expense of RES. Subsidies for introduction of RES into the market may be of particular relevance for state authorities that may seek new solutions for the energy supply due the presence of many dead-end feeders in the existing energy network. For this purpose, the Krasnodar region possess a high decentralized potential for the introduction of RES.

4.4 Wind energy potential

Stage 1: Available Theoretical Potential

The theoretical wind energy potential of the Krasnodar is represented by the spatial distribution of the average annual wind speed (Figure 4.8).

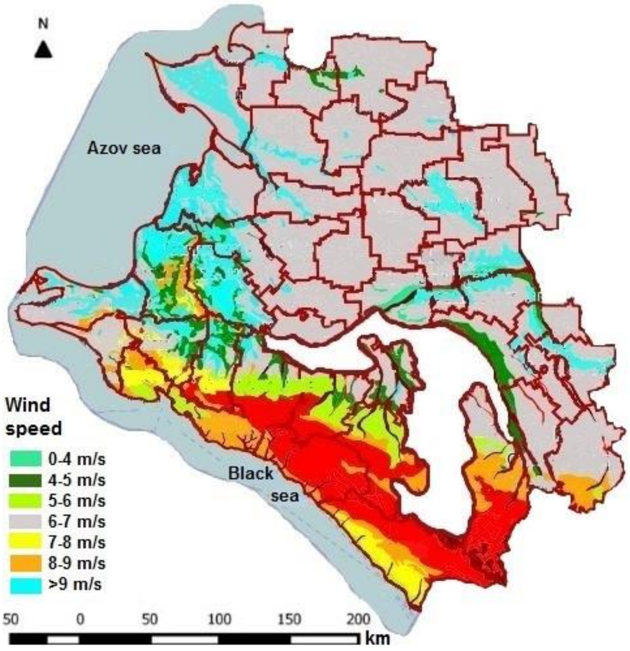


Figure 4.8 Stage 1: Wind speed distribution of the Krasnodar region

The application of constraints (wind regime, slope, urban area, etc.) prohibiting the installation of wind turbines reduced the theoretical potential and yielded all the available sites for technical exploitation (Figure 4.9). All the available sites are grouped in 6 land suitability classes. Sites with wind speeds > 9 ms^{-1} and no environmental and infrastructural restrictions are classified as having high suitability level. Sites with a high suitability level are lying in the north and south-west and cover an area of 12,000 km^2, i.e. approximately 1/6th of the Krasnodar region.

The distribution of the wind power density across the Krasnodar region (Figure 4.10) also confirms the location of the best-suited sites for the exploitation of wind energy. The wind power is a measure for the kinetic energy in the wind motion. As wind power density of ≤ 200 Wm^{-2} is characterized as poor to fair, the most suitable sites are in the north and south-west of the region.

Sites of good and medium suitability have wind speeds > 9 ms^{-1}, but may also have infrastructure limitations (e.g. large distance to the existing power grid). Frequent hurricane winds and floods characterize sites of bad suitability. The territory of the Caucasian Reserve is excluded due to prohibition of the installation of all technical facilities. The not suitable areas are sites with protected water bodies.

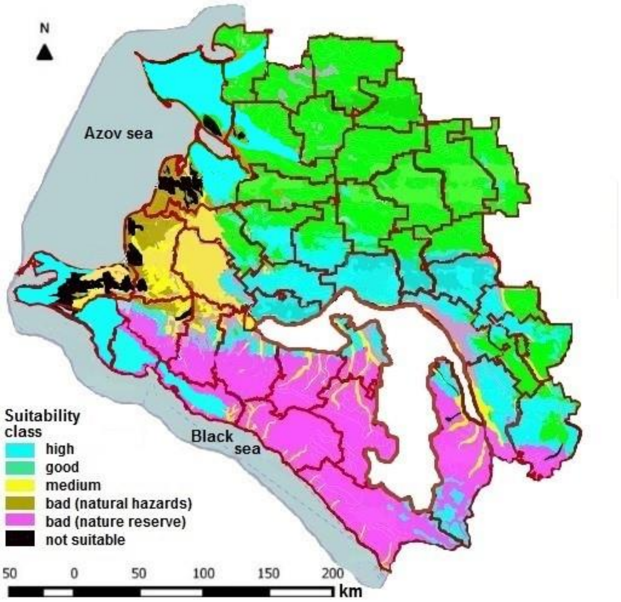


Figure 4.9 Stage 1: Available theoretical wind potential of the Krasnodar region distinguished in suitability classes

Stage 2: Available Technical Potential

For all sites of the high suitability class and power density of 250 Wm^{-2}, the maximum installed capacity of wind turbines is estimated to yield an electricity production of 23 GWh.

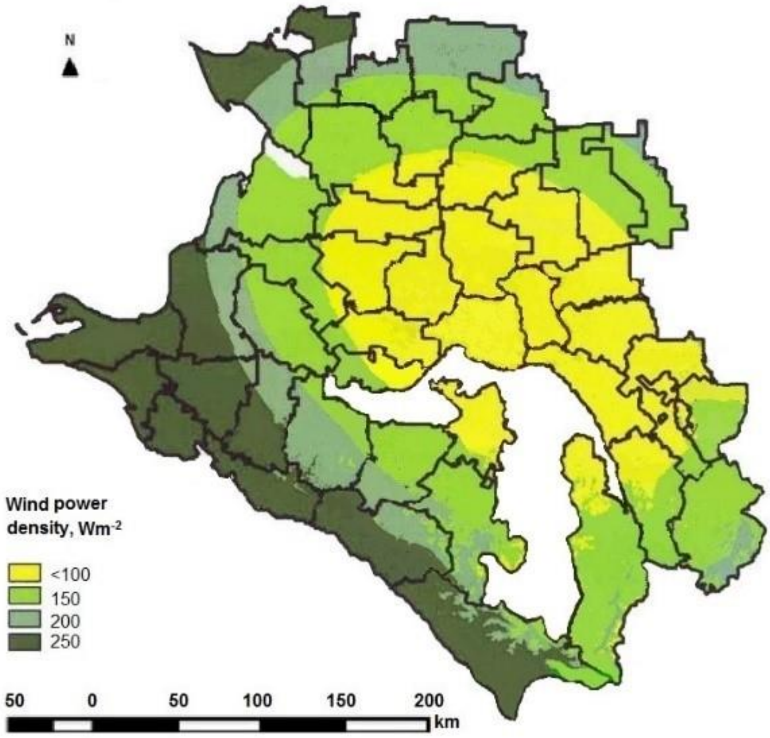


Figure 4.10 Stage 2: Spatial distribution of the wind power density of the Krasnodar region

Figure 4.12 and Table 4.2 demonstrate the location of districts with the highest technical wind energy potential. For the site Mirny (district Yeysky) (Table 4.2), the CUBE GmbH (2007) reported an estimation on the technical wind energy potential of 60 MW. For the estimation, wind speed data was collected on site using wind masts. The present estimation of the technical wind energy potential shows a high correspondence with that of CUBE GmbH. The small difference between the on-site and the remote (this thesis) estimations is probably due to different type of wind turbines that were used for the technical wind energy output (CUBE GmbH, 1.8 MW turbine; this thesis, 2 MW wind turbine).

Table 4.2 Districts with the highest technical potential for wind energy production

	District: Location	**Maximum energy output,** MW year^{-1}
1	**Anapsky:** (1) Bugazskaya spit; (2) suburbs of Anapa city	320 (1) 170; (2) 150
2	**Temryuksky**: (1) Taman peninsula; (2) Chushka peninsula; (3) suburbs of Temryuk city	400 (1) 150; (2) 100; (3) 150
3	**Novorossiysk:** suburbs of Novorossiysk city	200
4	**Gelendzhik:** suburbs of Gelendzhik city	200
5	**Primorsko-Akhtarsky:** suburbs of the town Primorsko-Akhtarsk	170
6	**Yeysky:** (1)Mirny (2) other suburbs	170 70 100

The maxim annual technical potential for the sites of the high suitability class is estimated to be 1.8 MWh km^{-2} year^{-1}. The calculation of the electricity production based on the characteristics of wind turbines Vestas80 (Figure 4.11). It is assumed that Vestas 80 has an efficiency ratio and 28% produces 40 – 70 % of time electric energy during the year according to the annual wind speed distribution of the Krasnodar region.

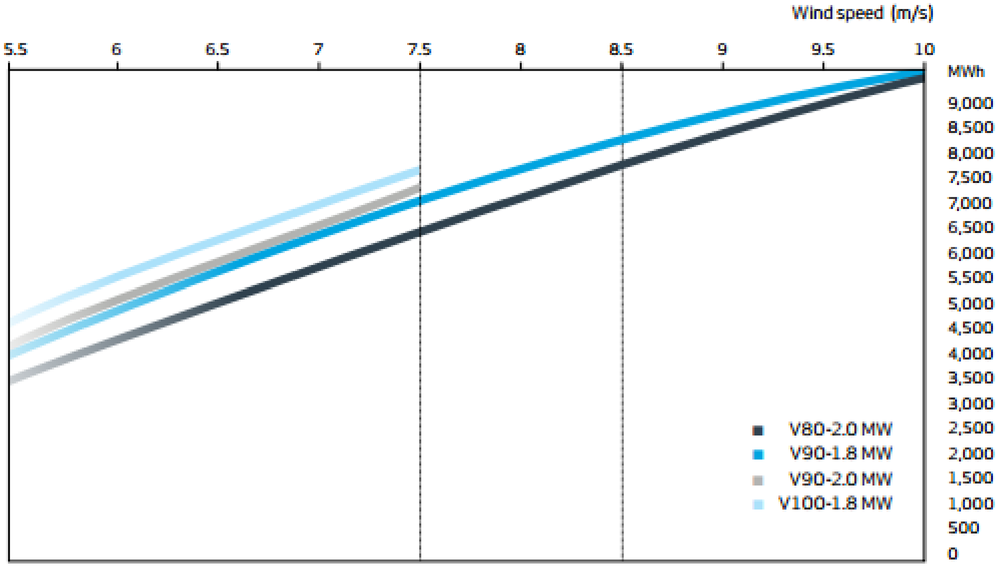


Figure 4.11 Stage 2: Annual energy production for different Vestas turbines
Vestas tutorial, (2011)

The estimation of the annual technical electricity production of 23 GWh $year^{-1}$ based on data for the years 2014 – 2016. For the same period, the energy deficit in the Krasnodar region amounted around to 22 GWh $year^{-1}$. Theoretically, the estimated technical wind electricity potential is sufficient to balance the energy deficit. The construction of wind power plants is reasonable especially for the coastal zones of the Azov and Black Seas since the construction sector along with access ways are available there, and the appropriate distance from direct electric energy consumers may be provided. Furthermore, there is a well-developed electric grid infrastructure with 110 – 220 kV power transmission lines as well as an adequate transportation network (highway and railroad) capable of delivering wind energy equipment to the installation site fast and inexpensively.

Stage 3: Available Economic Potential

The economic feasibility for the construction of wind power facility in the coastal zone is demonstrated using a hypothetical wind energy production facility of 40 – 60 MW at the area of Yeysk and Anapa (Figure 4.12). Input characteristics such as the number of wind turbines, rated generation power, etc. for both facilities are depicted in Table 4.3.

Table 4.3 Economic potential based on two wind farm projects near Yeysk and Anapa

Wind park location	**Amount of wind turbines,** 2 MW	**Rated power,** MW	**Overall project costs**	**Cost for 1 kWh**
Yeysk	30	60	€7.2 million	€0.20 – 0.15
Anapa	23	46	€6.2 million	€0.20 – 0.15

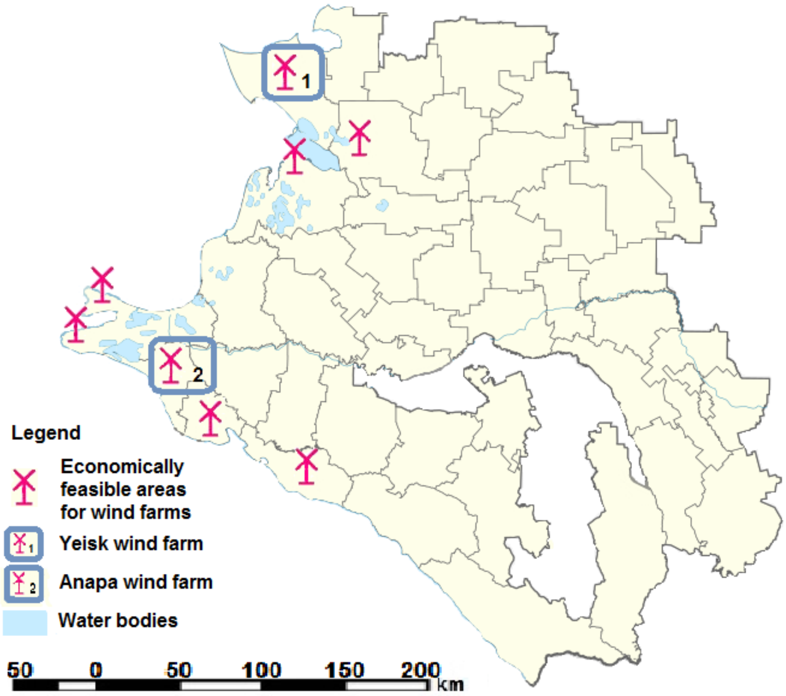


Figure 4.12 Stage 3: Economically feasible areas for the construction of wind energy facilities

The total economic potential of wind energy along the coastline of the Azov Sea amounts maximum of 350 MW. The total costs for the Yeysk wind energy facility including design works, equipment, installation, and commissioning were estimated to be €7.2 million. If the project is fully funded (installation and putting into operation of 20 wind turbines) and financed through the state grant amounting to 50% of total investments, then the payback period of funds provided on a repayable basis at the price for 1kWh of €0.20 (tariff for rural area) will be 7.6 years. With the cost of 1 kWh electricity of €0.15 (tariff for urban area of Yeysk) the payback period will be 12 years. After this period, the wind farm will generate net income for further 18-20 years. This price estimation is in accordance with Grigorash (2013) demonstrating the cost for 1 kWh wind electricity produced in the same area of €0.18.

The total economic potential of wind energy along the coastline of the Black Sea amounts only 400 – 450 MW. This area is characterized by seasonally growing demand for electric energy due to high concentration of tourism and recreational facilities. Anapa is one of the tourist centers of the Black Sea coast and have suitable sites for the construction of wind energy facilities. The total expenditures of a hypothetical facility with 23 wind turbines generating about 46 MW (Figure 4.2) are estimated to be €6.2 million. Putting the wind energy facility into operation is designed to approach in two steps. First, the installation of a 25 MW capacity with the unit generation cost of €0.2 for kWh takes place. This energy production allows for partial abandonment of the centralized energy supply especially for the sanatorium-resort facilities. Recreational facilities, which are facing an energy deficit of 30 MW $year^{-1}$ are the potential consumers of this energy. Thus, a continuous sale of the energy produced at the first stage may be ensured by the tourism and services sector. Second, the remaining 15 MW are put into operation within 3 – 5 years. These capacities may be distributed between residents of Anapa at a price of €0.15 per kWh, which would not be attended with a proportional reduction of total expenditures for a reconnection of energy consumers. The two-step development scheme may provide missing capacities and partially cover the energy deficits in Anapa.

According to the report of SOWITEC GmbH (2016), only 5-7% of the technical potential can be realized into the economic potential of wind energy in the Krasnodar region. Moreover, based on the author's calculations this amount is even smaller and equal to 3.6 % (around 800 MW) from of the original technical potential.

However, small wind energy systems, which typically generate just enough power to meet the demands of a household, farm or small business, belong to a renewables genre that continues to grow in stature. Small wind turbines (SWT) are now more reliable, quieter and safer than those introduced in past decades. According to SolarWindHome (2016), one 3 – 5 kW wind turbine is needed to cover the full consumption of average Russian household. The cost of wind turbines of this type produced in Russia is currently ranging from €2,400 to 4,250 depending on technical specifications and warranty period.

4.5 Solar energy potential

Stage 1: Available Theoretical Potential

Figure 4.13 demonstrates the theoretical solar energy potential of the Krasnodar region. While the areas with the highest yield of solar irradiation of 1400 – 1500 kWh m^{-2} are in the coastal zone of the Azov and Black Seas, the location with lower solar radiation of 1200 – 1300 kWh m^{-2} are further inland. Thus, the region is attractive for the development of solar energy.

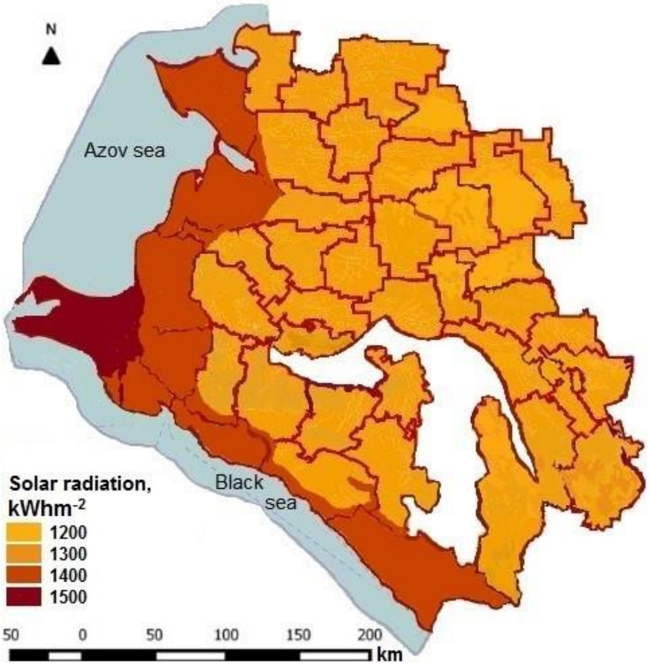


Figure 4.13 Stage1: The theoretical solar energy potential of the Krasnodar region

The application of exclusion zones and restricting factors limiting the installation of solar energy facilities have reduced the initial theoretical solar energy potential (Figure 4.14). Around 38% (29,000 km^2) of the total area of the region is highly accessible for developing solar energy. Another 34% (26,000 km^2) of the total territory have weak or a medium degree of limitations and may be characterized as having a “good” or “medium” suitability. Areas of “bad” suitability or “not suitable” at all amount to 12% and 16% of the Krasnodar region.

According to Kostukova et.al (2014) - the whole territory of the Krasnodar Territory is suitable for use PV systems as well solar collectors, due to “unlimited” possibility for installation of solar systems on the most productive angle of inclination. But still, there are environmental and market restrictions that have not been taken into account.

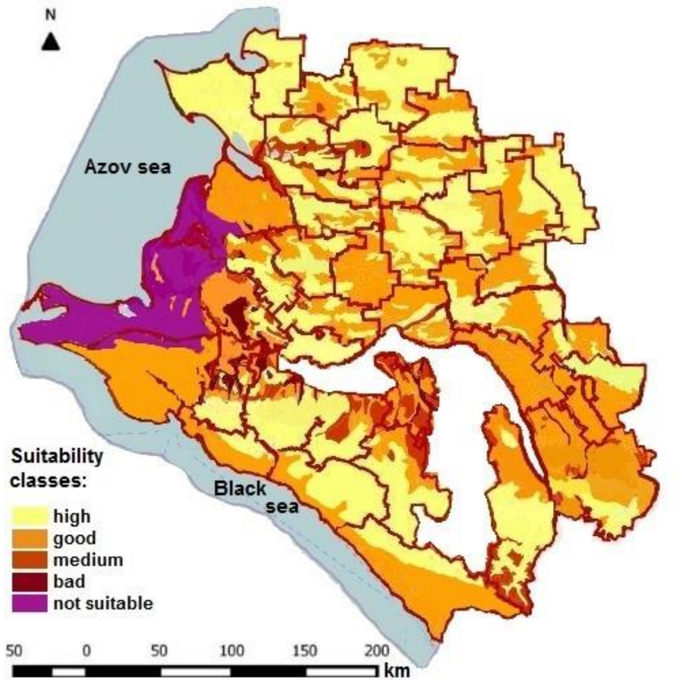


Figure 4.14 Stage 1: The theoretical solar energy potential of the Krasnodar region after application of limiting factors and grouped in suitability classes

Thus, not much of the territory of the region has been excluded from the initial theoretical solar energy potential. The total area available for the technical exploitation of the solar energy is estimated to be 55,000 km^2. However, not all the territory is technically accessible for the installation of solar energy facilities, which indicates that the area may be further reduced. Charabi and Gastli (2010) propose a 10% factor for correction of the available area for the technical potential of solar energy.

Stage 2: Available Technical Potential

For reasons of rationalization and viability, the rooftop area of 550 km^2 was used in this thesis for the assessment of the technical solar energy potential and the technologically exploitation via PV modules. This area implies PV systems in the decentralized and sparsely populated areas of the region for rural application on roofs of private households, farms and industrial buildings.

The efficiency of PV energy production depends on only solar radiation. The cloudiness and albedo play an important role in assessing technical potential, and therefore were included in the calculations (Figure 4.15).

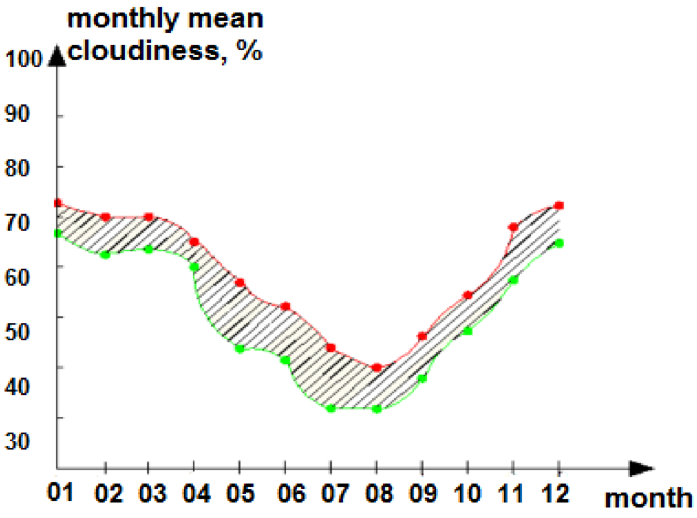


Figure 4.15 Stage 2: Average monthly values of the sky cover in the Krasnodar region Author's calculation according to KubanMeteo, 2015-2016. Green line indicates the night trend; red line indicates the daily trend.

The analysis of the average monthly cloudiness has revealed that the annual average cloudiness in the Krasnodar region may exceed 55% of time. The PV energy production on a cloudy day may decrease in comparison with that on a sunny day due to less solar radiation falling on the receiving surface. Usually, a PV system may generate up to 80% of its maximum capacity on a partly sunny day. This value may decrease to 30% on a cloudy day (Gastli and Charabi, 2010). Due to these factors, the energy conversion efficiency may vary within a cloudy day in a range of 800 – 1,000 Wm^{-2}.

The radiation balance of the Krasnodar region may amount to 16 – 35% of the absorbed solar radiation in winter and to 50 – 66% in summer (KubanMeteo, 2015). The ground albedo values in the area under consideration may vary from 22 to 35%. Thus, 26 – 32% and 20 – 22% of incoming short-wave radiation may be reflected by the surface. The effective radiation in coastal area and on the territory of the Caucasus Nature Reserve with dense vegetation may amount to 30 – 33% of total radiation, while in areas with thin vegetation it may be 34 –39%.

By taking into account the average annual solar irradiation, the average monthly cloudiness and the albedo factor, the average annual energy output was estimated to yield 3.7 kWh m^{-2} day^{-1} or 1,350 kWh m^{-2} year^{-1}. Private one-, two- and three-store houses account for 53.6% of the housing stock in the Krasnodar region (KrasnodarStat, 2015) have chosen for estimation of the regional technical potential of PV systems. Thus, the technical potential of solar energy was calculated as a function of the total available rooftop area. The overall technical solar energy potential was calculated to yield 24 GWh year^{-1}. This estimation is in accordance with the Voeikov Main Geophysical Observatory (2014) and their estimation of the overall technical solar energy potential of 25 GWh year^{-1}. The explanation for the lower annual solar energy potential is the fact that the present assessment accounted for the cloudiness and albedo as additional factors that have reduced the PV system output (Figure 4.16).

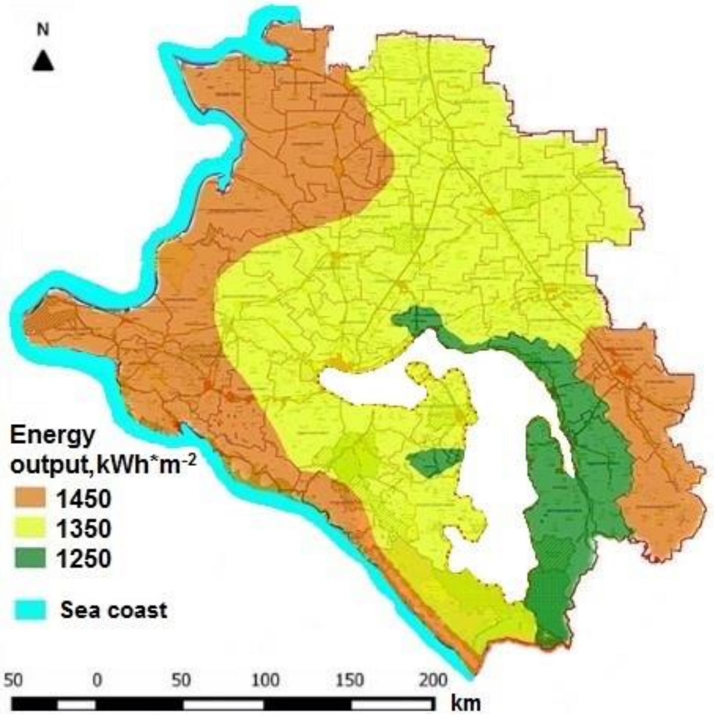


Figure 4.16 Stage 2: Spatial distribution of the technical solar energy potential (Whm^{-2})

The daily average total solar radiation on a horizontal surface within the Krasnodar region may amount to 3.5 – 4.0 kWh m^{-2} day^{-1}; from April to October (warm half-year) average

– 5.0 – 6.0 kWh m^{-2} day^{-1}; summer time can amount – 5.0 – 6.5 kWh m^{-2} day^{-1}. Thus, the period from April to October has been selected as the most productive time for further analysis. This period is characterized by increased energy consumption related to the tourist season as well as to an active air conditioning from May to October. Simultaneous occurrence of seasonal peak values of solar radiation and an increased energy demand make the Krasnodar region a favorable area for the development of solar energy projects (Figure 4.17).

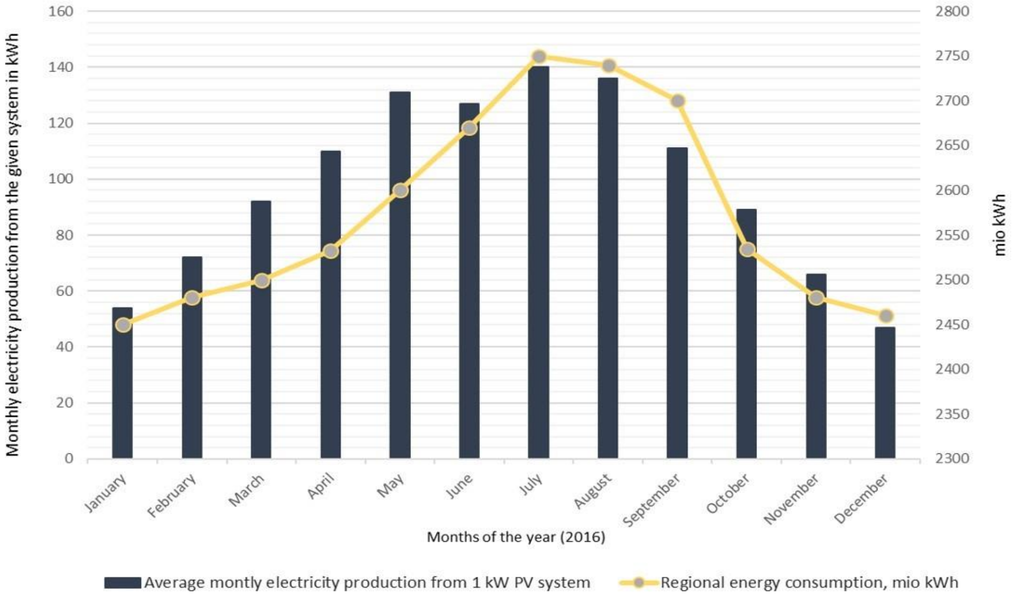


Figure 4.17 Stage 2: Variations in regional energy consumption and average electricity production from 1KW PV system by month in Krasnodar region.

For the assessment of the economic solar energy potential, areas belonging to either the population or tourism and services sector were grouped and the available roof area of private household as well as recreational resorts was estimated to amount to 332 km^2. Thus, the total economically useful potential amounts 4.5 GWh year^{-1}.

Therefore, it is possible to rely not only to cover local energy deficits but also an increasing demand in the peak load periods during the tourist season (the estimated period is from May till October) actively. The increases of energy demand of the tourism and population sector coincide with the period of the longest sunshine duration and thus this sector was hypothesized to have the most benefit form installation of PV systems. The peak energy demands occur during the tourist season and due to active air conditioning.

Stage 3: Available Economic Potential

The spatial distribution of the generation costs for 1 kWh are displayed in Figure 4.18.

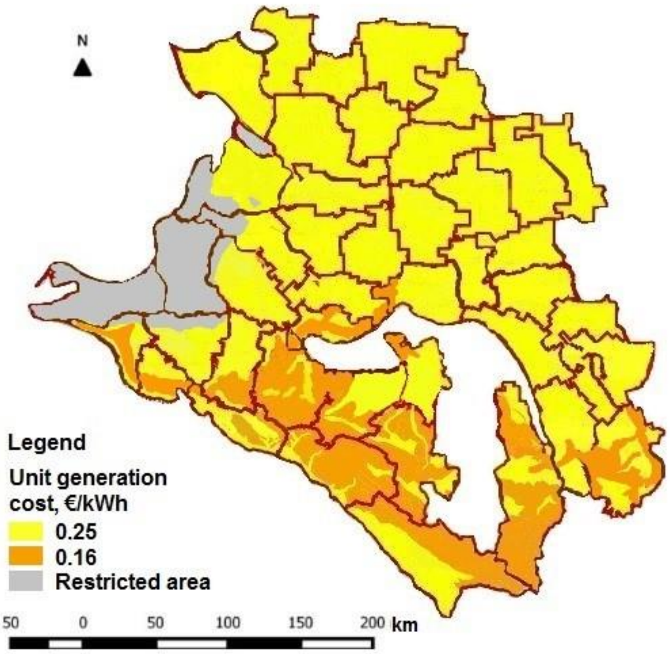


Figure 4.18 Stage 3: Spatial distribution of PV production unit energy cost

The generation prices for 1 kWh range from €0.16 to 0.25 kWh. The comparably lower generation costs are related to large solar energy projects, which are generally more cost-effective than small projects. Therefore, allocated areas with prices of €0.16 correspond to locations with large recreational complexes and peak values of solar radiation from May to October. However, these prices are considerably higher than the prices of traditional energy sources in the Krasnodar region (€0.06). Therefore, the benefit of solar energy for this region is primarily in covering the growing deficit and preserving the ecology at a level of recreational needs and requirements of environmental legislation.

Introduction of solar energy facilities may become particularly critical in the Krasnodar region since the majority of tourists (up to 13 million per year) visit the region from May to October (KrasnodarStat, 2015). One-third of tourists stay for 10 days (KrasnodarStat, 2015) and consume around 2.4 kWh day^{-1} and person. Under these circumstances, solar PV systems may return the investment costs within 7 – 8 years. An example is the “Smart Railway Station” in Anapa whereat most of energy consumption has been replaced by solar energy via solar cells, and initial investments returned within 7 years (KubanMeteo, 2017).

An average family consumes from 2,556 kWh year^{-1} living in an apartment to 3,420 kWh year^{-1} when living in a house (Ministry of Fuel and Energy Complex, Housing and Communal Services of Krasnodar Region, 2017). Given that an average annual solar energy production in Krasnodar region may yield 1,350 kWh m^{-2}, an area of ≥ 2 m^{2} of PV panels for an apartment and ≥ 3 m^{2} for a house is needed for private application to reach self-sufficiency for a family of 3 – 4 persons.

Grid connection costs reach in the Krasnodar region up to ₽1 million (i.e. €15,000) depending on the remoteness from the central power grid and other infrastructure factors. This amount is equivalent to the procurement of all necessary constituent parts of a PV system with a nominal electricity generation capacity of 4,500 – 5,400 kW. This generation capacity would be sufficient to cover energy demands of an average family or to power four double rooms in recreational resort.

However, under the current national energy policy, the generation of PV electricity is still economically not feasible. With regard to energy policy instruments, it is advisable to develop a governmental subsidy program in order to introduce new solar energy facilities in areas with high available technical potential to cover local electricity shortages. However, the government longer discusses the possibilities of subsidies for RES, despite the fact that the region continues to receive funds from the federal budget for the development of RE programs. Indeed, the Krasnodar region may be one of the most economically promising regions in Russian Federation for the generation of PV electricity as well as for solar water heating systems (IRENA, 2015). However, only a few projects are currently carried out at a private level by RES enthusiasts and by researchers as small pilot projects without any commercial benefit.

4.6 Biomass energy potential

Stage 1: Available Theoretical Potential

The Krasnodar region has a well-developed agriculture and is the leader in producing agricultural products in the Russian Federation (KrasnodarStat, 2016). Grain growing, plant growing (sunflower, sugar beet and maize) and animal husbandry (mainly cattle, pig breeding and aviculture) are the key branches of the agricultural sector in the Krasnodar region.

The theoretical biomass potential of the Krasnodar region is depicted in Figure 4.19. The annual biomass residues vary from 0 to 2,400 t km^{-2}. This amount of biomass relates to plant residues only and does not include farm wastes and organic wastes of settlements, which will be addressed later on.

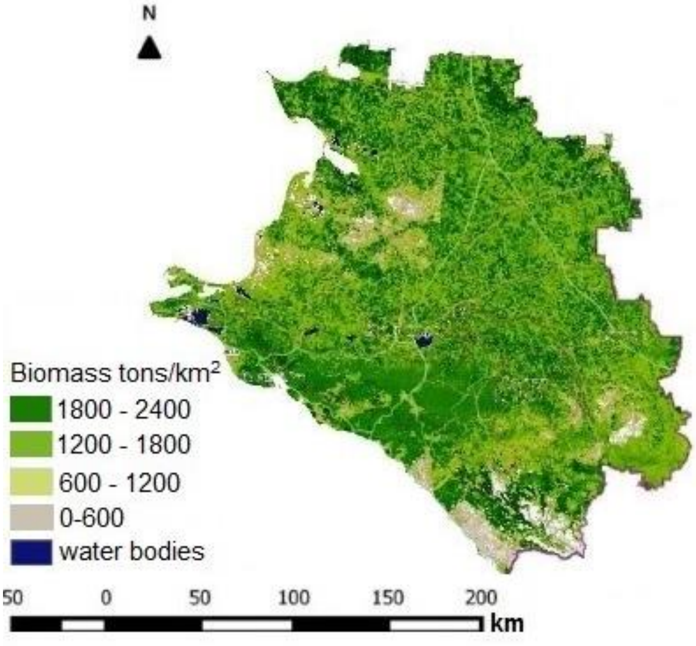


Figure 4.19 Stage 1: Model of the theoretical biomass potential
Spatial vegetation layer from GIS-Lab (2016). Territory of Republic of Adygea was not excluded.

The application of exclusion zones (mainly nature reserves, forests and gardens) reduced the initial theoretical biomass potential and yielded an available potential (Figure 4.20). The southwestern part of the Krasnodar region is occupied by forests with nature reserve status. Farmland and residues from crop dominate the remaining territory. Thus, the available biomass potential in the study region is abundant. The suitable land area amounts to 59,000 km^2 and involves the following types of agricultural activities: hay harvesting (25%), tillage (55%) and pasteurage with farms (20%). Despite potential positive effects from biogas plants the territory of the Caucasus Nature Reserve (around 3,000 km^2) was excluded. In the Caucasus Nature Reserve Reserve, there are species of flora and fauna listed in the Red Book of the Russian Federation, which legally prohibits any economic activity in this area (Red Book of the Russian Federation, 2015*)*. Regional wetlands (around 3,000 km^2) were also excluded from the potential area for biomass facilities.

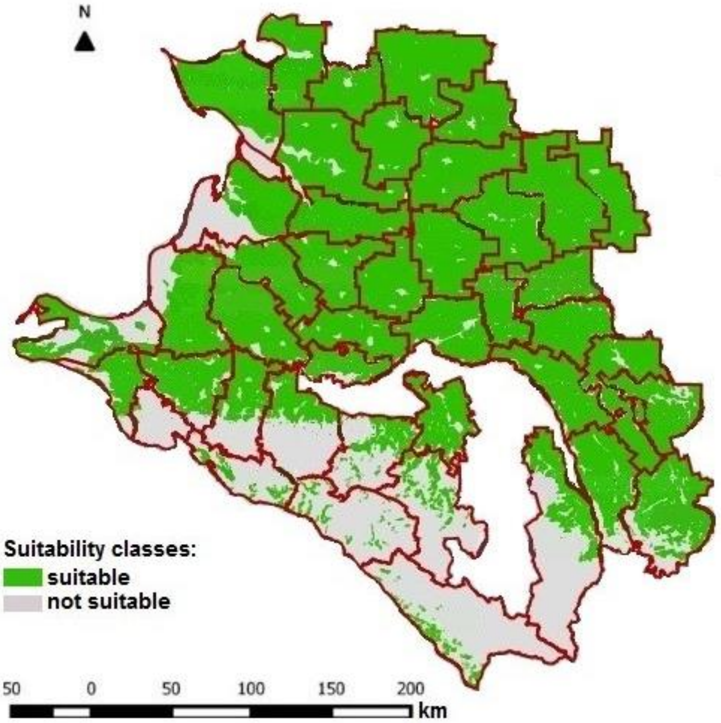


Figure 4.20 Stage 1: The available theoretical biomass potential after application of exclusion zones
Mainly the territory of the Caucasus Nature Reserve and flood areas are excluded.

The Krasnodar region have the highest annual average vegetation growth in Russia with more than 2,000 tons km^{-2} (Saevitch et al., 2016). Having a suitable area of available biomass of 59,000 km^2 the region generates annually 118 million tons plant biomass. Chernokov (2017) reported that 1 kWh electricity can be produced from about 1 kg biomass using combustion technology in the Krasnodar region. Based on this transfer parameter, the annual initial biomass power potential in the region may amount to 118 TWh.

Stage 2: Available Technical Potential

The technological energy potential for biomass energy in the Krasnodar region is estimated to around to 30 GWh year^{-1} (Table 4.4; Ministry of Agriculture and Processing Industry of Russia, 2016). The estimation included data on animal wastes and organic waste of settlements, which significantly contribute to the overall energy potential. As can be seen, the combined technical potential of biomass is significantly less than the values on the initial potential.

Table 4.4 Technical biomass potential from different types of biomass

Type of biomass	Usable biomass	Theoretical power potential, MWh year^{-1}
Crop waste	Straw and stems (cereals, legumes)	4,500
	Tops (potatoes, vegetables, sugar beets)	2,500
Animal waste	Cattle	7,300
	Small cattle	850
	Pigs	650
	Chickens (laying hens + broilers)	250
Organic waste of settlements	Food industry waste	3,530
	Liquid household waste (sewage sludge)	2,470
	Municipal solid waste	7,600
	Total	**29,650**

Data on types of biomass originate from the Ministry of Agriculture and Processing Industry of Russia (2016).

Figure 4.16 demonstrates the spatial distribution of the biomass energy output on the district level. Taken all districts together, the total estimated technical potential of biomass energy amounts to 25 GWh year^{-1}. The result is initially different from the data obtained from the Ministry of Agriculture and Processing Industry of Russia (Table 4.4), since the territories with restrictions on economic activities such as nature reserves were excluded from the calculations (Figure 4.21).

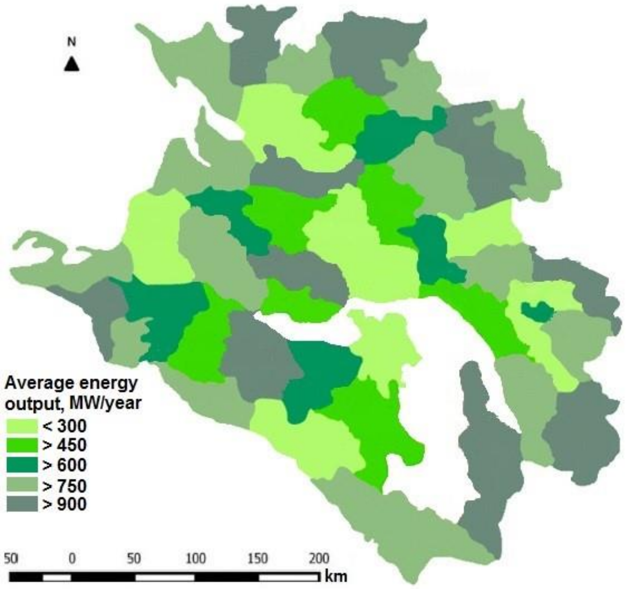


Figure 4.21 Stage 2: Spatial distribution of technical biomass energy potential

The productive bioenergy potential of the agricultural wastes in the Krasnodar region is suggested to be strategically an important energy resource of the region (Grigorash et al., 2013). According to the draft of the regional development program for the Krasnodar region by 2020, all biogas energy facilities based on biomass waste may produce more than 100 MW heat or 80 MW electricity per day. However, in comparison with the results of this thesis, these production volumes are too optimistic and may never be achieved.

Stage 3: Available Economic Potential

The assessment of location that fulfil the requirements specific for an economic viable installation of biomass facilities is given in Figure 4.22 and 4.23. The results are presented through a distribution of possible projects for urban and rural energy consumer (and at the same time deliverers of biomass) from biogas plants.

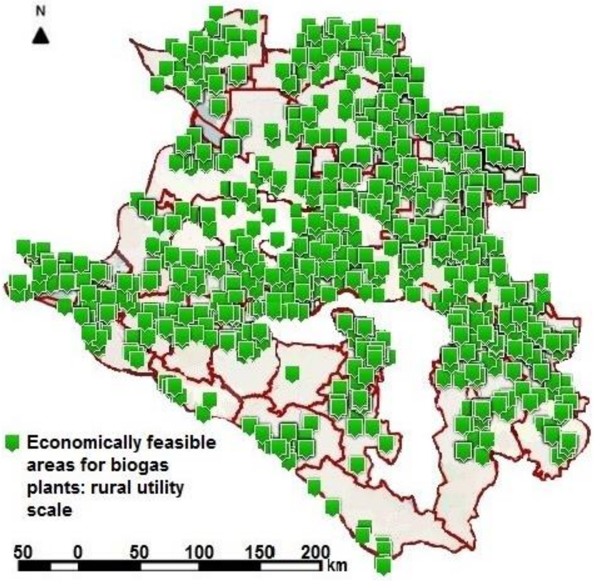


Figure 4.22 Stage 3: Spatial distribution of annual usable biomass for rural biomass power plants

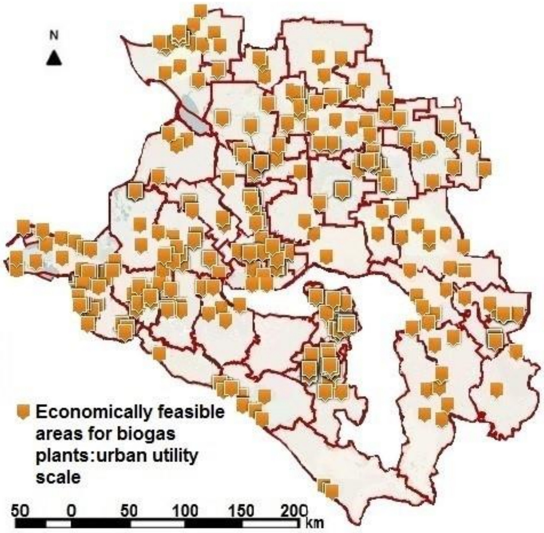


Figure 4.23 Stage 3: Spatial distribution of annual usable biomass for urban biomass power plants

The economic feasibility of a bioenergy technology is generally based on specific economic factors, which vary with the energy demand/deficit, price of biomass energy unit (€/kWh) and many others (installation costs, transport costs). Since the cost of equipment generally amount to up to 60% of the total project cost, the equipment cost are the main investment expenditures when developing a biogas plant. Nevertheless, the following specific cost components were also taken into account while calculating the economic potential and investment value of a biogas plant:

(1) Cost of the design estimate and engineering documentation;
(2) Cost of equipment and its delivery;
(3) Cost of construction works;
(4) Cost of testing and commissioning;
(5) Other costs (permissions, coordination, personnel training etc.).

The amount of capital costs for the construction of a biogas plants are given in Table 4.5.

Table 4.5 Capital costs for the construction of a biogas plants

Bioplant capacity by poultry manure recycling, tons day^{-1}	**Energy production kWh day^{-1}**	**Capital cost (€) with a cogeneration block***
10	2,600	156,082
50	13,000	344,882
100	26,000	677,725
200	52,000	1,239,570
300	90,000	1,807,608

* The cost includes a cogeneration block of the TCG-series (MWM GmbH, Germany) including value added tax and custom fees.

Based on the experience of the biomass plant project implemented nearby the city of Tikhoretsk in 2012, previous capital costs for the construction have been reduced almost two times due to the German cogeneration block combined with locally produced installation parts (Agrobiogas Ltd., 2015). This indicates an optimal scheme for combining local with foreign constituent parts.

In general, the installation of biomass power plants may allow obtaining energy for different applications simultaneously, namely as engine fuel, heat or electric energy. Therefore, a regional program on decentralized biomass energy production is developed that intends to cover 44% of the region’s energy deficit with biomass energy (Ministry of agriculture of the Krasnodar region, 2017). However, there is no clear legal framework and information on subsidies from the government.

The additional factor having a positive impact on the market attractiveness of biogas plants in Krasnodar region is the production of a high grade of bio fertilizers as a secondary product of the fermentation process. In general, wastes such as manure or grain stillage become an effective fertilizer after 3 – 5 years only. While using a biogas plant, fermented wastes become an effective fertilizer almost immediately, while their production cost is equal to zero. Therefore, the energetic exploitation of biomass can solve problems of the energy production, but also provide savings in fertilizer costs.

However, the collection of biomass residues is still in a great difficulty. The price of 1 ton of biomass residues for biomass power plants is around €40 in the study region, which includes collection and transportation cost. The farmer has to collect the biomass residues from the farmland, take the residues to a retrieving point and receives a maximum of €10 t^{-1} from the dealer. Compared to the revenue of €10 t^{-1}, the physical collection workload is too heavy. Therefore, the combustion of the biomass residues is more preferable for the farmer to collection and sale. A possible solution to this problem is the purchase collection machines to collect residues free of charge.

For the further analysis of the economic feasibility of biomass power plants, a production of two hypothetical power plants, one for the rural area and one for the urban area, is modelled taking into account the factors on biomass energy development described above. The biomass power plant in the rural area is near the village Vyselki and has a hypothetical installed capacity of 12 MW. The urban area power plant is situated near the city Anapa and has a 30 MW installed capacity.

The Vyselki power plant is rated for conversion of 4 tons day^{-1} of meat processing wastes (a meat processing industry is located directly in the village), 6 tons day^{-1} of chicken manure (solids content is 5%), 2 tons day^{-1} of sewage (slime) and 13 tons day^{-1} of silage. The estimated annual production may amount to 27.6 million kWh of electricity and 67,000 tons of organic fertilizer. The investments required for this project may amount to more than 270,000 €, including all costs mentioned above. This implies the energy unit price from such a power plant for rural areas of €0.12 per kWh.

Raw materials for the energy production at the Anapa power plant include conversion of 16 tons day^{-1} of organic waste from Anapa and neighboring settlements (solids content is 5%), 14 tons day^{-1} of pig manure (solids content is 5%), 10 tons day^{-1} of chicken manure (solids content is 5%) and 12 tons day^{-1} of silage. The annual electricity production at the Anapa biogas power station may amount up to 48.7 million kWh. The project investments amount to €760,000. The estimated unit energy price is €0.14 per kWh due to higher O&M and transport costs for the bigger facility.

Nonetheless, based on the number of possible rural and urban biomass power stations, and assuming an average installation capacity of 10 MW (rural area) and 25 MW (urban area), the consolidated economic potential may amount to 4,700 MW, which can cover 21% of the annual energy deficit in the Krasnodar region.

Among the three energy sources investigated in this thesis, the biomass power is the most profitable, but still not competitive in comparison with conventional energy sources, since unit energy price of the latter is 0,06 € per kWh. However, the evaluation of the mentioned biomass energy potential is not considered to be a complete bioenergy assessment of the region (e.g. no payback period calculation was addressed). Nevertheless, the applied approach could be very necessary for investigating biomass as an additional source for developing modern and environmentally friendly energy infrastructure in the region.

4.7 Scenarios on development of RES potentials in the Krasnodar region

This section deals with the prospects of RES in the Krasnodar region based on a series of possible scenarios for the development of RES facilities in the coming decades. The exploratory scenarios have considered to what extent the energy situation in the Krasnodar region may be improved (e.g. in case of energy deficits) with the exploitation of RES potentials under the existing economic, legal conditions and in case of changes (e.g. subsidy programs). Following three scenarios for the development of the wind, solar and biomass energy potential in the Krasnodar region were elaborated:

(1) Baseline scenario: current regional policy for the implementation of RES determines the further exploitation of RES in the Krasnodar region,
(2) Worst-case scenario: maximum consideration of economic and infrastructural limitations and restrictions determine the further exploitation of RES,
(3) Best-case scenario: intensive government support determines further exploitation of RES.

Baseline scenario or business as usual

The projections of the baseline scenario are based on the current energy policy and assume that the development of RE will be supported by certain federal and regional programs. The federal and regional authorities may define target areas for the development of energy supply from RES. The current energy program of the Krasnodar region for the period 2010 – 2030 provides the planning basis for development of new RES facilities. The energy program aims at supporting a series of investment projects for the implementation of RES facilities in industrial conglomerates with a minimum capacity of 500 MW year^{-1} for wind, 370 MW year^{-1} for solar and 400 MW year^{-1} for biomass energy.

Furthermore, the energy program defines various actors to support the implementation of the proposed objectives. Therefore, a number of energy and refined petroleum products companies will have the task to diversify their activities and introduce new shares of energy produced from RES. Thus, the energy program aims at restructuring of a number of energy and refined petroleum products companies and the energy complex. The primary objective is, however, the development of new RES clusters in the Krasnodar region. Given the specific resource conditions of the region, an intensive implementation of PV systems and biomass power plants on liquid waste will take place particularly in tourism areas.

To support the exploitation of RES, the establishment of the Federal Agency for RES is envisaged (Krasnodar Chamber of Commerce and Industry, 2015). The Federal Agency for RES is an authority responsible for the development and implementation of state policy, supporting science and technology branches in the Krasnodar region with a budget of more than €1 billion. However, the Federal Agency for RES needs a close international scientific and technical collaboration with countries having a long standing experience in the exploitation of RES (e.g. Germany, Sweden, Canada) to build and expand knowledge on the assessment and development of RES potentials.

The baseline scenario considers all limitations related to nature conservation interests. On the one hand, it reduces the available RES potentials, while on the other hand it may result in sustainable energy production due to environmental concerns and restrictions. Thus, under the baseline scenario, only limited development of certain types of RES will be possible. Nevertheless, the course taken on the gradual development of RE sector can provide valuable practical reference, since the role of the state in the development of RE remains unclear and still not manifested due to a lack of large realized projects.

Worst-case scenario or reliance on exports of hydrocarbons

The projections of the worst-case scenario seem more realistic against the background of the current development of RES in Russian Federation. The scenario was defined as worst-case since it implies the rejection of previous strategic energy plans for the period until 2035 due to strong foreign or domestic factors. It is assumed that planned structural reforms in the energy sector will not be carried out. This development path might imply a continuation of trends of the years 2015 – 2016 when the economic sanctions and the global collapse of oil prices postponed the implementation of previously projected RES downward (Krasnodar Chamber of Commerce and Industry, 2015).

Currently, the energy infrastructure of the Krasnodar region is technologically underdeveloped and heavily worn out. The development of the autonomous local energy production may impose heavy demands on financial and human resources as well as on the quality of corporate governance and planning (KubanEnergo, 2016). The Russian companies cannot satisfy these requirements properly, the more so concerning RES projects.

The regional energy industry will not be able to explore and develop the RES potentials of the Krasnodar region without reforms in the energy and tariff sector. Therefore, the share of RES in the total energy balance of the study region does not exceed 2% (Butuzov (2017). Energy deficits along with the problems of the fuel and energy complex are primarily associated with an imperfection of the Russian legal framework for RES. Very often RES projects were stopped at the financing stage.

Besides that, there is no coherent development strategy for RES in the Krasnodar region. For instance, 58 wind turbines with a total capacity of 232 kW were installed in the Krasnodar region in 1970s. However, these projects are still considered as research ones. Another example is the Garrad Hassan & Partners Ltd. (UK) engineering company, which have confirmed the economic feasibility of constructing wind turbines in the most extensive areas on the cost of the Black and Azov Sea (Monitoring Reports, 2007 – 2008). Despite investments of €1.8 million received from the Regional Commission on Energy Efficiency in 2012 (for the development of RE-based infrastructure facilities in Sochi), none of the proposed RE projects can be currently found in officially records and on satellite maps.

Against this background, it can be assumed that the worst-case scenario is the most realistic for the exploration and exploitation of RES in the Krasnodar region.

Best-case scenario or the scenario of 3 D’s

The best-case scenario includes the three “D-components “: diversification, decentralization and disintermediation (elimination of superfluous intermediaries). The assumptions of the best-case scenario are a sustainable development of the economy in the Krasnodar region, diversification of the economy structure, improvements of the investment climate as well as access to financial resources and new technologies at international markets for energy companies. All these factors can provide a successful sequential development of the RE sector in the Krasnodar region. This development path is characterized by a steady GDP growth along with enhanced investment in fixed capital and “green” technologies. Some of the positive effects of this development are:

(1) Increased construction of RE facilities for decentralized energy supply;
(2) Implementation of RE projects within the regional development strategy with the comprehensive energy supply based on local/intraregional RES;
(3) Improvements in access to energy from RES for various consumer groups;

(4) Improvements in environmental and microclimate conditions;
(5) Employment growth in the new economic sector;
(6) Positive changes in the population mobility model.

Successful reforms are strictly necessary for implementing the best-case scenario. In the case of Russian Federation, the reforms should affect monopolization and intermediation of the energy complex. A special role in these reforms should be envisaged for increasing the share of the decentralized energy production. The problem of decentralization may be also closely related to the problem of regionalizing the activities of energy companies to increase their efficiency. The solution to this problem may also assume building effective subregional relationships as well as developing long-term projects on energy supply using RES.

One of the future idea of RE-enthusiasts in the Krasnodar region is the usage of hybrid systems including solar panels, wind generators and small hydropower systems or biogas plants to develop autonomous systems for the continuous energy supply (RIA News, 2015). In such a case, if there were some disruptions in the energy supply from solar or wind plants, the remaining portion would be taken up from the primary source, the small hydropower or biogas systems.

Therefore, the best-case scenario integrates a spatial diversification of RES, constant financial support and creation of complementary autonomous systems based on RES. For instance, it may be more reasonable to develop wind projects as well as to build a network of medium-capacity biogas plants based on crop residues and livestock wastes in agriculture areas. However, along with the baseline scenario and the worst-case scenario, the best-case scenario needs very strong, and in some cases, cardinal changes of the RE introduction strategy in the Krasnodar region. Therefore, it is the most difficult and hard-to-reach scenario for RES in the case of the Krasnodar region.

4.8 Recommendations for an improved introduction of RES in the model region

Positive effects of using RES may be self-evident in most cases. However, this type of energy sources is progressing in a rather complicated way in many developing countries (IRENA Global Report, 2014). The world's experience in the development of RE shows the need for the support from federal and regional authorities. In the case of Russian Federation, the support may come from the following sources:

(1) Administrative bodies of constituent entities of the Russian Federation directly responsible for the energy supply; for the Krasnodar region it is the Administration of the Krasnodar region;
(2) Funds for special federal programs to construct RES facilities as the implementation of the section on Energy Efficient Economy (KubanEnergy, 2015). Annual funding of €10 million and more to implement the subprogram on Energy Supply in Remote Regions Using RES may be in particular possible;
(3) Funds from the investment component of the electricity tariff, which can be invested in RES development.

It may be essential not only to provide governmental support for this energy sector by subsidies, but also to finance related industries such as research and technical development along with manufacturing of the equipment for constructing and completing RES systems and facilities. Promotion of consumers using RE facilities may be of prime importance during integration of RES in the energy production. The following set of proposed measures is aimed at overcoming the backwardness of Russian Federation and its regions in terms of RES exploration and exploitation:

(1) To amend the Federal Law On Renewable Energy Sources (FZ-35, 2014) as well as to ensure proper control contributing to the consistent implementation of this law at the regional level;
(2) To elaborate and adopt the Decree of the Government "On Measures to Promote the Use of Renewable Energy Sources" (Degree Nr. 165, 2012) specifying the state policy on introducing facilities based on RES;
(3) To appoint federal executive body responsible for promoting the use of RES in constituent entities of the Russian Federation as well as to implement priority projects on the decentralized energy supply in the regions;

(4) To establish a network of energy clusters and support services for RES projects in different climatic zones of Russian Federation;

(5) To establish the Centre-Association of industrial and scientific partners in order to facilitate an active national, regional, international cooperation and exchange of experience with the countries experienced in the exploitation of RES;

(6) To finance and stimulate research efforts related to the development of equipment for power plants using RES;

(7) To establish public database on the basis of open GIS maps allowing any interested person to assess RES potential available for the individual/group using;

(8) To develop and implement a soft loan program for individuals, households and small business entrepreneurs to build power plants based on RES (like KfW Credit, Germany);

(9) To subsidize enterprises and research laboratories producing equipment for power plants using RES;

(10) To subsidize calculated in this study unit energy prices to be competitive with the conventional unit energy price of €0.06 kWh: for wind energy by 70% (€0.14 kWh) for rural area projects and by 67% (€0.09 kWh) for urban area projects; for solar energy by 65% (€0.1 kWh) for large PV installations and by 76% (€0.19 kWh) for small PV installations; for biomass energy by 50% (€0.06 kWh) for small biomass plants (assumed to be typical for rural areas) and by 57% (€0.08 kWh) for large biomass plants (assumed to be typical for urban areas);

(11) To introduce a simplified tax system for manufacturers and users of the energy equipment based on RES and to establish a tax on using fossil fuels taking CO_2 emission into account;

(12) To implement the purpose-oriented program on training specialists, required by the sector at higher education institutions and specialized schools.

This set of recommendations can impart a positive impetus to RES development not only in the Krasnodar region, but also in other regions of Russian Federation and developing countries with the same policy on RES. Consistent implementation of these can result in considerable changes in the energy structure, economy and environment of the regions introducing RE.

5 Overall conclusion

This thesis has presented a multi-criteria assessment methodology for estimation of wind, solar and biomass energy potentials at regional scale using GIS. The proposed methodology allows for integration of climatic and geographical conditions as well as of technological and economic characteristics of a study region. The multi-criteria assessment methodology has been applied for the exploration of RES potentials of the Krasnodar region used as a model region. The exploration of RES potentials has been performed beginning with the assessment of the available resource potential of three types of RES to the assessment of the economically viable share of the initial resource potential. For a comprehensive and critical assessment, all available data and information on the energy status of the Krasnodar region, the specific environmental restrictions and the conditions of the market have been researched and evaluated.

One of the priority objectives of this study was to contribute bridging the gap between insufficient data and decision-making for regions that have no comprehensive input data for the assessment of RES potentials in GIS.

For the Krasnodar region, the assessment of wind, solar and biomass energy potential has been started with the description of three important regional characteristics:

(1) Energy status

The rapid economic development of the Krasnodar region has created a situation of energy infrastructure overload. The current energy deficits of the region amount to 22 GWh year^{-1} with a tendency for a further increase. Therefore, the current energy situation in the model has been described in the first place. Energy planners have to plan the implementation of new RES facilities taking into consideration the state and quality of energy infrastructure in order to find potential problems and weaknesses.

(2) Environmental restrictions

Second, the environmental restricts has been taken into consideration. Notably for the assessment of wind and solar energy potentials, the consideration of environmental restrictions is necessary since many regions may have large recreational and natural protected areas, where activities related to the exploitation of RES potentials are legally prohibited. Despite the positive effect of RES facilities (e.g.

GHG mitigation) some of side effects have to be analyzed (e.g. the impact on biodiversity migratory birds by wind installations).

(3) Market conditions

The assessment of the energy market conditions is an essential step in the analysis since it gives an impression on the truly viable share of the initial RES potential. The assessment of the market conditions for the exploration of RES potential may provide valuable insights into the current legal framework of development strategies and help to understand the competitiveness of the energy produced from RES in the study region.

In the case of the Krasnodar region, no subsidies have been provided to compensate electricity costs from RES production. Furthermore, there are many bureaucratic and financial barriers for a further development and implementation of RES projects.

In order to describe the distribution of the theoretic resource potential for wind energy, wind speed and wind power density data of the Krasnodar region were digitalized, quantified und displayed in digital maps. In the region, the wind speed varies from 3.6 to 9.0 m s^{-1} at 80 m above ground. The wind power density range is 75 to 250 Wm^{-2}. The northwestern and the southeastern cost areas have excellent wind energy potentials indicated by the high and constant wind speed and wind power density values. The most suitable area for the installation of wind turbines amounts to 12,000 km^2 accounting for 15.2% of the Krasnodar region.

Taking the Vestas 80 wind turbine (2.0 MW) as the reference turbine, the technical wind energy yield can reach 23 GWh $year^{-1}$, whereas the electricity deficit in the Krasnodar region exceeded 22 GWh in 2016. However, a more detailed analysis of the market conditions and relevant characteristics of the energy infrastructure have demonstrated that only 3.6 % (around 800 MW) of the technical wind energy yield may be economically viable now. For two hypothetical wind farms with an installed capacity of 60 MW (Anapa wind farm) and 46 MW (Yeysk wind farm), the unit generation prices of €0.15 for kWh electricity (Anapa wind farm) and €0.20 (Yeysk wind farm) were calculated to demonstrate the current economic potential of wind energy in the Krasnodar region. The obtained unit generation prices demonstrate that wind energy is not competitive on the regional market without any governmental subsidies and due to comparably low unit generation costs of conventional energy sources.

The theoretic resource potential for solar energy of the Krasnodar region ranges from 1200 to 1500 kWhm^{-2}. The most suitable area for installation of PV systems amounts to 55,000 km^2 accounting for 72 % of the Krasnodar region. The technical solar energy yield can reach 24 GWh year^{-1} with PV systems and, thus, can cover the regional energy deficit of 22 GWh year^{-1}. However, the economically feasible output may amount to 4.5 GWh year^{-1} with the suitable rooftop area of 332 km^2. For two hypothetical PV facilities, the unit generation prices of €0.16 for kWh electricity (large-scale PV facility) and €0.25 (small-scale PV facility) were obtained. As for the wind power energy, the solar energy is not yet sufficiently competitive without government subsidies. Stronger energy policy incentives may help stimulate the development of large-scale PV facilities or of decentralized small-scale PV facilities for households or multi-store buildings.

The assessment of the biomass energy potential yielded the annual usable biomass residues density of up to 2400 tons km^{-2}. The dominant land cover type is farmland, and the residues from crops provide opportunities for the exploitation of biomass energy. Animal wastes and organic wastes of settlements are also abundant. In the Krasnodar region, these three types of available biomass amount to 118 million tons. From this biomass, the technical biomass power potential was estimated to amount to 25 GWh year^{-1}.

Siting biomass power plants differ from siting wind and solar power plants, and their locations rely on the availability of resources. Biomass residue needs to be transported from retrieval points to power plants, thus optimal sites can reduce transportation costs. Once restricted areas have been excluded, the location allocation analysis model coupled with road network information is adopted to search for optimal sites. After considering population density and existing biomass potential, the author retained two optimal sites for the case assessment.

For two hypothetical biomass power plants with a capacity of 12 MW (Vyselki; rural area) and 30 MW (Anapa; urban area), the unit generation prices of €0.12 for kWh electricity for the former and €0.14 for the later location were obtained. In comparison with the unit generation prices for the wind and solar energy, the unity generation prices for the biomass energy require the least amount of subsidies to compete with conventional energy sources.

For all three types of RES investigated, the initial theoretical resource potential experienced a substantial reduction with each assessment stage to eventually, yield a comparably low share of the economically feasible potential. However, the multi-criteria assessment methodology allowed for the most realistic assessment of RES potentials in the Krasnodar region compared to other studies.

However, RE still attract a great deal of attention, due to increasing energy shortages, notably in summer time when thousands of tourists need extra power. Many owners of off-grid solar systems name practicality and affordability as the main reasons for their purchase as a way to generate power and increase independence from unreliable local electricity systems. This is especially true for small tourist businesses such as mini-hotels, restaurants and stores.

Based on the results of the assessment of RES potentials as well as on the current state of RE production in the Krasnodar region, energy scenarios and recommendations were provided for improved planning of future projects on RES. From these scenarios and recommendations, decision makers may define different parameters for analyzing of effects from the exploitation of RES as an additional energy resource. Furthermore, energy project developers may quickly identify new profitable projects based on the feasible areas for the development of RES provided in this study.

In the present, such variables as constraints, the energy situation and the market climate were combined with renewable energy potentials for an comprehensive assessment. In addition, problems in the development of RE have been pointed out and possible solutions were provided particularly by proposal of specific measures such as subsidizing of unit generation costs for each studied RES. The present methodology is not limited to the studied model region; so that policy makers, project investors and developers, as well as energy planners in other study areas, can apply it. Policy makers can define different parameters (such as restricted areas and energy incentive policy) to analyse their effects on power generation, while energy project developers can quickly identify new profitable areas based on the land suitability analysis.

To sum up, the results of the assessment of RES potentials in the Krasnodar region is a valuable data basis that facilitates the decision making process for policy makers, investors, private users and utility companies involved in the development of projects on RES.

6 Outlook

With a few exceptions, most of the existing research on RES in the Krasnodar region has been focused on the estimation of the theoretic resource potential of RES. Some studies have combined the economic potential of RES with a qualitative description of the current energy policy. The multi-criteria assessment methodology proposed in this thesis combined all the essential assessment stages in a certain sequence, which makes the approach applicable to other regions or study areas. The application of the proposed methodology for the exploration of RES potentials in the Krasnodar region allowed to successfully achieving the following intended objectives:

(1) A multi-criteria GIS-analysis to present the spatial distribution of wind, solar and biomass energy potential in GIS maps;
(2) Analysis of the energy status, environmental restrictions and market conditions*;
(3) Adaptation of calculation schemes to conditions of insufficient input data;
(4) Zoning of area allowing the installation of RES facilities based on the suitability maps;
(5) Developing of energy scenarios and recommendations for improved implementation of RES in the model region;
(6) Assessment of risks and benefits* for potential investors involved in projects on RES in the model region.

* issues were not fully explored due to the lack of available data and information

For many reasons, preliminary GIS-based assessments of RES potentials should become a fixed component in the development process of projects on RES. To improve the precision of the output data obtained, more initial better-resolved GIS data is needed, yet not possible due to many reasons. For instance, the access to large non-public databases is limited or expensive. Against this background, it is a significant achievement of this thesis, that despite the general lack of data and other limitations, sufficient input data for a multi-stage assessment of RES potentials in the Krasnodar region could be allocated and verified.

The results of the assessment also show that it may be essential to focus on the end-user of the cartographic product, e.g. state administration bodies involved in in planning processes, or investment companies planning to implement MW-class projects as well as private consumers. In this case, it may be necessary to provide information in a manner easy to use and understand.

The presented assessment of RES potentials can be used to highlight relevant support that would need to be put in place when RES were proposed for the future development. However, the proposed assessment methodology is not a universal blueprint and may be complemented with other features specific for a study area. The proposed assessment methodology provides an instrument for the assessment of supply-side options from RES for the regional electricity demand. Future work may address impacts from localized energy storage systems, the assessment of emission-savings from the implantation of RES along or surveys on social acceptance of RES. Understanding these and other factors may provide a deeper knowledge on the role of decentralized RE facilities and provide an evidence base for future policy decisions.

In case of the assessment of the economic potential of RES in the Krasnodar region more research on e.g. payback periods, forecasts on electricity prices under various schemes of governmental subsidies as well as supply cost curves for RES is need for a more elaborated analysis. These calculations were not included in the present assessment due to the lack of relevant data. Furthermore, it is important to include surveys on social acceptance as well as the assessment of positive impacts (e.g. reduction of greenhouse gases) of RES on the environment to demonstrate a comprehensive picture of RES potentials in the Krasnodar region.

The author of this thesis is aware of the complexity involved when estimating RES potentials and recommends complementing the present analysis on the implementation of RES in the Krasnodar region with additional local conditions.

Appendix

Appendix 3.1

Georeferencing of data

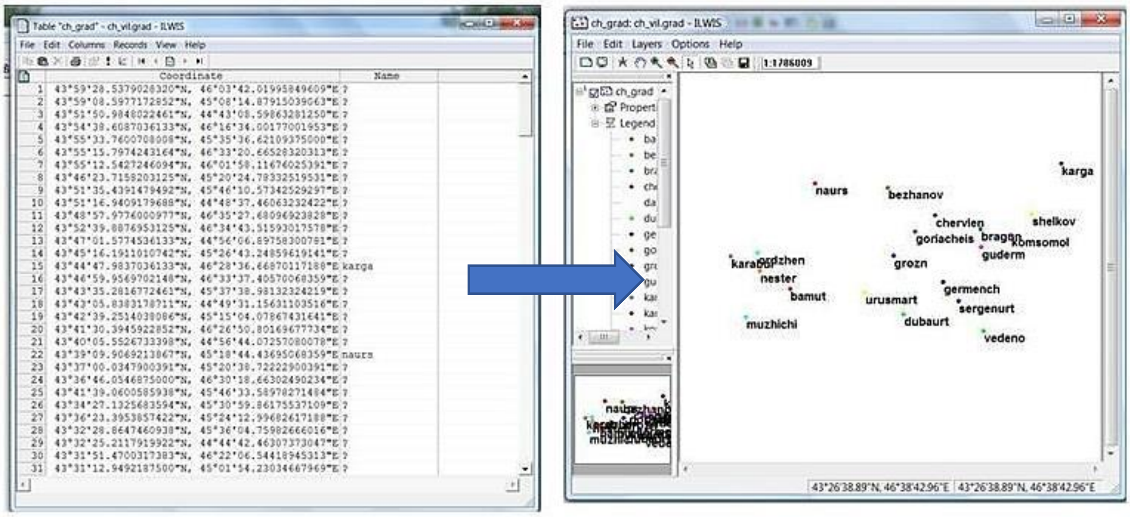
Raster data is commonly obtained by scanning maps or aerial photographs and satellite images. Normally, scanned map datasets do not contain spatial reference information (embedded either in the file or as a separate file). With aerial photography and satellite imagery, the location information sometimes delivered with them is inadequate, and the data does not align properly with other data you have. Thus, to use some raster datasets in conjunction with other spatial data it is necessary to align or georeference those to a map coordinate system (Lorenc, 2005). A map coordinate system is defined using a map projection (a method by which the curved surface of the earth is portrayed on a flat surface). It will be briefly described the data conversion work flow using a file fragment (Figure A3.1). Each boundary of two neighboring regions is provided with a *.doc file containing the description of so called turning points belonging to a certain boundary.

Описание прохождения границы
между Алтайским краевым (№22) и Новосибирским (№54)
кадастровыми округами

Сведения об узловых и поворотных точках границы				Сведения об участках границы		
Номер точки	Координаты*		Описание местоположения точки	Направление участка границы	Длина участка границы (км)	Описания прохождения участка границы
	X (или B)	Y (или L)				
1	2	3	4	5	6	7
1 (32)	5911,0	13693,9	На государственной границе с Казахстаном в 0.7км к востоку от восточной края озера Заливное (Казахстан), в 1.4км к югу от точки с отметкой 108,9	Северное	8,6	По прямой, пересекает полевую дорогу
				Юго-восточное	3,6	По прямой до береговой линии озера Большое Топольное в 0,45 км северо-восточнее лесополосы, пересекает полевую дорогу
2	5918,4	13695,9	На береговой линии озера Большое Топольное	Северо-восточное	4,5	По береговой линии озера Большое Топольное
3	5922,0	13697,5	На береговой линии озера Большое Топольное	Северо-западное	2,3	По прямой
				Северное	1,8	По прямой

Figure A3.1 An example of Rosreestr table
The Federal Service for State Registration, Cadastre and Cartography of Russia

The first two columns of the Table may be the most important for GIS processing. They contain the description of the following elements: point number, X-coordinate and Y-coordinate. These three columns should be selected and copied to any tabular processor, e.g. OO Calc. Then, empty lines as well as lines without data on coordinates should be deleted. The coordinates are indicated in kilometers in the example described, so the X- and Y-coordinate values should be multiplied by 1,000. The number of zone to which each turning point belongs should be determined using raster images. Examining each raster sequentially, we shall find the point number from the Table and identify the page number (Figure A3.2).



	Coordinate	Name
1	43°59'28.5379028320"N, 46°03'42.01995849609"E	?
2	43°59'08.5977172852"N, 45°08'14.87915039063"E	?
3	43°51'50.9848022461"N, 44°43'08.59863281250"E	?
4	43°54'38.6087036133"N, 46°16'34.00177001953"E	?
5	43°55'33.7600708008"N, 45°35'36.62109375000"E	?
6	43°55'15.7974243164"N, 46°33'20.66528320313"E	?
7	43°55'12.5427246094"N, 46°01'58.11676025391"E	?
8	43°46'23.7158203125"N, 45°20'24.78332519531"E	?
9	43°51'35.4391479492"N, 45°46'10.57342529297"E	?
10	43°51'16.9409179688"N, 44°48'37.46063232422"E	?
11	43°48'57.9776000977"N, 46°35'27.68096923828"E	?
12	43°52'39.8876953125"N, 46°34'43.51593017578"E	?
13	43°47'01.5774536133"N, 44°56'06.89758300781"E	?
14	43°45'16.1911010742"N, 45°26'43.24859619141"E	?
15	43°44'47.9837036133"N, 46°28'36.66870117188"E	karga
16	43°46'59.9569702148"N, 46°33'37.40570068359"E	?
17	43°43'35.2816772461"N, 45°37'38.98132324219"E	?
18	43°43'05.8383178711"N, 44°49'31.15631103516"E	?
19	43°42'39.2514038086"N, 45°15'04.07867431641"E	?
20	43°41'30.3945922852"N, 46°26'50.80169677734"E	?
21	43°40'05.5526733398"N, 44°56'44.07257080078"E	?
22	43°39'09.9069213867"N, 45°18'44.43695068359"E	naurs
23	43°37'00.0347900391"N, 45°20'38.72222900391"E	?
24	43°36'46.0546875000"N, 46°30'18.66302490234"E	?
25	43°41'39.0600585938"N, 45°46'33.58978271484"E	?
26	43°34'27.1325683594"N, 45°30'59.86175537109"E	?
27	43°36'23.3953857422"N, 45°24'12.99682617188"E	?
28	43°32'28.8647460938"N, 45°36'04.75982666016"E	?
29	43°32'25.2117919922"N, 44°44'42.46307373047"E	?
30	43°31'51.4700317383"N, 46°22'06.54418945313"E	?
31	43°31'12.9492187500"N, 45°01'54.23034667969"E	?

```
43°26'38.89"N, 46°38'42.96"E | 43°26'38.89"N, 46°38'42.96"E
```

Figure A3.2 Determination and snapping of the turning points
Data for Federal Service for State Registration, Cadastre and Cartography of Russia, a part of the land cadaster map layer.

The points belonging to one layer should be selected into a separate *.csv-file (as a result, the number of csv-files should be equal to the number of zones with turning points of the boundary under consideration). Then, each csv-file should be converted and saved in the following sequence:

1. Launch QGIS;
2. Modules → Delimited Text → Add Delimited Text Layer;
3. Open csv-file, select Y in X field and X in Y field, then click [OK];
4. Right click the layer name, select Properties and go to the General tab;
5. Coordinate System Selection
6. Select Coordinate System → WGS 84/Pseudo-Mercator projection;
7. Right click the layer name and select Save As a shape file. Choose Pseudo Mercator (WGS84) while saving.

The result obtained could be checked by opening the saved file in any GIS program. If the points with identical numbers in raster coincide with those on the vector, then all steps are performed correctly. In case some points do not coincide, then an error may have occurred while selecting zones. However, errors might exist in the initial data as well, so the quality of initial databases should be thoroughly verified. The official statistics and regional cadastral data would suit best of all. As mentioned above, the problem of an inadequate network (i.e. inhomogeneity) of meteorological and aerological stations along with inhomogeneity in satellite data may determine the need for providing additional data and improving conventional calculation methods. Thus, an example of the adaptation or conversion of non-GIS data sources to GIS-referenced data, namely, the construction of the vector point layer from tables and text databases was demonstrated.

Appendix 3.2

The *r.sun* model

The *r.sun* model is implemented in the GRASS GIS open source environment using the C programming language. The model works in two modes. In mode 1 for the instant time [second], it calculates raster maps of selected components (beam, diffuse and reflected) of solar irradiance [Wm^{-2}] and solar incident angle [degrees]. In mode 2, the raster maps of daily sum of solar irradiation [Whm^{-2}] and duration of the beam irradiation [minutes] are computed as integration of irradiance values that are calculated in a selected time step from sunrise to sunset. The model requires only a few mandatory input parameters, viz. digital terrain model (elevation, slope, aspect), day number (for mode 2), and additionally a local solar time (for mode 1). Several other parameters can be set to fit the specific user needs. Therefore, modelling of the solar energy potential combines two functions necessary for this study, viz. the adaptation and computing of nonhomogeneous and non-uniformly distributed datasets.

Spatially distributed parameters was set as raster maps. Geographical latitude for each cell was computed internally. The real-sky irradiance/irradiation was calculated from clear-sky raster maps by the application of a factor parameterizing the attenuation of cloud cover. Becker et al. (2001) give examples of explicit calculations of this parameter. The parameters have default values, unless they are overridden by user settings as a single value or a name of the raster. Solar declination was computed internally using equation [A3.1] according to Gruter (1984):

$$\boldsymbol{\delta = \arcsin(0.3978 \sin(j' - 1.4 + 0.0355 \sin(j' - 0.0489)))} \qquad \text{[A3.1]}$$

j’: day angle [radians];
T: hour angle [rad]; calculated from the local solar time t expressed in decimal hours

on the 24-hour clock as T = 0.261799 (t - 12).

According to the setting of the output parameters, the model automatically distinguishes between mode °1 and °2. When calculating in mode 1, the solar incident angle, and solar irradiance raster maps are computed. Calculation in mode 2 gives the sums of solar irradiation within a specified day for selected components of global irradiation. A raster map showing duration of beam irradiation can be computed as well. The incidence angle and irradiance/irradiation maps can be computed without considering the terrain shadowing by default or with shadowing effects by setting the flag -*s*. In mountainous areas, this can lead to very different results especially at low sun altitudes. The value of a shadowed area is written to the output maps as zero. Table A3.1 presents a list of all output raster maps and Table A3.2 the necessary input parameters.

Table A.1 The output raster maps from the *r.sun* model

Parameter name	**Description**	**Mode**	**Units**
incidout	solar incidence angle	1	decimal degrees
beam_rad	beam irradiance	1	W m^{-2}
diff_rad	diffuse irradiance	1	W m^{-2}
refl_rad	ground reflected irradiance	1	Wm^{-2}
insol_time	duration of the beam irradiation	2	min
beam_rad	beam irradiation	2	Wh m^{-2} day^{-1}
diff_rad	diffuse irradiation	2	Wh m^{-2} day^{-1}
refl_rad	ground reflected irradiation	2	Wh m^{-2} day^{-1}

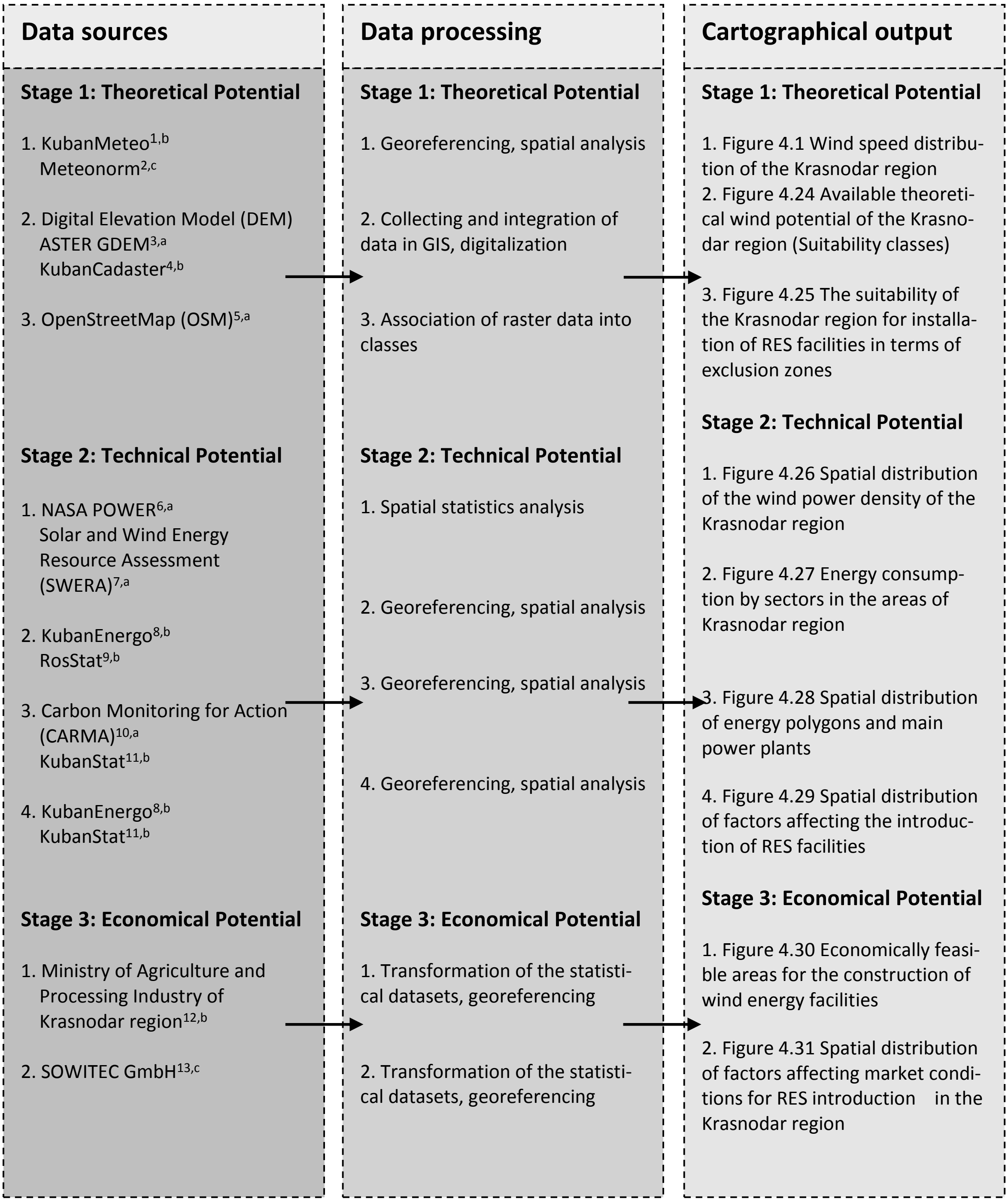
GRASS GIS manual, 2016

Table A.2 Necessary input parameters for *r.sun* model

Parameter	**Type of input**	**Description**	**Mode**	**Units**	**Interval of values**
elevin	raster	elevation	1, 2	meters	0 – 8900
aspin	raster	aspect (solar panel azimuth)	1, 2	decimal degrees	0 – 360
slopein	raster	slope (solar panel inclination)	1, 2	decimal degrees	0 – 90
linkein	raster	linked atmospheric turbidity	1, 2	dimensionless	0 - ≈7
lin	single value	linked atmospheric turbidity	1, 2	dimensionless	0 - ≈7
albedo	raster	ground albedo	1, 2	dimensionless	0 – 1
alb	single value	ground albedo	1, 2	dimensionless	0 – 1
latin	raster	latitude	1, 2	decimal degrees	-90 – 90
lat	single value	latitude	1, 2	decimal degrees	-90 – 90
coefbh	raster	clear-sky index for beam component	1, 2	dimensionless	0 – 1
coefdh	raster	clear-sky index for diffuse component	1, 2	dimensionless	0 – 1
day	single value	day number	1, 2	dimensionless	0 – 366
declin	single value	solar declination	1, 2	radians	-0.40928 – 0.40928
time	single value	local (solar) time	1	decimal hours	0 – 24
step	single value	time step	2	decimal hours	0.01 – 1.0
dist	single value	sampling distance coefficient for shadowing	1, 2	dimensionless	0.1 – 2.0

GRASS GIS manual, 2016

Appendix 3.3

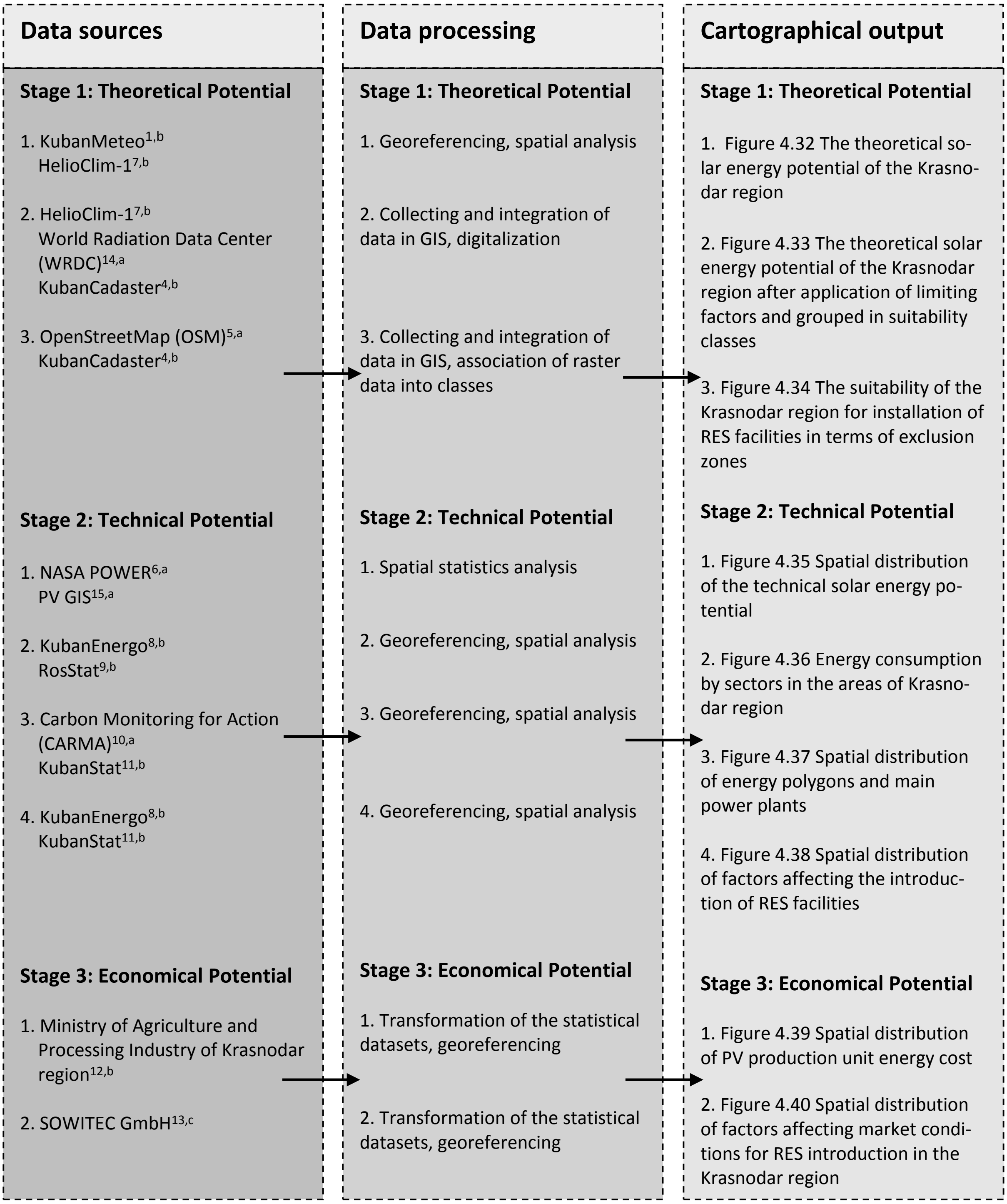


Data sources	Data processing	Cartographical output
Stage 1: Theoretical Potential	**Stage 1: Theoretical Potential**	**Stage 1: Theoretical Potential**
1. KubanMeteo[1,b] Meteonorm[2,c]	1. Georeferencing, spatial analysis	1. Figure 4.1 Wind speed distribution of the Krasnodar region 2. Figure 4.24 Available theoretical wind potential of the Krasnodar region (Suitability classes)
2. Digital Elevation Model (DEM) ASTER GDEM[3,a] KubanCadaster[4,b]	2. Collecting and integration of data in GIS, digitalization	
3. OpenStreetMap (OSM)[5,a]	3. Association of raster data into classes	3. Figure 4.25 The suitability of the Krasnodar region for installation of RES facilities in terms of exclusion zones
Stage 2: Technical Potential	**Stage 2: Technical Potential**	**Stage 2: Technical Potential**
1. NASA POWER[6,a] Solar and Wind Energy Resource Assessment (SWERA)[7,a]	1. Spatial statistics analysis	1. Figure 4.26 Spatial distribution of the wind power density of the Krasnodar region
2. KubanEnergo[8,b] RosStat[9,b]	2. Georeferencing, spatial analysis	2. Figure 4.27 Energy consumption by sectors in the areas of Krasnodar region
3. Carbon Monitoring for Action (CARMA)[10,a] KubanStat[11,b]	3. Georeferencing, spatial analysis	3. Figure 4.28 Spatial distribution of energy polygons and main power plants
4. KubanEnergo[8,b] KubanStat[11,b]	4. Georeferencing, spatial analysis	4. Figure 4.29 Spatial distribution of factors affecting the introduction of RES facilities
Stage 3: Economical Potential	**Stage 3: Economical Potential**	**Stage 3: Economical Potential**
1. Ministry of Agriculture and Processing Industry of Krasnodar region[12,b]	1. Transformation of the statistical datasets, georeferencing	1. Figure 4.30 Economically feasible areas for the construction of wind energy facilities
2. SOWITEC GmbH[13,c]	2. Transformation of the statistical datasets, georeferencing	2. Figure 4.31 Spatial distribution of factors affecting market conditions for RES introduction in the Krasnodar region

Figure A3.3 Wind energy potential: data sources, data processing and cartographical output

1 = kubanmeteo.ru; 2 = meteonorm.com; 3 = lpdaac.usgs.gov; 4 = frskuban.ru; 5 = openstreetmap.org; 6 = eosweb.larc.nasa.gov; 7 = soda-is.com; 8 = kubanenergo.ru; 9 = gks.ru; 10 = rma.org; 11 = http://krsdstat.gks.ru/; 12 = dsh.krasnodar.ru; 13 = sowitec.com

a = open source; b = partially open; c = paid access



Data sources	Data processing	Cartographical output
Stage 1: Theoretical Potential	**Stage 1: Theoretical Potential**	**Stage 1: Theoretical Potential**
1. KubanMeteo[1,b] HelioClim-1[7,b]	1. Georeferencing, spatial analysis	1. Figure 4.32 The theoretical solar energy potential of the Krasnodar region
2. HelioClim-1[7,b] World Radiation Data Center (WRDC)[14,a] KubanCadaster[4,b]	2. Collecting and integration of data in GIS, digitalization	2. Figure 4.33 The theoretical solar energy potential of the Krasnodar region after application of limiting factors and grouped in suitability classes
3. OpenStreetMap (OSM)[5,a] KubanCadaster[4,b]	3. Collecting and integration of data in GIS, association of raster data into classes	3. Figure 4.34 The suitability of the Krasnodar region for installation of RES facilities in terms of exclusion zones
Stage 2: Technical Potential	**Stage 2: Technical Potential**	**Stage 2: Technical Potential**
1. NASA POWER[6,a] PV GIS[15,a]	1. Spatial statistics analysis	1. Figure 4.35 Spatial distribution of the technical solar energy potential
2. KubanEnergo[8,b] RosStat[9,b]	2. Georeferencing, spatial analysis	2. Figure 4.36 Energy consumption by sectors in the areas of Krasnodar region
3. Carbon Monitoring for Action (CARMA)[10,a] KubanStat[11,b]	3. Georeferencing, spatial analysis	3. Figure 4.37 Spatial distribution of energy polygons and main power plants
4. KubanEnergo[8,b] KubanStat[11,b]	4. Georeferencing, spatial analysis	4. Figure 4.38 Spatial distribution of factors affecting the introduction of RES facilities
Stage 3: Economical Potential	**Stage 3: Economical Potential**	**Stage 3: Economical Potential**
1. Ministry of Agriculture and Processing Industry of Krasnodar region[12,b]	1. Transformation of the statistical datasets, georeferencing	1. Figure 4.39 Spatial distribution of PV production unit energy cost
2. SOWITEC GmbH[13,c]	2. Transformation of the statistical datasets, georeferencing	2. Figure 4.40 Spatial distribution of factors affecting market conditions for RES introduction in the Krasnodar region

Figure A3.4 Solar energy potential: data sources, data processing and cartographical output

1 = kubanmeteo.ru; 2 = meteonorm.com; 3 = lpdaac.usgs.gov; 4 = frskuban.ru; 5 = openstreetmap.org; 6 = eosweb.larc.nasa.gov; 7 = soda-is.com; 8 = kubanenergo.ru; 9 = gks.ru; 10 = rma.org; 11 = http://krsdstat.gks.ru/; 12 = dsh.krasnodar.ru; 13 = sowitec.com; 14 = wrdc.mgo.rssi.ru; 15 = http://re.jrc.ec.europa.eu/pvgis;

a = open source; b = partially open; c = paid access

Data sources	Data processing	Cartographical output
Stage 1: Theoretical Potential	**Stage 1: Theoretical Potential**	**Stage 1: Theoretical Potential**
1. KubanStat[11,b] OSM[5,c]	1. Transformation of the statistical datasets, georeferencing, spatial analysis	1. Figure 4.41 Model of the theoretical biomass potential
2. OSM[5,c] KubanCadaster[4,b]	2. Collecting and integration of data in GIS, digitalization, spatial analysis	2. Figure 4.20 The available theoretical biomass potential after application of exclusion zones
3. OSM[5,c] KubanCadaster[4,b]	3. Collecting and integration of data in GIS, digitalization, spatial analysis	3. Figure 4.42 The suitability of the Krasnodar region for installation of RES facilities in terms of exclusion zones
Stage 2: Technical Potential	**Stage 2: Technical Potential**	**Stage 2: Technical Potential**
1. Ministry of Agriculture and Processing Industry of Krasnodar region[12,b]	1. Transformation of the statistical datasets, georeferencing, spatial analysis	1. Figure 4.43 Spatial distribution of technical biomass energy potential
2. KubanEnergo[8,b] RosStat[9,b]	2. Georeferencing, spatial analysis	2. Figure 4.44 Energy consumption by sectors in the areas of Krasnodar region
3. Carbon Monitoring for Action (CARMA)[10,a] KubanStat[11,b]	3. Georeferencing, spatial analysis	3. Figure 4.45 Spatial distribution of energy polygons and main power plants
4. KubanEnergo[8,b] KubanStat[11,b]	4. Georeferencing, spatial analysis	4. Figure 4.46 Spatial distribution of factors affecting the introduction of RES facilities
Stage 3: Economical Potential	**Stage 3: Economical Potential**	**Stage 3: Economical Potential**
1. Ministry of Agriculture and Processing Industry of Krasnodar region[12,b]	1. Transformation of the statistical datasets, georeferencing	1. Figure 4.47 Spatial distribution of annual usable biomass for rural biomass power plants
2. SOWITEC GmbH[13,c]	2. Transformation of the statistical datasets, georeferencing	2. Figure 4.48 Spatial distribution of annual usable biomass for urban biomass power plants
		3. Figure 4.49 Spatial distribution of factors affecting market conditions for RES introduction in the Krasnodar region

Figure A3.5 Biomass energy potential: data sources, data processing and cartographical output

1 = kubanmeteo.ru; 2 = meteonorm.com; 3 = lpdaac.usgs.gov; 4 = frskuban.ru; 5 = openstreetmap.org; 6 = eosweb.larc.nasa.gov; 7 = soda-is.com; 8 = kubanenergo.ru; 9 = gks.ru; 10 = rma.org; 11 = http://krsdstat.gks.ru/; 12 = dsh.krasnodar.ru; 13 = sowitec.com

a = open source; b = partially open; c = paid access

References

Adler, P. R., Sanderson, M. A., Boateng, A. A., Weimer, P. J., & Jung, H. J. G., 2006. Biomass yield and biofuel quality of switch grass harvested in fall or spring. Agronomy Journal, 98, 1518–1525.

Ahmed, M., Ahmad, F., & Akhtar, M., 2006. Assessment of wind power potential for coastal Areas of Pakistan. Turkish Journal of Physics, 30, 127–136.

Akash, B. A., Mamlook, R., & Mohsen, M. S., 1999. Multi-criteria selection of electric power plants using analytical hierarchy process. Electric Power Systems Research, 52(1), 29–35.

Allen, R., 1997. Self-calibrating method for estimating solar radiation from air temperature. Journal of Hydrologic Engineering, 2, 56–57.

Amerkhanov R., Bihari & S. Szalai, 2007. Comparison of Geostatistical and Meteorological Interpolation Methods (What is What?). Spatial interpolation for climate data: the use of GIS in climatology and meteorology, 45–56.

Angelis-Dimakis, A., Biberacher, M., Dominguez, J., Fiorese, G., Gadocha, S.,Gnansounou, E., 2011. Methods and tools to evaluate the availability of renewable energy resources. Renewable and Sustainable Energy Reviews, 15, 1182–1200.

Ångström A., 1924. Solar and terrestrial radiation. Report to the international commission for solar research on actinometric investigations of solar and atmospheric radiation. Quarterly Journal of the Royal Meteorological Society, 50 (210), 121-126.

Arnette, A.N.; Zebel, C.W. Spatial analysis of renewable energy potential in the greater southern appalachian mountains. Renew. Energy 2011, 36, 2785–2798.

Aydin, N. Y., Kentel, R., & Duzgun, H. S., 2013. GIS-based site selection methodology for hybrid renewable energy systems: a case study from western Turkey. Energy Conversion and Management, 70, 90–106.

Aydin, N.Y., Kentel, E., Duzgun, S., 2010. GIS-based environmental assessment of wind energy systems for spatial planning: a case study from Western Turkey. Renewable and Sustainable Energy Reviews 14, 364–373.

Baban S, Parry T. Developing and applying a GIS-assisted approach to locating wind farms in the UK. Renewable Energy 2001; 24:59–71.

Beccali, M.; Cellura, M.; Mistretta, M. Decision-making in energy planning. Application of the electre method at the regional level for the diffusion of renewable energy technology. Renew. Energy 2003, 28, 2063–2087.

Ben Salah, C., Chaabene, M., & Ben Ammar, M. (2008). Multi-criteria fuzzy algorithm for energy management of a domestic photovoltaic panel. Renewable Energy, 33, 993–1001.

Bergmann, A.; Hanley, N.; Wright, R. Valuing the attributes of renewable energy investments. Energy Pol. 2006, 34, 1004–1014.

BirdLife International requirements http://www.birdlife.org/ Accessed 2.10 2014

Blanco, M.I., 2009. The economics of wind energy. Renewable and Sustainable Energy Reviews13, 1372–1382.

Blanco MI. The economics of wind energy. Renewable and Sustainable Energy Reviews 2009; 13, 1372–82.

Blaschke, T., Biberacher, M., Gadocha, S., & Schardinger, I., 2013. ‘Energy landscapes’: meeting energy demands and human aspirations. Biomass and Bioenergy, 55, 3–16.

Bristow, K. L., & Campbell, G. S., 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology, 31, 159–166.

Brown, S., & Gaston, G.,1995. Use of forest inventories and geographic information systems to estimate biomass density of tropical forests: Application to tropical Africa. Environmental Monitoring and Assessment, 38(2-3), 157–168.

Buflasa, H., Infield, D., & Thomson, M., 2008. Wind resource assessment for the Kingdom of Bahrain. Wind Engineering, 32(5), 439–448.

Cadenas, E., & Rivera, W.,2007. Wind speed forecasting in the South Coast of Oaxaca, México. Renewable Energy, 32, 2116–2128.

Calvert, K., Luciani, P., & Mabee, W. E., 2014. Thematic land cover map assimilation and synthesis: the case of estimating biomass supply in eastern Ontario, Canada. International Journal of GIS, 28, 274–295.

Calvert, K., & Mabee, W.,2014. Spatial analysis of biomass resources within a socioecologically heterogeneous region: identifying opportunities for a mixed feedstock stream. ISPRS International Journal of Geo-Information, Special Issue on GIS for Renewable Energy, 3(1), 209–232.

Calvert, K., Pearce, J., & Mabee, W. E., 2013. Toward renewable energy geo-information infrastructures: applications of GIS and remote sensing that build institutional capacity. Renewable and Sustainable Energy Reviews, 18, 416–429.

Carbon Monitoring for action (CARMA) http://www.carma.org/ Accessed 13.07.2014

Castellano, P. J., Volk, T. A., & Herrington, L. P., 2009. Estimates of technically available woody biomass feedstock from natural forests and willow biomass crops for two locations in New York State. Biomass and Bioenergy, 33, 393–406.

Celiktas, M.S.; Kocar, G., 2010. From potential forecast to foresight of turkey’s renewable energy with Delphi approach. Energy 35, 1973–1980.

Cheng, E. W. L., & Li, C., 2005. Analytic network process applied to project selection. Journal of construction engineering and management, 131(4), 459–466.

Clarke, J.A.; Grant, A.D. Planning support tools for the integration of renewable energy at the regional level. Renew. Energy 1996, 9, 1090–1093.

Correia, P.F., Ferreirade Jesus, J.M., 2010. Simulation of correlated wind speed and power variates in wind parks. Electric Power Systems Research 80, 592–598.

Czaplicka-Kolarz, K.; Stanczyk, K.; Kapusta, K., 2009. Technology foresight for a vision of energy sector development in Poland till 2030. Delphi survey as an element of technology foresighting. Technol. Forecast. Soc. Chang, 76, 327–338.

Dawson, L., & Shlyter, P., 2012. Less is more: strategic scale site suitability for concentrated solar thermal power in Western Australia. Energy Policy, 47, 91–101.

Denholm, P., & Margolis, R. M., 2008. Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. Energy Policy, 36, 3531–3543.

De Schepper, E., Van Passel, S., Manca, J., & Thewys, T., 2012. Combining photovoltaics and sound barriers e a feasibility study. Renewable Energy, 46, 297–303.

De Vries, B. J. M., van Vuuren, D. P., & Hoogwijk, M. M., 2007. Renewable energy sources: their global potential for the first-half of the 21st century at a global level: an integrated approach. Energy Policy, 35, 2590–2610.

Dijkman, T. J., & Benders, R. M. J., 2010. Comparison of renewable fuels based on their land use using energy densities. Renewable and Sustainable Energy Reviews, 14, 3148–3155.

Dominguez, J., Casals, X. G., & Pascua, I. P., 2007. GIS approach to the definition of capacity and generation ceilings of renewable energy technologies. Energy Policy, 35, 4879–4892.

Durpaz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A., & Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimizing land use: towards new agrivoltaic schemes. Renewable Energy, 36, 2725–2732.

Elliott, D. Renewable energy and sustainable futures. Futures 2000, 32, 261–274.

Eltham DC, Harrison GP, Allen SJ. Change in public attitudes towards a Cornish wind farm: implications for planning. Energy Policy 2008; 36, 23–33.

European Renewable Energy Council. Energy Sustainable Communities. http://www.erec.org/ Accessed 16.11.2015.

Fargione, J. E., Plevin, R. J., & Hill, J. D., 2010. The ecological impact of biofuels. Annual Review of Ecology, Evolution, and Systematics, 41, 351–377.

Feder, D., 2004. A regionally based energy end-use strategy: case studies from Centre County, Pennsylvania. The Professional Geographer, 56, 185–200.

Federal State Information System for Territorial Planning http://www.fgis.minregion.ru/ Accessed 20.05.2017

Fortier, J., Gagnon, D., Truax, B., & Lambert, F., 2010. Biomass and volume yield after 6 years in multiclonal hybrid poplar riparian buffer strips. Biomass and Bioenergy, 34, 1028–1040.

Frid, S.E. Yohanis, Y.G. Popel O.S., Norton, B., 2006 The annual number of days that solar heated water satisfies a specified demand temperature. Solar Energy,80, No. 8, 1021–1030.

Furlan, C., Oliveira, A. P. de, Soares, J., Codato, G., & Escobedo, J. F., 2012. The role of clouds in improving the regression model for hourly values of diffuse solar radiation. Applied Energy, 92, 240–254.

Gelfand, I., Sahajpal, R., Zhang, X., Izaurradle, R. C., Gross, K. L., & Roberston, G. P., 2013. Sustainable bioenergy production from marginal lands in the US Midwest.Nature, 493, 514–520.

Geogopoulou, E.; Lalas, D.; Papagiannakis, L., 1997. A multi-criteria decision aid approach for energy planning problems: The case of renewable energy option. Eur. J. Oper. Res. 103, 38–54.

Gil, M.V.; Blanco, D.; Carballo, M.T.; Calvo, L.F., 2011. Carbon stock estimates for forest in the Gastilla y Leon Region, Spain. A GIS based method for evaluation spatial distribution of residual biomass for bio-energy. Biomass Bioenergy 35, 243–252

Gillenwater M. Redefining RECs—part 1: untangling attributes and offsets. Energy Policy 2008; 36, 2109–19.

Grassi, S., Chokani, N., Abhari, R.S., 2012. Largescale technical and economical assessment of wind energy potential with a GIS tool: case study Iowa. Energy Policy 45,73–85.

Gret-Regamey, A.; Crespo, R., 2011. Planning from future vision: Inverse modeling in spatial planning. Environ. Plan. B: Plan. Design, 38, 979–994.

Greening, L. A., & Bernow, S. , 2004. Design of coordinated energy and environmental policies: use of multi-criteria decision-making. Energy Policy, 32, 721–735.

Grigorash O.V. Estimation of renewable energy perspectives in the Krasnodar region. Netradicionnye avtonomnye istochniki jelektrojenergii 36, 19–32. (in Russian)

Hernandez, R. R., Hoffacker, M. K., & Field, C. B., 2013. Land-use efficiency of big solar. Environmental Science and Technology, 48, 1315–1323.

Hoare, A. G., 1979. Alternative energies: alternative geographies. Progress in Human Geography, 3, 506–537.

Hoesen, J.V.; Letendre, S., 2010. Evaluating potential renewable energy resources in poultney, vermont: A GIS-based approach to supporting rural community energy planning. Renew. Energy 35, 2114–2122.

Hoogwijk, M. M., 2004. On the global and regional potential of renewable energy sources. University of Utrecht PhD Thesis.

Huld T., Müller R. and Gambardella A., 2012. A new solar radiation database for estimating PV performance in Europe and Africa. Solar Energy, 86, 1803-1815.

Jabareen, Y. Sustainable urban forms: Their typologies, models, and concepts. J. Plan. Educ. Res. 2006, 26, 38–52.

International Renewable Energy Agency (IRENA) http://globalatlas.irena.org/ Accessed 24.01.2015

Izquierdo, S., Dopazo, C., Fueyo, N., 2010. Supply-cost curves for geographically distributed renewable-energy resources. Energy Policy, 38, 667–672.

Janjai, S., Pankaew, P., Laksanaboonsong, J., 2009. A model for calculating hourly global solar radiation from satellite data in the tropics. Applied Energy, 86, 1450–1457.

Jiang, B., Zhao, S., Ma, Z., Hou, P., Xu, H., 2010. Temporal spatial distribution of the wind energy in Liaoning littoral. Marine Science, 35, 56– 62.

Kaldellis, J.K., Gavras, T.J., 2000. The economic viability of commercial wind plants in Greece– a complete sensitivity analysis. Energy Policy 28, 509–517.

Kiseleva S., Tarasenko A., 2015. Economic and social attitude towards wind energy applications in Russia. Energy Policy; 33, 595–602.

Krewitt, W., Nitsch, J., 2003. The potential for electricity generation from on-shore wind energy under the constraints of nature conservation: a case study for
two regions in Germany. Renewable Energy 28, 1645–1655.

Krohn, S., Damborg S., 1999. On public attitudes towards wind power. Renewable Energy, 16, 954–60.

KubanCadaster. Information of the land use and construction activity in Krasnodar region http://www.kcadaster.ru/ Accessed 2.10 2014 (In Russian).

KubanEnergo. Power Industry and electrification of Krasnodar region http://kubanenergo.ru Accessed 12.12 2015 (In Russian).

KubanMeteo. Information of the weather forecast and data from weather stations in Krasnodar region http://kubanmeteo.ru/ Accessed 18.06 2016 (In Russian).

KubanStat The territorial body of the Federal State Statistics Service in the Krasnodar Region http //kubanstat.gsk.ru/ Accessed 19.06 2016 (In Russian).

Labrecque, M., & Teodorescu, T. I., 2005. Field performance and biomass production of 12 willow and poplar clones in short-rotation coppice in southern
Quebec (Canada). Biomass and Bioenergy, 29, 1–9.

Liu, T., Ma, Z., Kulshreshtha, S., McConkey, B., Huffman, T., Green, M., 2012. Bioenergy production potential on marginal land in Canada. First International Conference on Agro-Geoinformatics 08, 2–4.

Loken, E., 2007. Use of multi-criteria decision analysis methods for energy planning problems. Renew. Sustain. Energy Rev. 11, 1584–1595.

Mabee, W., & Mirck, J., 2011. A regional evaluation of potential bioenergy production pathways in Eastern Ontario, Canada. Annals of the Association of
American Geographers, 101, 897–906.

Marrou, H., Wery, J., Dufour, L., & Dupraz, C., 2013. Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. European Journal of Agronomy, 44, 54–66.

Mendoza, G., 1997. A GIS-based multicriteria approach to land suitability assessment and allocation. United States Department of Agriculture Forest Service General Technical Report NC, 89-94.

Mikhail, A. S., 1985. Height extrapolation of wind data. Journal of Solar Energy Engineering, 107(1), 10-14

Milbrandt, A. R., Heimiller, D., Perry, A. D., & Field, C. B., 2014. Renewable energy potential on marginal lands in the United States. Renewable and Sustainable Energy Reviews, 29, 473–481.

Moran, D., Sherrington, C., 2007. An economic assessment of wind farm power generation in Scotland including externalities. EnergyPolicy35 (5), 2811–2825.

Muneer, W., Bhattacharya, K., & Canizares, C., 2011. Large-scale solar PV investment models, tools and analysis.Transactions on Power Systems, 26, 2547–2555.

NASA database Surface meteorology http://eosweb.larc.nasa.gov/ Accessed 06.10.2015

National Renewable Energy Laboratory of the USA. http://www.nrel.gov/gis/about.html Accessed 10.04.2016

Nema, P., Nema, R. K., & Rangnekar, S. (2009). A current and future state of art development of hybrid energy system using wind and PV-solar: a review. Renewable and Sustainable Energy Reviews, 12, 2096–2103.

Neudoerffer, R.C.; Malhotra, P.; Ramana, P.V., 2001. Participatory rural energy planning in India—A policy context. Energy Pol. 29, 371–381.

Nguyen, H. T., & Pearce, J. M., 2010. Estimating potential photovoltaic yield with r.sun and the open source geographical analysis support system. Solar Energy, 84, 831–843.

Nogueira, L. A. H., Moreira, J. R., Schuchardt, U., & Goldemberg, J., 2013. The rationality of biofuels. Energy Policy, 61, 595–598.

Ohl, C., & Eichhorn, M., 2010. The mismatch between regional spatial planning for wind power development in Germany and national eligibility criteria for feedin tariffs e a case study in West Saxony. Land Use Policy, 27, 243–254.

OpenStreetMap (OSM) Cartographic web service. http://www.openstreetmap.org/ Accessed 07.11.2016

Pohekar, S.D.; Ramachandran, M., 2004. Application of multi-criteria decision making to sustainable energy planning. A review. Renew. Sustain. Energy Rev. 8, 365–381.

Popel, O., Fortov, E. 2015, Renewable Power in the modern world. A book. Publishing House MEI, Moscow, 357. (in Russian)

Portland Sustainability Institute. Eco Districts. Available online: http://ecodistricts.org/ Accessed 14.01.2015

QGIS Mapping Software. http://www.qgis.com/ Accessed 02.10.2014

Nassi O Di Nasso, N., Guidi, W., Ragaglini, G., Tozzini, C., & Bonari, E., 2010. Biomass production and energy balance of a 12-year-old short-rotation coppice poplar stand under different cutting cycles. Global Change Biology, Bioenergy, 2, 89–97.

Nguyen, H., and Pearce, J., 2010. Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System. Solar Energy, 84, 831–843.

National Renewable Energy Laboratory, 2013. Land-Use Requirements for Solar Power Plants in the United States. http://www.nrel.gov/docs/fy13osti/56290.pdf Accessed on 10.12.2014

Oberschmidt, J., Geldermann, J., Ludwig, J., Schmehl, M., 2010. Modified PROMETHEE approach for assessing energy technologies. International Journal of Energy Sector Management, 4, 183–212.

Odo, F., Offiah, S. U., Ugwuoke, P., 2012. Weibull distribution-based model for prediction of wind potential in Enugu, Nigeria. Adv Appl Sci Res, 3(2), 1202-1208.

Price, L., Bullard, M., Lyons, M., Anthony, S., & Nixon, P., 2004. Identifying the yield potential of Miscanthus x giganteus: an assessment of the spatial and temporal variability of M. x giganteus biomass productivity across England and Wales. Biomass and Bioenergy, 26, 3–13.

PRISM Group http://www.prism.oregonstate.edu/ Accessed 05.12.2014

PVGIS Photovoltaic Geographical Information System http://re.jrc.ec.europa.eu/pvgis/ Accessed 09.07.2015

Rafikova J., 2015 A GIS-planning approach for the promotion of renewable energies in the south-west regions of Russia. Renew. Energy 18, 317–330.

Ramachandra, T., Shruthi, B., 2007. Spatial mapping of renewable energy potential. Renewable and Sustainable Energy Reviews 11, 1460–1480.

Resch, B., Sagl, G., Tornros, T., Bachmaier, A., Eggers, J. B., Herkel, S., et al., 2014. GIS-based planning and modeling for renewable energy: challenges and future research avenues. International Journal of Geo-Information, 3, 662-692.

Renewable Energy Atlas of Vermont State, USA http://www.vtenergyatlas.com Accessed 14.03.2015

RETScreen International. Renewable energy decision support center. http: // www.retscreen.net Accessed 22.08.2016

RIA News https://ria.ru/ Accessed 23.10.2015 (In Russian)

Rio, P.; Burguillo, M., 2008. Assessing the impact of renewable energy development on local sustainability: Towards a theoretical framework. Renew. Sustain. Energy Rev., 12, 1325–1344.

RosReestr. The federal service for state registration, cadaster and cartography. https://rosreestr.ru/ Accessed 30.03.2016 (In Russian).

RosStat. Federal State Statistics Service http://www.gks.ru/ Accessed 10.05.2015 (In Russian).

Russian Ministry of Energetics. Energy strategy until 2035. http://ac.gov.ru/files/content/1578/11-02-14-energostrategy-2035-pdf. Accessed 11.10.2016 (In Russian).

Saaty, T. L., 1980. The analytic hierarchy process: planning, priority setting, resources allocation. New York: McGraw

Saaty, T. L., Vargas, L. G. (2006). Decision making with the analytic networkprocess. Springer Science + Business Media, LLC.

Schmidt, J., Schonhart, M., Biberacher, M., Guggenberger, T., Hausl, S., Kalt, G., 2012. Regional energy autarky: potentials, costs and consequences for an Austrian region. Energy Policy, 47, 211–221.

Searcy, E., & Flynn, P., 2009. The impact of biomass availability and processing cost on optimum size and processing technology selection. Applied Biochemistry and Biotechnology, 154, 271–286.

Shafiullah, G. M., Amanullah, M. T. O., Shawkat Ali, A. B. M., Jarvis, D., & Wolfs, P., 2012. Prospects of renewable energy e a feasibility study in the Australian context. Renewable Energy, 39, 183–197.

Shiftan, Y.; Kaplan, S.; Hakkert, S. Scenario building as a tool for planning a sustainable transportation system. Transp. Res. Part D: Transp. Environ. 2003, 8, 323–342.

Simao, A.; Densham, P.J.; Haklay, M. Web-based GIS for collaborative planning and public participation: An application to the strategic planning of wind farm sites. J. Environ. Manag. 2009, 90, 2027–2040.

Sims, R. E. H., Hastings, A., Schlamadinger, B., Taylor, G., & Smith, P., 2006. Energy crops: current status and future prospects. Global Change Biology, 12, 2054–2076.

Stremke, S.; Koh, J., 2010. Ecological concepts and strategies with relevance to energy-conscious spatial planning and design. Environ. Plan. B: Plan. Design 37, 518–532.

Tarasenko A., 2014. Sustainable energy planning by storage systems, application for Russian conditions. Energy Pol.37, 1587–1600. (in Russian)

Terrados, J.; Almonacid, G.; Perez-Higueras, P., 2009. Proposal for a combined methodology for renewable energy planning. Application to a Spanish region. Renew. Sustain. Rev. 13, 2022–2030.

Thenkabail, P. S., Stucky, N., Griscom, B. W., Ashton, M. S., Diels, J., Van Der Meer, B., Enclona, E., 2004). Biomass estimations and carbon stock calculations in the oil palm plantations of African derived savannas using IKONOS data. International Journal of Remote Sensing, 25(23), 5447-5472.

Thornton, P. E., Running, S. W., 1999. An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation. Agricultural and Forest Meteorology, 93, 211–228.

Tomberlin, G., Mosey, G., 2013. Feasibility Study of Economics and Performance of Biomass Power Generation at the Former Farmland. Industries Site in Lawrence, Kansas.

TRNSYS - The Transient System Simulation Program. http://sel.me.wisc.edu/trnsys/ Accessed 12.02.2017

United Nations Environment Programme (UNEP) http://www.unenvironment.org/ Accessed 13.02.2015

United States Geological Survey (USGS). https://lpdaac.usgs.gov/. Accessed 25.10.2014

Vera, I.; Langlois, L., 2007. Energy indicators for sustainable development. Energy 32, 875–882.

Vestas's website. https://www.vestas.com/ Accessed 15.11.2014

Voivontas, D., Assimacopoulos, D., Mourelatos, A., Corominas, J., 1998. Evaluation of renewable energy potential using a GIS decision support system. Renewable Energy 13, 333–344.

Wanderer, T., & Herle, S., 2015. Creating a spatial multi-criteria decision support system for energy related integrated environmental impact assessment. Environmental Impact Assessment Review, vol. 52, s. 2–8.

Wang, Q., M'Ikiugu, M.M., Kinoshita, I., 2014. A GIS-Based Approach in Support of Spatial Planning for Renewable Energy: A Case Study of Fukushima, Japan. Sustainability 6, 2087–2117.

WindPro Programm software http://windpro.uk Accessed 23.10.2014

Wiginton, L. K., Nguyen, H. T., & Pearce, J. M., 2010. Quantifying solar photovoltaic potential on a large scale for renewable energy regional policy. Computers and Environmental Urban Systems, 34, 345–357.

World energy council. World energy resource http://www.worldenergy.org/wpcontent/uploads/2013/09/Complete_WER_2013_Survey.pdf Accessed 23.09.2016

World Radiation Data Center, the laboratory of the Voyeikov Geophysical Observatory, the Federal Service of Russia for Hydrometeorology and Environmental Monitoring. http://wrdc.mgo.rssi.ru/ Accessed 27.08 2017

Yue, C.D.; Wang, S.S., 2006. GIS-based evaluation of multifarious local renewable energy resources: A case study of the Chigu area of Southwestern Taiwan. Energy Policy 34, 730–742.

Zhang, D., Xiong, W., Tang, C., Liu, Z., & Zhang, X., 2014. Determining the appropriate amount of subsidies for wind power: The integrated renewable power planning (IRPP) model and its application in China. Sustainable Energy Technologies and Assessments, 6, 141–148

Curriculum vitae

Personal data

Name	Alisa Melnikova
Postal address	Zweibruecker Strasse 89 66953 Pirmasens
Phone	+49 6341 280 31532
Mobile phone	+49 1525 748 5238
E-mail	melnikova@uni-landau.de
Date/Place of birth	11/10/1989 Bendery

Education

10/2014 – 2/2018	**PhD at the University of Koblenz-Landau, Campus Landau** PhD thesis: Assessment of renewable energy potentials based on GIS. A case study in southwest region of Russia.
2011 – 2013	**Master in Economics** Tyumen State University, Russia
2010 – 2012	**Master in Ecology and Ecology and Environmental Management** Tyumen State University, Russia
2006 – 2010	**Bachelor in Biology** Tyumen State University, Russia
1996 – 2006	**Secondary school** Novyi Urengoy, Russia

Professional experience

10/2009 – 09/2011

Environmental Protection Agency of the Tyumen region

My tasks as environmental inspector were:

- Mapping of territories with environmental issues
- Administrative fines for environmental violations
- Educational work with causers of environmental pollution

09/2009 – 09/2011

Biophysical laboratory practice at the Tyumen State University, Russia

My tasks as research assistant were:

- Seminars and testings in basics of human anatomy and body dynamics

- Seminars and testings in biophysical measurement methods

Organizational experience

04/2017	**International conference Distance Learning and Double Degree in a Modern University – a Way of Internationalisation** My tasks were: • Content conception of the conference • Contacting and support of participants • Evaluation of the conference
2017 – present	**Information events for PhD students and international students** • Workshops for doctoral candidates • Workshops for international students Topics: German job market (in English) • Colloquium on scientific networking • Mentoring of early-stage PhD student

Internships

04/2016 – 06/2016	**Online course Intercultural Competence** Purdue University, Indiana, USA
09/2011 – 12/2011	**ESRI Advanced training course: ArcGIS** applications Siberian Research and Analytics Center Tyumen
04/2009 – 10/2009	**Biophysics laboratory practice** Albert Ludwig University of Freiburg

External funding

2015 – 2018	DAAD Eastern Europe Partnerships Program (granted)
2014 – 2017	DAAD Mobility Program (granted)

Scholarships

09/2015 – 11/2017	Completion scholarship, DAAD
08/2015 – 08/2017	Doctoral scholarship Stipendien Stiftung Rheinland-Pfalz
08/2014 – 07/2015	Doctoral scholarship, DAAD
10/2012 – 03/2013	One-semester scholarship University of Koblenz-Landau, TEMPUS
10/2011 – 10/2012	Two-semester scholarship, Nord University, Norway
04/2009 – 10/2009	One-semester scholarship Albert Ludwig University of Freiburg TEMPUS

Participation in conferences

10/2016	Conference *Renewable Energy Sources* Lomonosov Moscow State University, Talk
09/2015	Summer School *Energy in Focus* TU Darmstadt, Poster
11/2014	Conference *InterCarto*, Kuban State University, Talk
09/2014	Trifelser Summer School *Risikokompetente Gesellschaft*, University of Koblenz-Landau, Organisation

Publications

11/2016	**Melnikova A.**, Rafikova Y. (2016): Multi-step analysis to estimate the conditions for the implementation of solar energy installations. Alternative Energy and Ecology (ISJAEE), (15 – 18): 12-2
11/2015	**Melnikova A.**, Jergentz S., Frör O. (2015): The assessment of economic and ecological potentials for the implementation of renewable energy sources (RES) in Krasnodar region. Conference InterGIS; 1 (21): 289-295

Additional skills

Computer literacy	MS Office: Word, Excel, PowerPoint GIS: ArcGIS, SAGA GIS, Q GIS Statistic programs: SPSS, R Statistics
Language skills	German (fluently in spoken and written) English (fluently in spoken and written) Russian (native language)
Driving license	Class B

Voluntary activities

01/2017 – present	**Freiwillige Promotionsinitiative Landau (FPL)** Cooperation and support of the interdisciplinary doctoral center of the University of Koblenz-Landau
10/2015 – present	**Voluntary initiative for the International Office of the University of Koblenz-Landau** Cultural hiking tours for international students in the Palatinate Forest
09/2008 – 12/2013	**Web conferences between the Tyumen State University and the University of Kansas, USA** Co-moderation