

A thesis submitted to the Department of Environmental Sciences and Policy of
Central European University in part fulfillment of the
Degree of Master of Science

Development of energy systems and energy policies in Ukraine:
historical analysis, current state and future scenarios

by Anna SHUMEIKO

Supervisor: Professor Aleh CHERP

May 2014

**Erasmus Mundus Masters Course in Environmental
Sciences, Policy and Management**

MESPOM



This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).



Education and Culture

Erasmus Mundus

Notes on copyright and the ownership of intellectual property rights:

(1) Copyright in text of this thesis rests with the Author. Copies (by any process) either in full, or of extracts, may be made only in accordance with instructions given by the Author and lodged in the Central European University Library. Details may be obtained from the Librarian. This page must form part of any such copies made. Further copies (by any process) of copies made in accordance with such instructions may not be made without the permission (in writing) of the Author.

(2) The ownership of any intellectual property rights which may be described in this thesis is vested in the Central European University, subject to any prior agreement to the contrary, and may not be made available for use by third parties without the written permission of the University, which will prescribe the terms and conditions of any such agreement.

(3) For bibliographic and reference purposes this thesis should be referred to as:
Shumeiko, A. 2014. *Development of energy systems and energy policies in Ukraine: historical analysis, current state and future scenarios*. Master of Science thesis, Central European University, Budapest.

Further information on the conditions under which disclosures and exploitation may take place is available from the Head of the Department of Environmental Sciences and Policy, Central European University.

Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.



Anna SHUMEIKO

THE CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:

Anna SHUMEIKO for the degree of Master of Science and entitled: *Development of energy systems and energy policies of Ukraine: historical analysis, current state and future scenarios.*

Month and year of submission: May, 2014

The modern ages are characterised with our growing dependence on previously unknown forms of energy, such as electrical and nuclear, due to world population growth and increasing energy demand in practically every corner of the planet. Climate change, energy security and energy access are the three global energy challenges which have to be addressed by humanity in 21st century. However, as some authors state, there is no global energy governance as such. Thus, in order to achieve global sustainability goals, national energy systems should be transformed and guided by internationally accepted principles focused on dealing with the mentioned above challenges. From this perspective, there is a clear necessity to study and analyse each country in particular, as a part of global and regional energy transitions research.

The present thesis focuses on energy system of Ukraine as a country rich with natural resources and with an immense untapped potential for energy efficiency, renewable energies and extraction of fossil fuels. Ukraine's geographic location at the Black Sea and between the two large political powers of the present, the EU and Russia, gives the country a substantial strategic importance, and at the same time puts it at the crossroads as a direction for its future development is concerned. The International Energy Agency states that Ukraine "... has the unique opportunity to undertake an energy revolution" by driving economic growth, modernising infrastructure of its energy sector, reforming its energy markets, increasing energy efficiency and exploitation of indigenous energy resources. However, what are the current real priorities of Ukraine's energy policy? Who and what stands behind them? And what are the possible paths for the development of its energy system?

The analysis carried out in the work is based on a theory of historic and modern transformations of a state and state's energy systems, vital energy systems theory and a framework where energy systems, energy institutions and energy policies interact driving the development of the country's energy sector. The results show that Ukraine's vital energy systems (electricity, nuclear, natural gas, coal, oil) through history are deeply imbedded in its economy and closely related to the state of Ukraine-Russia relationship. The study concludes that a 'business as usual' scenario could become the most deteriorating one for the country's energy sector. A simultaneous cooperation with the EU and Russia would provide a smooth path towards economic growth, ensuring that the country meets its future energy demand, while in case of EU integration and hostile relationship with Russia Ukraine would have to face many difficulties, such as phasing out its nuclear power capacities and looking for alternatives to meet its energy demand.

Keywords: Ukraine, energy, system, policy, environment, history, nuclear, coal, oil, gas, electricity, crisis, scenarios, development

Acknowledgements

The subject of the thesis occurred naturally as an attempt to combine the knowledge and experience which I gained while living, studying and working in Ukraine, as well as the knowledge on environmentally-related issues during the two years at MESPOM.

The topic of energy became a source of my deep fascination during the first academic years at the National Technical University of Ukraine “KPI” thanking to the wonderful professors and old school professionals who opened us the enchanting world of power engineering: O.V. Georgiev, V.V. Bosyi, N.M. Fialko, L.O. Kesova to name but a few. Also I would like to express my cordial gratitude to M.F. Onyshchenko and D.O. Vest, with whom I learnt about energy design and international cooperation during the time of working at “Ukrenergoprom-2” Ltd., and who always supported me in all my aspirations. Constant contributions and sincere devotion to development and improving of the Ukrainian energy system of these people made me believe that notwithstanding all the difficulties Ukraine has been facing since its independence, the country has a bright future until their experience is not forgotten and passed further to future generations.

To say that a decision to apply for MESPOM was one of the most important ones in my life is to say nothing. There were moments of happiness and excitement, moments of despair and loss of reality; there was a colourful Budapest autumn, a rainy Manchester winter and a warm sunny Lesvos spring. Through all this I was lucky to go through with the most amazing and unique people from all around the world. I would like to say thank you to Shu-Yuan, Saurabh, Sophia, Boris, Kata, Gabor and Omniah, who were there to share the happiest and saddest times. You are my angels. Also I would like to thank all the MESPOM staff, who made this unparalleled experience possible and were always there to support and help. Special thanks to prof. Aleh Cherp, who kindly agreed to guide me through the interesting and tangled thesis writing process. His clear views, rich experience and academic works opened a whole new world of energy policy to me constantly inspiring and pushing forward.

I wouldn't have been who I am and where I am now without my parents. Thank you. For everything. Marta, Tanja, Anton, Konstantin, Viktoria, Abi, Niels, thank you for believing, guiding, inspiring.

While I was working on the thesis, Ukraine was going through extremely difficult times struggling for democracy, dignity and freedom: a good and simultaneously tragic example of “transition”, which currently takes place in a number of developing countries around the world. My friends and relatives were there in the centre of events, and so my heart had been with them, as well as with the whole country. Never before in my life had I felt as patriotic, as worried, as proud to be a Ukrainian. Thus, I would like to dedicate this work to the new Heroes of Ukraine: to the dreamers, who believe in a brighter future, who are ready to fight until the very end for peace, integrity and better lives of our next generations. Some of them may not be with us anymore, but their energy of a strong will is always there in our hearts and memories.

Table of Contents

| | |
|---|------|
| Acknowledgements | v |
| List of figures | x |
| List of tables | xiii |
| Abbreviations | xv |
| Information on energy units | xvi |
| 1. INTRODUCTION | 1 |
| 1.1. Background | 1 |
| 1.2. Thesis statement, aims and objectives | 2 |
| 1.3. Implications of research | 3 |
| 1.4. Methodology and tools | 3 |
| 1.5. Scope and limitations | 5 |
| 1.6. Thesis structure outline | 5 |
| 2. LITERATURE REVIEW | 8 |
| 2.1. Introduction. Global energy policies: their transitions and challenges | 8 |
| 2.2. Explaining national energy policies | 13 |
| 2.2.1. ... through historic and contemporary analyses | 13 |
| 2.2.2. ... through energy architecture | 15 |
| 2.2.3. ... through vital energy systems | 17 |
| 2.3. Energy systems & policy in Ukraine: current state of knowledge | 19 |
| 2.3.1. History of establishment of Ukraine's energy system | 19 |
| 2.3.2. Current political and economic context | 22 |
| 2.3.3. Energy policy plans and projections | 24 |
| 2.4. Conclusion | 26 |
| 3. THEORETICAL FRAMEWORK AND METHODS | 28 |
| 3.1. Theoretical framework | 28 |
| 3.2. Method | 31 |

| | |
|---|----|
| 4. RESULTS: ENERGY SYSTEMS OF UKRAINE | 36 |
| 4.1. Background information | 36 |
| 4.1.1. Energy resources of Ukraine | 36 |
| 4.1.2. History of energy systems in Ukraine | 46 |
| 4.2. Coal energy system | 64 |
| 4.2.1. History | 64 |
| 4.2.2. Current state | 67 |
| 4.2.3. System governance | 71 |
| 4.2.4. Vulnerabilities | 72 |
| 4.3. Oil energy system | 73 |
| 4.3.1. History | 73 |
| 4.3.2. Current state | 74 |
| 4.3.3. System governance | 76 |
| 4.3.4. Vulnerabilities | 77 |
| 4.4. Gas energy system | 78 |
| 4.4.1. History | 78 |
| 4.4.2. Current state, importance and connections to other systems | 81 |
| 4.4.3. System governance | 82 |
| 4.4.4. Vulnerabilities | 84 |
| 4.5. Hydroelectric power system | 84 |
| 4.5.1. History | 84 |
| 4.5.2. Current state, importance and connections to other systems | 85 |
| 4.5.3. System governance | 87 |
| 4.5.4. Vulnerabilities | 88 |
| 4.6. Nuclear power system | 89 |
| 4.6.1. History | 89 |
| 4.6.2. Current state | 93 |

| | |
|---|-----|
| 4.6.3. System governance and structure..... | 95 |
| 4.6.4. Vulnerabilities | 97 |
| 4.7. Renewables energy system | 99 |
| 4.7.1. History..... | 99 |
| 4.7.2. Current state, importance and connections to other systems | 101 |
| 4.7.3. System governance..... | 103 |
| 4.7.5. Vulnerabilities | 104 |
| 4.8. Electric power system..... | 105 |
| 4.8.1. History..... | 105 |
| 4.8.2. Current state, importance and connections to other systems | 108 |
| 4.8.3. System governance..... | 109 |
| 4.8.4. Vulnerabilities | 111 |
| 4.9. Current strategies and policies | 112 |
| 4.10. Chapter findings..... | 116 |
| 5. DISCUSSION AND ANALYSIS | 120 |
| 5.1. Vital energy systems and their vulnerabilities | 120 |
| 5.1.1. Identifying Ukrainian VES | 120 |
| 5.1.2. Vulnerabilities | 122 |
| 5.2. Energy system drivers..... | 126 |
| 5.2.1. Driving forces..... | 126 |
| 5.2.2. Policy interests and stakeholders | 127 |
| 5.3. Energy policy priorities | 131 |
| 5.5. Future scenarios of Ukraine's energy | 132 |
| 6. KEY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS..... | 139 |
| 6.1. Key findings..... | 140 |
| 6.2. Conclusions and recommendations | 143 |
| 6.3. Implications for future research..... | 144 |

| | |
|---------------------|-----|
| Reference List..... | 146 |
| Appendix | 166 |
| Figures | 166 |
| Tables..... | 177 |

List of figures

| Main text | page |
|--|------|
| Figure 1. Thesis analysis stages..... | 4 |
| Figure 2. Evolution of primary energy shown as absolute contributions by different energy sources..... | 10 |
| Figure 3. Interactions and connections between energy policies, systems and institutions..... | 29 |
| Figure 4. Sankey diagram for Ukraine, 2011..... | 35 |
| Figure 5. Geologic structure of Ukraine | 37 |
| Figure 6. Coal reserves and main coal basins of Ukraine..... | 38 |
| Figure 7. Oil and gas resources of Ukraine..... | 40 |
| Figure 8. Nuclear energy map of Ukraine | 42 |
| Figure 9. Ukrainian territories in XVIII – beginning of XIX centuries..... | 47 |
| Figure 10. Industry and agriculture in Ukrainian gubernias of the Russian Empire in 1900 | 50 |
| Figure 11. Distribution of Ukrainian power plants of capacities more than 1 MW between various sectors of economy in 1913..... | 52 |
| Figure 12. Extraction of coal, oil, gas and generation of electricity in Ukraine in 1990 – 2013..... | 60 |
| Figure 13. Emissions from stationary sources in Ukraine in 1990 – 2012..... | 60 |
| Figure 14. The structure of final energy use in Ukraine, 2010..... | 62 |
| Figure 15. Fuel/energy used at power plants of Ukraine, 2011 | 63 |
| Figure 16. Extraction of coal in Ukraine in 1990 – 2013..... | 67 |
| Figure 17. Intersectoral flows of money and goods related to coal industry..... | 69 |
| Figure 18. Coal consumption by economic sectors of Ukraine, 2011..... | 70 |
| Figure 19. Oil extraction in Ukraine in 1990 – 2013..... | 74 |
| Figure 20. Oil consumption by economic sectors of Ukraine, 2011..... | 75 |

| | |
|---|-----|
| Figure 21. Ukraine oil and gas extraction 1930 to 2030..... | 79 |
| Figure 22. Extraction of domestic natural gas in Ukraine in 1990 – 2013..... | 80 |
| Figure 23. Natural gas consumption by economic sectors of Ukraine, 2011..... | 82 |
| Figure 24. Electricity generation energy mix in Ukraine in 1991 – 2012..... | 106 |
| Figure 25. Change of the structure of energy resources in electricity and heat generation at TPPs and CHPPs in Ukraine in 1991-2012..... | 107 |
| Figure 26. Structure of electricity market and electricity system governance of Ukraine..... | 110 |
| Figure 27. Extraction of coal, oil, gas and generation of electricity in Ukraine in 2010 – 2013 (factual data) and 2015 – 2030 (the Strategy ‘baseline’ scenario projections)..... | 114 |
| Figure 28. Electricity generation energy mix in Ukraine in 2010 – 2013 (factual data) and 2015 – 2030 (the Strategy ‘baseline’ scenario projections)..... | 114 |
| Figure 29. Major stakeholders in electricity generation and supply activities in Ukraine..... | 128 |
| Figure 30. Trends and uncertainties for development of Ukraine’s energy sector..... | 132 |
| Appendix | |
| Figure A.1. Energy architecture conceptual framework..... | 166 |
| Figure A.2. Distribution of mineral and energy resources in Ukraine..... | 167 |
| Figure A.3. Potentials for application of different types of renewable energy resources in Ukraine..... | 167 |
| Figure A.4. Solar energy potential map of Ukraine..... | 168 |
| Figure A.5. Environmental map of Ukraine..... | 169 |
| Figure A.6. Electricity consumption by economic sectors of Ukraine, 2011..... | 170 |
| Figure A.7. Heat consumption by economic sectors of Ukraine, 2011..... | 170 |
| Figure A.8 (a-d) Distribution of energy consumption in Ukraine by sectors, 2011..... | 171 |

| | |
|---|-----|
| Figure A.9 (a-k) Energy consumption by Ukrainian industries, 2011 | 173 |
| Figure A.10 (a-c) Energy consumption by residential, public and agriculture sectors of Ukraine, 2011..... | 174 |
| Figure A.11. Power system of Ukraine: power plants and transmission lines..... | 175 |
| Figure A.12. Tariffs for electricity in Ukraine, July 2013 | 176 |

List of tables

| | |
|--|------|
| Main text: | page |
| Table 1. The main global energy governance arenas..... | 12 |
| Table 2. Classification of states | 14 |
| Table 3. Transformations of a state..... | 15 |
| Table 4. Current energy architecture archetypes..... | 16 |
| Table 5. Three perspectives on energy security..... | 18 |
| Table 6. Template for characterizing the major energy systems of Ukraine..... | 32 |
| Table 7. A matrix for evaluating the importance of energy systems according to imperatives of a state..... | 33 |
| Table 8. Information on unconventional gas reserves in Ukraine..... | 41 |
| Table 9. Estimations of renewable energy resource potentials in Ukraine..... | 44 |
| Table 10. Fuel extraction in Ukrainian SSR 1940 – 1978..... | 57 |
| Table 11. Major energy institutions of Ukraine and USSR before 1991..... | 91 |
| Table 12. Installed capacities of renewable power plants in Ukraine by July 2013..... | 101 |
| Table 13. Results of analysis of energy systems of Ukraine..... | 118 |
| Table 14. Rating of Ukraine’s energy systems according to the six imperatives of a state..... | 121 |
| Table 15. Susceptibility of Ukrainian energy systems to externally-caused interruptions..... | 123 |
| Table 16. Top energy market stakeholders in Ukraine according to a revenue they generate..... | 130 |
| Appendix | |
| Table A.1. Distribution of Ukrainian power plants of capacities more than 1,000 kW between various sectors of economy in 1913..... | 177 |
| Table A.2. Information box: Historical transition from firewood and charcoal to coal in Ukraine..... | 177 |

| | |
|---|-----|
| Table A.3. Change of the structure of energy resources in generation of electric energy at TPPs and CHPPs in Ukraine in 1991-2012..... | 178 |
| Table A.4. General information on energy generating companies related to thermal power production, 2012..... | 178 |
| Table A.5. Top Ukrainian companies according to their revenue in 2012..... | 180 |
| Table A.6. Ownership of the Ukrainian oil refineries..... | 183 |
| Table A.7. Structure of installed electricity generating capacities of power plants of Ukraine in 2003 – 2013..... | 184 |
| Table A.8. State institutions governing the renewable energy in Ukraine..... | 185 |
| Table A.9. Ranking of energy systems (ES) according to state imperatives..... | 185 |

Abbreviations

| | |
|-----------------|---|
| CHPP | combined heat-and-power plant |
| CIS | Commonwealth of Independent States |
| CCS | carbon capture and storage |
| EC | (European) Energy Community |
| EU | European Union |
| GDP | gross domestic product |
| GHG | greenhouse gas(es) |
| HAPP | hydro-accumulating power plant |
| HPP | hydropower plant |
| JSC | Joint-Stock Company |
| LLC | limited liability company |
| Mt | million tonnes |
| Mtoe | million tonnes of oil equivalent |
| NASU | National Academy of Sciences of Ukraine |
| NERC | National Electricity Regulatory Commission |
| NPP | nuclear power plant |
| OJSC | Open Joint-Stock Company |
| PJSC | Private Joint-Stock Company |
| RBMK | graphite-moderated nuclear reactor |
| RES | renewable energy sources |
| SE | State(-owned) Enterprise |
| Strategy | Updated Energy Strategy of Ukraine until 2030 |
| TPP | thermal power plant |
| UES | United Energy System |
| US | United States of America |
| USSR | the Union of Soviet Socialist Republics |
| VES | vital energy system |
| VVER | pressurized-water nuclear reactor |

Information on energy units

Table for conversion of energy units

| | GJ | tce | toe | Gkal | MWh |
|-------------|-----------|------------|------------|-------------|------------|
| GJ | 1 | 0.0341 | 0.0239 | 0.239 | 0.278 |
| tce | 29.31 | 1 | 0.700 | 7.0 | 8.130 |
| toe | 41.87 | 1.429 | 1 | 10.0 | 11.63 |
| Gkal | 4.19 | 0.143 | 0.100 | 1 | 1.163 |
| MWh | 3.60 | 0.123 | 0.0861 | 0.861 | 1 |

J – Joule

tce – tonne of coal equivalent

toe – tonne of oil equivalent

cal– calorie

Wh– Watt in an hour

Meaning of prefixes placed before energy measurement units:

| | | |
|-------------|-----|-----------|
| Kilo | (k) | 10^3 |
| Mega | (M) | 10^6 |
| Giga | (G) | 10^9 |
| Tera | (T) | 10^{12} |
| Peta | (P) | 10^{15} |

1. INTRODUCTION

1.1. Background

The simple definition of energy from the perspective of physics, as a “capacity to do work” (Demirel 2012), gives us a clear understanding that without energy we cannot make a single step, take a breath, or carry out any work. This is especially pertinent for the modern age, where we are becoming more and more dependent on previously unknown forms of energy, such as electrical and nuclear. In 2011 the world population reached 7 billion (Ezeh *et al.* 2012), with every single human requiring energy for food, water, light, electricity, heat and other needs.

There is a range of energy challenges for the humanity in the 21st century. These include climate change, energy access and energy security. Although some of these challenges are global in nature they can only be achieved through appropriate national policies. This makes research of national energy policies and their transformations crucially important. As a comparative policy analyst Francis Castles (1985) states: “Only when we seek to focus on the detailed historical evolution of particular policies in particular countries can we gain a better understanding of the complex interaction of the multiple variables which jointly influence policy development”. Moreover, a better understanding of historical evolution of such a complex system as an energy system, together with policies related to its formation, can thus give us a clearer picture of the system’s current state and possible directions of its further development.

Ukraine, a country with a diverse and complex energy system confronted with many challenges is currently at crossroads with a high possibility of significant transformations to occur. According to IEA (2012), “... the country has the unique opportunity to undertake an energy revolution” by driving economic growth, modernising infrastructure of its energy sector, reforming its energy markets, untapping its potential for energy efficiency increase and

exploitation of indigenous energy resources. Can this, however, be implemented? And if not, which other scenarios for transformations of the country's energy sector are possible? The thesis will attempt to answer these questions by analysing development of Ukraine's energy system: from its roots until the present day, and by proposing possible scenarios as continuous pathways, rather than simple projections derived from the current state without considerations of the important transitions of the past.

1.2. Thesis statement, aims and objectives

Statement

There is a need of a comprehensive research of national energy policies. Ukraine is a country in transition with immense opportunities for future development, where energy sector plays a crucial role in the country's economy and to a large extent identifies the future transformations of the state. Thus, it is necessary to study Ukraine's energy system, its evolvement, drivers and challenges it is facing and it is about to face, in order to find unique, sustainable and energy policy solutions.

Aims:

- ❖ Identification and understanding of the main drivers of the Ukrainian energy policy through historical and contemporary analysis of energy systems and institutions with a view to develop scenarios of future of Ukraine's energy.

Objectives

- ❖ Theoretical framework (how national energy policies are shaped);
- ❖ analysis of the current and historic state of the energy sector: position in the international energy market, present issues impeding sustainable development, challenges, goals;
- ❖ description of the current energy policy priorities in Ukraine (including analysis of the Updated Energy Strategy until 2030);

- ❖ identification of main drivers for development of the energy system of Ukraine as it is today;
- ❖ developing scenarios of the country's energy system based on the identified key drivers, historical and contemporary analyses.

1.3. Implications of research

As it is shown in the next chapter (literature review), there is a relatively small number of studies which focused on energy transformations of a state, especially when Eastern Europe and Ukraine specifically are concerned. A whole range of literature on the history of establishment of the Ukrainian energy system is available and will be used in the thesis as a baseline for research. However, there are practically no attempts to analyse historical implications and identify the main drivers that shaped the country's energy system as we see it today. Moreover, only one comprehensive document was found, namely "The Updated Energy Strategy until 2030" (MECIU 2012a), which attempts to build projections for the energy system's development. The projections are, however, based fully on the present situation and do not take into account the historical evolvement of the current circumstances. From this perspective, the results of the thesis may be useful for deeper understanding of the existing and future energy challenges of Ukraine, as well as for establishment of a more effective energy policy framework directed towards sustainable development.

1.4. Methodology and tools

The thesis will be written in a form of a theoretical analysis focusing on separate energy systems of Ukraine, as well as on the national energy system as a whole. Briefly, the analysis will be comprised of the following stages:

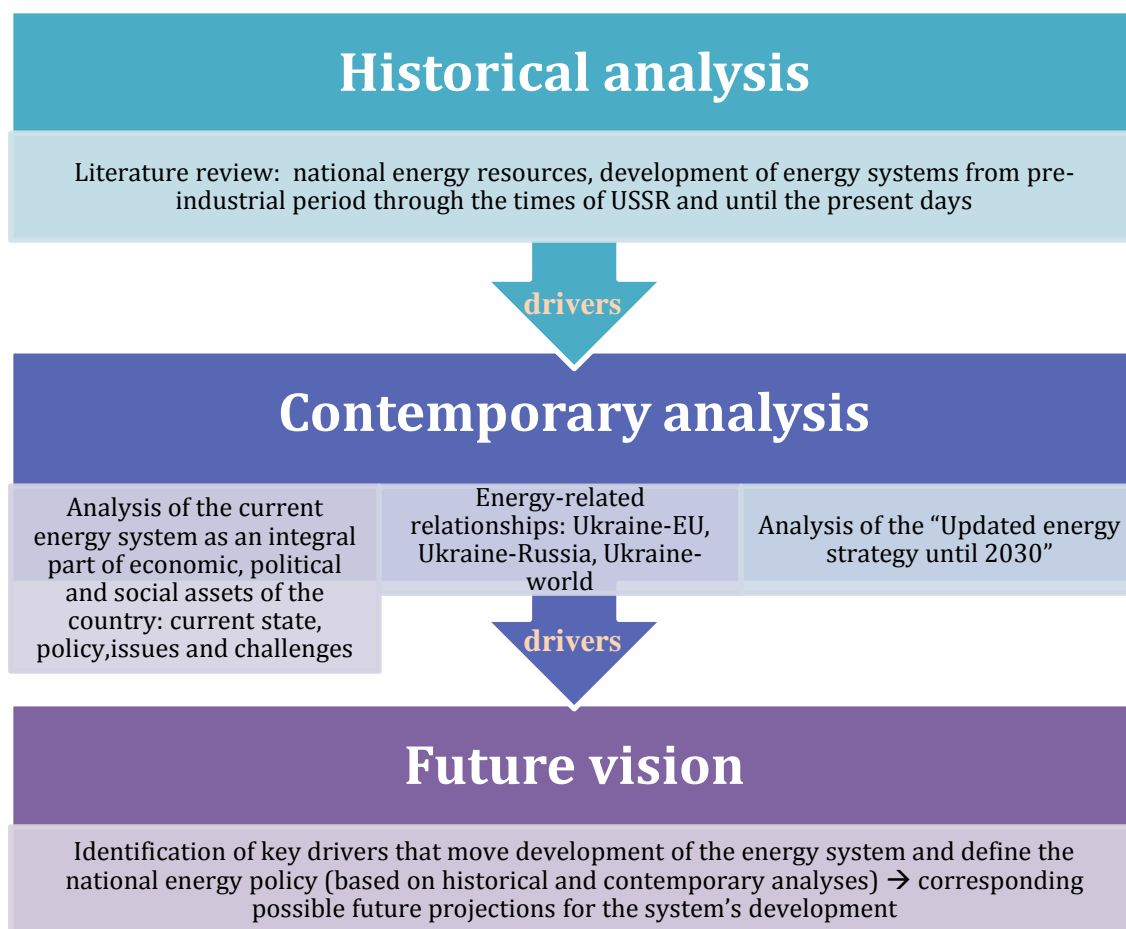


Figure 1.Thesis analysis stages

The main tools which are to be used in the research include:

- literature review (books, articles, scientific papers, international and national policy, environmental and energy reports, other related literature);
- a range of data analysis tools such as diagrams (e.g., Sankey diagram), maps and others.

Chapter 3, Theoretical Framework and Methodology, will provide a more comprehensive outlook on the essence and structure of the analysis.

1.5. Scope and limitations

Although a large number of issues are to be covered within the thesis framework, there are certain limitations to the project. Some of the latter can be clearly distinguishable from the start, while others are expected to appear as the research advances. Apparent limitations include:

- ❖ limited access to data and information;
- ❖ data bias associated with mismatches between the real and “paper” information and possible misrepresentation of the situation, including official national reports;
- ❖ time constraints associated with a relatively short period of time provided for the research, which limits the amount of information that the author is able to collect and consequently cover in the work;
- ❖ the current unstable political and economic situation in the country may bring a certain level of uncertainty into the research;
- ❖ possible discovery of new energy technologies/sources in the nearest future;
- ❖ fluctuating global energy prices and energy resource distribution.

The author’s main goal is, however, to establish a foundation for further research of the energy system and energy policy of Ukraine, which can be carried out and continued in the future. Encompassing all the issues and interconnections within such a complex system is hardly achievable. Thus, the research will focus on main drivers, challenges and opportunities of the Ukrainian energy system on its way towards sustainable development.

1.6. Thesis structure outline

In order to achieve the primary aims and objectives of the research, the current work will be structured in the following way.

A literature review is conducted in Chapter 2. The review aims to underline key concepts and ideas in the field of energy systems, policies and governance, explain the importance of the current research from the global energy governance perspective and identify gaps in the existing knowledge on the chosen topic. This is done by reviewing a broad range of literature sources representing different views and theories on energy transitions, on explaining national energy policies and development of national energy systems and development of the energy system of Ukraine in particular.

Based on the literature review, Chapter 3 outlines theoretical premises guiding the thesis work, establishes the framework for the current research and explains the methods used to carry out the analysis. Connections of the framework and methods to the thesis' primary aims and objectives are drawn describing how the latter are going to be reached.

Chapter 4 represents an analysis of Ukraine's energy systems: a historical overview of their development and current state, energy policies associated with them and an overview of the Updated Energy Strategy of Ukraine until 2030. Each system is analysed to identify its importance on the national level, stakeholders and main actors involved in its functioning and governance, connections of the system to other economic sectors of the country, and to track the past, current and possible future changes of the system's role.

Chapter 5 discusses the results, interprets the collected data and information with a primary aim to reach the thesis objectives: to identify main drivers for development of the national energy system of Ukraine and develop a range of possible scenarios for the development. The chapter also implies a discussion of significance of research's finding, specifically in the view of the current political and economic crisis, and points out limitations of the findings.

The final chapter, Chapter 6, draws conclusion of the work, identifies key findings, reflects upon aims and objectives of research and explains how they were achieved. Implications and recommendations for future research are also provided.

2. LITERATURE REVIEW

*“Who would not have been laughed at if he had said in 1800 that metals could be extracted from
their ores by electricity or that portraits could be drawn by chemistry.”*

(Michael Faraday)

The present literature review examines the origins of the research aim and is directed to show the importance of understanding and a need of research of national energy policies and systems; to outline the existing theories on development of national energy systems and policies; to establish the background for research on Ukraine outlining the current state of knowledge of the country's energy systems, energy policy priorities and existing projections for the system's future development. The former objective of the review derives from global energy policy issues, which are thus discussed in the introduction.

2.1. Introduction. Global energy policies: their transitions and challenges

2.1.1. Energy and environment

Human activities have been altering the global energy flows for decades. The anthropogenic pressure on the environment has been steadily increasing since the middle of the 19th century – the time that was marked as the beginning of the industrial revolution (IPCC 2013; see Figure 2). During the period 1750 - 2010, humanity was responsible for releasing more than 360 gigatonnes of carbon dioxide (CO₂) into the atmosphere by combustion of fossil fuels and cement production only, causing subsequent changes in the planet's atmospheric and surface composition (IPCC 2013). And although a whole range of environmental issues, such as global climate change and its consequences, have been widely discussed around the world for many years, the emissions from the combustion of fossil fuels continue to rise. The rate of their increase is also accelerating and currently makes 1% annually (IPCC 2013). According to

the latest EIA report (EIA 2013), global energy consumption and the use of fossil fuels, as well as related CO₂ emissions, will continue to grow within the next several decades. This is primarily attributable to the increasing energy demand in the developing world (India, China, South American and African countries) as they transition to the Western birth-death equilibrium scenario associated with the simultaneous population and economic growth. Energy together with industrial sector are expected to become the largest contributors to global warming over the next 50-100 years (IPCC 2013), which makes research of these energy transition issues crucially important, particularly as an integral part of the global environmental discourse.

2.1.2. Global energy transitions

The energy systems have undergone significant changes over the last two centuries shifting from one set of energy sources, carriers and technologies to another as technological advancement, new inventions and discoveries were taking place (see Figure 2 below). These changes are often termed “energy transitions”. Smil (2010) describes an energy transition as “the gradual shift from a specific pattern of energy provision to a new state of an energy system”. In this way, the shifts from biomass to fossil fuels and from coal to gas are probably the most notable transitions in energy history occurring on the global scale (GEA 2012; Smil 2010). The International Energy Agency’s special report suggests that the new century may become “the golden era of gas” with another shift, from coal to gas, occurring globally (IEA 2011). The latter is due to a number of reasons, including the environmental concerns worldwide.

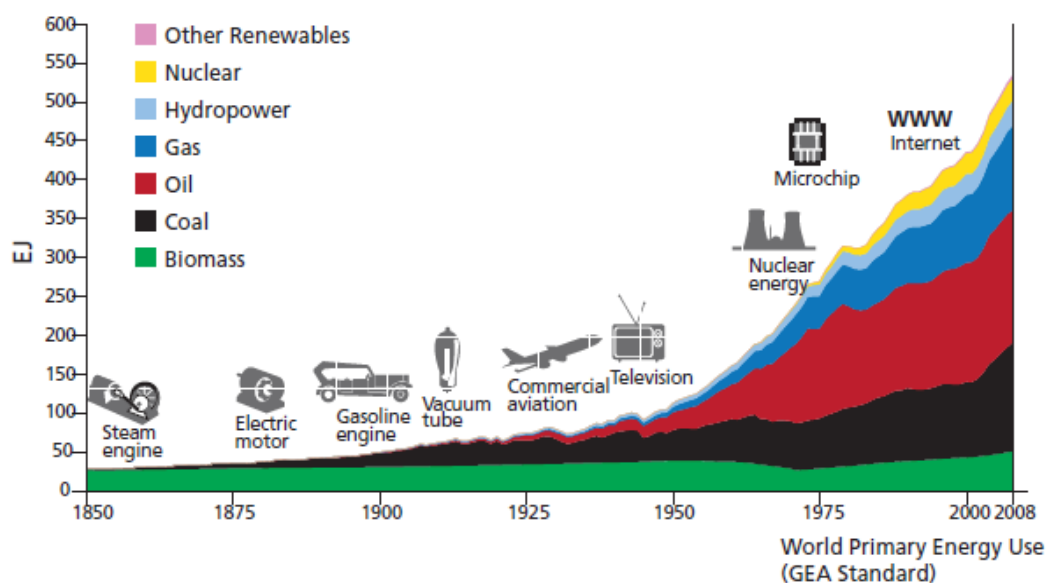


Figure 2. Evolution of primary energy shown as absolute contributions by different energy sources

Source: GEA 2012

According to Smil (2010), large-scale energy transitions take a long period of time to accomplish, which is due to the fact that dependence on a particular energy source and the associated production and transmission infrastructure increases with time, as well as its substitution with another source cannot be abrupt but needs at least a few decades to accomplish. For example, the proven world coal reserves are equivalent to around 120 years of stable supply at the current rate of extraction (WCA 2012). Hence, coal can be viewed as a secure type of energy: the infrastructure for its extraction, transportation and use has been developed and established for many years. This is why coal remains an important primary energy source in many countries around the world, notwithstanding its negative environmental impacts. And although application of carbon capture and storage (CCS) technologies within energy sector often appear in global to national energy reports as one of key tools in tackling climate change (CCSA 2013), the progress in their development appears to be very slow due (IPCC 2005). According to IEA and GCCSI (2012), this is largely due to the fact that “...current global efforts do not match the significant emission reduction ambitions associated with CCS”.

At the same time, action towards minimization of global greenhouse gas (GHG) emissions and the negative impact on the environment from the extraction of fossil fuels is becoming more pressing. In the view of this, we need a rapid transformation to decarbonize energy systems; and this transformation, unlike the previous transitions which occurred naturally, shall be carefully planned. Moreover, we require a better understanding of the global, national and local energy transitions, their significance and importance, in order to guarantee the occurrence of all the needed transformations of the world energy system.

2.1.3. Energy governance challenges on global scale

The facts stated in the previous section show the unequivocal importance of the effective global energy governance and one of many issues which have to be faced by the humanity in the 21st century: reducing the impacts of the global climate change by bringing the GHG emissions to the lowest possible level in the complexly structured energy systems around the world. Two more urgent global challenges were marked out among others by Goldthau and Sovacool (2012) and Cherp et al. (2011): provision of energy access to all people and the need to ensure energy security for every nation. Thus, the three following challenges constitute the main global energy governance arenas: ‘*climate change*’, ‘*energy security*’ and ‘*energy access*’.

These arenas appear to be poorly connected between one another with only a few links existing between them and different, sometimes even contrasting, goals, mechanisms and actors (Cherp *et al.* 2011; see Table 1). For example, the ‘energy security’ arena often implies increased exploitation of energy resources. If a country has large coal resources and aims to become independent from gas imports (e.g., Poland, Ukraine), one of the possible ways to gain energy security is to increase coal production. However, this would lead to enhancement of GHG emissions and thus, will contravene with the ‘climate change’ agenda and its targets. Cherp *et al.* (2011) argue that this particular lack of interconnection between the agendas is a

substantial problem resulting in a failure of the global energy governance “... to address the major energy challenges in an integrated manner”. Similar conclusion was made by Florini and Sovacool (2009), who argue that there is a mismatch in energy policies on national and to a larger extent on international level, as well as that none of the existing forms of global energy governance address the global energy challenges adequately.

Table 1. The main global energy governance arenas

| | | Governance arenas | | |
|-------------------------------------|---------------------------------------|--|--|--|
| | Criteria | Climate change | Energy Access | Energy security |
| <i>I Historical context</i> | <i>Historic origins</i> | Environmental sustainability, 1990s-2000s | Development movement of 1960s-2000s | Oil crises of the 1970s |
| | <i>Major actors and organisations</i> | Nation states, ICOs, NGOs, e.g., UNFCCC, IPCC, UNEP, UNDP, GEF, WWF | International development organisations and NGOs, multilateral partnerships, e.g. World Bank, UNDP | Major exporters and importers of energy (nation states) and their alliances, e.g. IEA, OPEC, IEF, OLADE, SCO |
| | <i>Main paradigm</i> | Concerted international action motivated by shared goals can deal with ‘common bads’ such as environmental pollution | Development and modernisation needs to be catalysed by international assistance | Sovereign nation states acting in their self-interest establish arrangements guaranteeing mutual energy security |
| <i>II Scope</i> | <i>Central goals</i> | Reduce GHG emissions from energy systems | Increase access to modern forms of energy | Stable and secure global energy supply |
| | <i>Sectors</i> | Supply and demand side | Supply side, virtually all technologies | Supply side, primarily oil |
| | <i>Scales Time horizons</i> | Global Long and medium term | National and local Medium and short term | National Primarily short term |

Source: Cherp *et al.* 2011

As it is shown in Table 1, the scale of the discussed governance arenas varies from local (energy access) to national (energy security) to global (climate change), from the long-term time horizons (climate change) to the short-term ones (energy security). Consequently, in order to manage the needed transition and to coordinate the immediate and long-term goals, there is an urgent need to prepare strategies for the future change, to find solutions for sustainable development of the energy sector, to change energy policies and practices at all the levels (Bhattacharyya 2011). Cherp *et al.* (2011) state that the global energy governance simply does

not exist. Thus, in order to achieve global sustainability goals, the national energy systems should be transformed and, as a result, guided by the internationally accepted principles focused on dealing with the challenges discussed above. The next section of the literature review will, thus, provide information on national energy policies and systems and how their transformations and development are explained in academic literature.

2.2. Explaining national energy policies

2.2.1. ... through historic and contemporary analyses

The growing demand for energy, escalating energy prices and a whole range of environmental and other issues related to energy supply are putting a constant pressure on governments, managers, engineers and researchers around the world trying to find better solutions for effective energy use and predict the future of energy. This, however, requires a solid knowledge of both the current state of energy systems and of the history of their development and transitions. A mere current-state analysis may give only a superficial understanding of an energy system, although is useful for urgent short-term planning and decision-making. A combination of contemporary and historic analyses is more commonly used, in order to comprehend the roots of the current issues related to energy, as well as to make finer predictions and adopt comprehensive energy policies for long-term transitions and changes.

At the same time, the latter is not easily achievable. Each state on the planet largely depends on the presence (or absence) of particular energy resources, by their certain amount and quality, distribution and the possibilities for their extraction (technology, human capital, amount of recoverable resources etc.). The historical development of national energy systems, although driven by the same technologies inherited from the industrial revolution, progressed

in their own way depending on many internal and external factors, which were also unique for the particular time and location.

But which factors determine national energy transitions? A number of studies attempted to answer this question, particularly while exploring national environmental transitions, e.g. a study of environmental transformations of the state by Dryzek *et al.* (2002). The authors follow the development of environmental movement in the Germany, Norway, the United Kingdom (UK) and the United States (US) trying to investigate what makes/can make a state “green”. They consequently build a theory of national energy policies based on definitions of “exclusive” and “inclusive”, “passive” and “active state”, as well as on five characteristic imperatives, which according to the authors, constitute the core of a state: domestic order, survival, revenue, economic and legitimation (see Tables 2 and 3 below).

Table 2. Classification of states

| Representation: | Social interests: | |
|--|---|---|
| | Inclusive (openness to wide range of interests) | Exclusive (effective representation limited to a chosen few people) |
| Passive (no tries to promote or impede capacities of particular groups) | <u>Pluralism:</u> USA | <u>Legal corporatism:</u> Germany |
| Active (tries to affect both the content and power of political interests) | <u>Expansive corporatism:</u> Norway | <u>Authoritarian liberalism:</u> UK, 1979-90 and beyond |

Source: Dryzek *et al.* (2002)

Dryzek *et al.* (2002) conclude that environmental conservation could become the sixth core imperative, or “the core business of the state”, rather than a simple government activity. However, the authors argue that this would require the economic growth and legitimation transformations to occur first (see Table 3), as well as establishment of an active, effective and autonomous public sphere “as both a memory and a presence” (Dryzek *et al.* 2002). The

ultimate role of social forces in energy transitions is recognized by other authors, with the subsequent need of comprehensive analysis of energy policies and transitions from not only economic but also social and environmental perspectives (Barca 2011).

Table 3. Transformations of a state

| Kind of state | Movement incorporated | State imperatives |
|---------------------------|-------------------------------|--|
| Early modern | None | Domestic order, survival, revenue |
| Liberal capitalism | Early bourgeois public sphere | Domestic order, survival, revenue, economic growth |
| Keynesian welfare | Unions, socialist parties | Domestic order, survival, revenue, economic growth, legitimation |
| Green | Environmentalism | Domestic order, survival, revenue, economic growth, legitimation, conservation |

Source: Dryzek *et al.* 2002

Thus, while the global environmental issues are shared internationally, each country will have to find its unique solutions to address all the energy challenges discussed above. Moreover, with the existing interconnections between energy systems, between energy and other sectors (i.e., industry, transport, agriculture, etc.) (Cherp *et al.* 2011), the energy policies adopted for a certain energy system may influence other ones through these links. From this perspective, there is a clear necessity to focus on each country in particular, as a part of the global and regional energy transitions analysis.

2.2.2. ... through energy architecture

A new approach towards understanding of energy systems and policies was recently drawn by the World Economic Forum specialists in their report “New energy architecture: enabling an effective transition” (WEF 2012). The work explores the current energy systems, or the so-called “energy architectures”, of different countries in the world, in order to give

suggestions and identify main challenges for the future sustainable development of the systems.

The authors argue that “to meet the demands of tomorrow, nations or regions must consider a broad range of issues, taking a system-level approach that includes resources and technical capabilities in the context of social, regulatory and market aspects”.

Table 4. Current energy architecture archetypes

| Current energy architecture archetype | Short description | Representative countries | Key challenges | New energy architecture objectives & risks |
|---------------------------------------|--|---|--|--|
| Rationalize | Established energy architectures that strongly supporting economic growth and development | Canada, Germany, France, Switzerland, UK | Maintaining economic growth and development given dips in performance, reducing import dependence, reducing carbon intensity | Overcoming architecture lock-in. Significant costs when adopting more sustainable energy technologies |
| Capitalize | Energy architecture that strongly promotes security, largely as a consequence of significant hydrocarbon reserves. | Iraq, Russia, Saudi Arabia | Reducing reliance on mineral products for export, increasing diversity | Maximize energy industry returns. Options with regard to maximizing the returns are not necessarily sustainable. |
| Grow | Energy architecture focused on securing continued and rapid economic growth | China, Hungary, India, Turkey, Ukraine | Improving GDP per capita, reducing import dependence, increasing share of non-carbon sources | Alleviation of supply-demand deficit. Risk of impacting environmental sustainability |
| Access | Energy architecture struggles to provide citizens with basic energy needs | Ethiopia, Mongolia, Nepal, Tanzania | Driving economic growth and quality of life, providing citizens with basic energy needs, dealing with water scarcity | Increase access to modern energy sources. Risk of impacting environmental sustainability. |

Source: WEF 2012

Analysis of current energy architectures used in (WEF 2012) implies archetype approach, which implies grouping of countries with similar energy architectures into four archetypes: *rationalize*, *capitalize*, *grow* and *access* (see Table 4 for details). This helps to outline key challenges and future objectives for different archetypes. At the same time, the authors emphasize on importance of designing new energy architectures around the world keeping in mind three ‘energy triangle’ imperatives related to economy, environment and energy security (see Appendix, Figure A.1). The key stakeholder groups here are civil society, industry and government, which have to work together to enable an effective transition “... towards an energy architecture needed to meet tomorrow’s energy requirement for different countries and globally”.

2.2.3. ... through vital energy systems

A concept of a ‘vital energy system’ (VES) was first introduced in the Global Energy Assessment (2012) and used later in a number of other studies (Cherp and Jewell 2013, Jewell 2012, Jewell *et al.* 2014, Leung *et al.* 2014). The concept is directly linked to one of the top global and national energy policy priorities: ensuring energy security. Jewell (2012) identifies VESs as such “... whose failure may seriously disrupt the functioning and stability of society”. There are two essential characteristics distinguishing a vital energy system:

- 1) it supports critical functions of a modern society;
- 2) it is a system consisting of elements (institutions, natural resources, technical infrastructure) connected to each other stronger than they are connected to elements outside the system (Leung *et al.* 2014).

VES are defined by their geographic boundaries (sub-national, national, regional and global) and sectorial boundaries (primary energy sources, energy carriers and energy end-users). Thus, within a national geographic boundary we can speak of such VESs as: a) coal, oil, natural gas, hydro, nuclear, renewable (according to energy sources); b) oil products,

electricity, biofuels etc. (according to energy carriers); c) industry, transportation, buildings, exports etc. (according to the end energy users) (Jewell 2012; Leung 2014).

Each energy system has certain ‘weak points’, or vulnerabilities, which have to be carefully considered when analysing the former. Jewell (2012), and Cherp and Jewell (2011) propose a generic way for structuring vulnerabilities of VESs by looking at them from three energy security perspectives shown below in Table 5. The ‘sovereignty’ perspective focuses on vulnerabilities associated with international (foreign) actions and agents, such as the 1970s oil crisis and the current worries over the high level of dependence of many European states on Russian gas. The ‘robustness’ perspective considers physical vulnerabilities of an energy system with primary concerns directed toward scarcity of resources, aging infrastructure, increasing demand for energy and other issues, where a human has little or no power to disrupt the system. And finally, the ‘resilience’ perspective addresses the “... capacity of energy systems to deal with evolving and unpredictable risks as reflected in diversity, energy intensity and vitality of energy markets” and thus, takes its roots from economics and complexity science (Jewell 2012). The framework can be used to categorize and analyse not only historic or current but also future vulnerabilities of energy systems: as Jewell (2012) states, even in case of radical energy transitions, all the concerns represented in the framework are most likely to persist in the future.

Table 5. Three perspectives on energy security

| Perspective | Sovereignty | Robustness | Resilience |
|-------------------------------------|--|--|---|
| Historic roots | war-time oil supplies and the 1970s oil crises | large accidents, electricity blackouts, concerns about resource scarcity | liberalization of energy systems |
| Key risks for energy systems | intentional actions by malevolent agents | predictable natural and technical factors | diverse and partially unpredictable factors |

| Perspective | Sovereignty | Robustness | Resilience |
|--------------------------------------|---|---|--|
| Primary protection mechanisms | control over energy systems, institutional arrangements preventing disruptive actions | upgrading infrastructure and switching to more abundant resources | increasing the ability to withstand and recover from various disruptions |
| Parent discipline | security studies, international relations, political science | engineering, natural science | economics, complex system analysis |

Source: Cherp and Jewell 2011

2.3. Energy systems & policy in Ukraine: current state of knowledge

The literature on Ukrainian energy policy and systems is scattered as both time scale and topics are concerned. There is only one recent work, which tried to follow the development of energy systems in Ukraine through time, namely a series of books in five volumes by Plachkova *et al.* (2012) “Power industry: the history, the present and the future”. The books represent a valuable source of data and information; however, they are largely descriptive and do not attempt to analyse the events, policies or draw interconnections between energy and economic systems. At the same time, there is a whole range of articles, books, reviews and other literature sources focused either on Ukrainian energy issues directly, or within broader geopolitical areas of research, such as “post-soviet states”, “developing countries”, “states of Eastern Europe”, “industrialized economies” etc.. With a primary focus on development of energy systems and policies of Ukraine, the following paragraphs will contain an analysis of the current state of knowledge on the issue, discover some of the gaps in the existing studies and explain why it is important to conduct the present research.

2.3.1. History of establishment of Ukraine’s energy system

The Ukrainian energy system, as we know it today, was largely formed in the Soviet era, namely between 1917 – 1991. However, in the thesis I would like to look further in the past to see how the energy resources had been used in the country before the Red Revolution, as well

as to follow the establishment of the first industries - the major consumers of energy. Such information is mainly scattered within the works on geography and history of Ukraine and Russia. Among the used sources are (Boscia 2010), (Channon and Hudson 1995), (Hrycak 2000), (Khromov 1950), (Lanovyk *et al.* 1994), (Munting 1996), (Plachkova *et al.* 2012), (Reshetilova *et al.* 1997), which are covering a wide range of issues starting from the use of fossil fuels in the old days (Reshetilova *et al.* 1997), industrial revolution in Russian and Austro-Hungarian Emires (Munting 1996; Plachkova *et al.* 2012), establishment of the modern Ukrainian nation (Hrycak 2000) and many others. Analysis of the data conducted in this section is expected to contribute to better understanding of the following up years of Soviet rule: 1) change of patterns of energy resources use in Ukraine; 2) main industries on the territory of Ukraine, their transformations and development; 3) development of main energy institutions; 4) changes of stakeholders in energy field.

A variety of literature sources is available on the energy industry of the USSR. This is not surprising due to the fact that with the Great October Socialist Revolution of 1917, the power industry became a main wheeling mechanism for construction of communism (Ananiev *et al.* 1977). At the same time, all the Soviet literature available in Russian unavoidably glorifies the ideas of communism and main Soviet leaders, emphasizes all the achievements of the Soviet energy sector functioning according to Five-Year Plans, while overlooking the major issues, difficulties and inconsistencies connected to energy developments (e.g., social and environmental issues). One of the latest works, which took a closer look at such issues, is “An environmental history of Russia” by Josephson *et al.* (2013), which I will be referring to, in order to pinpoint important aspects of Ukraine’s history related to environment-energy convergence.

A comprehensive policy and resource analysis of the whole Soviet energy sector was done by L. Dienes and T. Shabad in their book “The Soviet Energy System” published in 1979

in the US. The authors draw attention to strengths and weaknesses of the Soviet energy system. They predict the future leading role of the USSR (and consequently of Russia) as a gas exporter: “An expanding market in West Europe insures a long-term and increasing role for natural gas in the Soviet Union’s export plan. Natural gas ... is the ace in Soviet energy plans and provides a critical cushion for the uncertainties faced by planners with respect to other sources of supply” (Dienes and Shabad 1979). The authors also warn about certain drawbacks of the Soviet nuclear developments of 1960s - 1970s and disadvantages of RBMK reactors (see Paragraph 4.4.5) used in the first nuclear power plant of Ukraine - Chornobyl. Already in 1970s the physical structure and design of fixed equipment, as well as transport facilities operating in energy fields within the USSR were adjusted to a greater use of gas and oil. Dienes and Shabad (1979) state that “the shift toward greater use of coal in the Soviet Union is proving to be even more difficult than in the United States”; this is an important identifier of the beginning of transition towards oil and gas, as well as towards dependency on the two types of hydrocarbons in a range of Soviet republics, including Ukraine.

The modern history of Ukrainian energy with all the transformations of Ukraine as an independent state, starting from 1991 and onwards, is broadly covered in a whole range of academic literature, resources and media. While examining evolution of a Ukrainian state, Kudelia (2012) pinpoints its three primary characteristics: patrimonial bureaucracy, limited government accountability and a weak rule of law, which results in politicization of state structures in the country, widespread attacks against a nascent civil society and attempts to undermine independent businesses. On the whole, the first two decades of Ukraine’s independency according to Taras Kuzio (2012b) are characterised with a consistent widespread corruption of very high levels with energy sector being the most corrupt sector of Ukraine’s economy: “... the corrupt franchise model has remained the same and passed on to each successive Ukrainian president”.

2.3.2. Current political and economic context

During the soviet times Ukraine' economy was second largest within the USSR republics with industry and agriculture being its main sectors (Cherp *et al.* 2007; Plachkova *et al.* 2012). After collapse of the Soviet Union, the country started its transition from planned to market economy. Ukraine is known around the world as a grain exporter, producer of metallurgical products, ferrous and non-ferrous metals, high technological and transport goods and services, chemicals and food products (CIA 2013). Ukraine's economy is regarded to as 'developing' with an immense future potential (EIA 2006, EIA 2012).

The country's significant energy and mineral resources, location on the Black Sea, right in the middle between the two large political powers of the present, the EU and Russia, gives Ukraine a substantial strategic importance. For many years the country remains the main transit corridor for transportation of Russian gas to Europe with around 86 billion m³ passing through Ukrainian gas pipelines in 2013 (MECIU 2014b). At the same time, Ukraine is highly dependent on the neighbouring Russia in many economic and energy-related issues (Campbell 2013; Franke *et al.* 2010).

Franke *et al.* (2010) called Ukraine a "consolidating democracy" dependent to a large extent on cooperation with the EU, including economic and security-related dependence. The author argues that achieving an EU membership and implementation of all the corresponding EU demands should have low adaptation costs for Ukraine if compared to other European Neighbourhood Policy (ENP) countries. However, the current crisis and complication of relations between Ukraine, EU and Russia, creates a whole complex of issues for the future of Ukraine and its energy system, which is closely connected to the Russia (see Chapter 4).

Kropatcheva (2011) draws an important conclusion here that while the geopolitical games between Russia, Ukraine and the EU are taking place, "... mutual vulnerabilities are growing: vulnerability of demand, supply, transit, and of prices, but the biggest of all is the

vulnerability to geopolitical energy games, where parties not only maximise their own benefits, but also prevent an opponent from making gains”. This becomes especially evident in the view of the current political crisis and worsening of political relations between Ukraine and Russia. Ukraine’s decision to enhance its energy security and continue the EU integration, leave Russia as a main strategic partner and keep the system as it is, or try to find a balance between the two, will largely define the country’s future from economic, social, environmental and other perspectives.

As S. Kudelia (2012) in his analysis of evolution of the Ukrainian state pointed out, the challenge of state-building in the country in the last years was remaining almost as daunting as it had been in 1991. According to the author, however, completion of the state-building process these days depends “... less on the choices of political elites and more on the actions of wider societal forces” (Kudelia 2012). The recent events in the country, shortly described below, show that the “... constant cycling between hybrid types of authoritarianism and democracy” (Kudelia 2012) may finally be over for Ukraine, although the transition may take many more years to be accomplished.

In November 2013 Ukraine started facing a political and social crisis as its President Viktor Yanukovych refused to sign an EU association agreement and EU’s free-trade deal. This clearly has identified the Government’s intentions to ‘go east’ strengthening the ties with Russia and signing the Customs Union Agreement (Belarus, Kazakhstan and Russia) instead of the EU one. Peaceful demonstrations in support of EU integration, which started in the capital Kyiv in the end of November, turned into mass civil unrest around the whole country as the Government used physical force against the protesters. By February 2014, the protests had been boosted by the perception of widespread corruption, abuse of power by high-level officials and violation of human rights in Ukraine (DT News 2014). The situation in the country kept destabilizing after the Government’s resignation in January, almost hundred

protesters being shot by the military forces and hundreds of people on both sides being injured during the clashes in January-February, and President Yaukovych searching a refuge to Russia. These events, however, urged the Ukrainian parliament (Verkhovna Rada) to discard Yanukovych from his duties, appoint new presidential elections in May 2014 and create an interim Government with its leader, PM Arseny Yatsenyuk, belonging to a west-oriented party. One of important decisions of Verkhovna Rada was return of 2004 Constitution implying parliament-presidential form of government in contrast to the presidential-parliament form giving more legal rights to a president of the state.

The situation worsened in the end of February as Russia sent its military troops, ships and artillery to Crimea, south of Ukraine, organized an ambiguous referendum at the peninsula and subsequently claimed its right to annex Crimea to the Russian territory. The possibility of military conflict between Russia and Ukraine caused an escalated international attention to the crisis. Leaders of different countries, including United States, Germany and the UK, officially condemned Russia's actions towards Ukraine. Separatist intentions of Kreml and its actions contravening the Budapest 1994 Memorandum on Security Assurances, when Ukraine gave up its large nuclear weapons stockpile in return of recognition of its political independence and territorial integrity, are among the most pressing issues for Ukraine at the moment with no simple way out of the crisis to be seen in the nearest future.

2.3.3. Energy policy plans and projections

According to IEA (2012), Kuzio (2012b), Omelyanovsky *et al.* (2010), Plachkova *et al.* (2012), fuel and energy complex of Ukraine can be characterised with:

- high level of wearing of the main production funds (technologies, equipment), which in average makes 80-90%;
- very high energy intensity of economy combined with low effectiveness of energy saving policy;

- constant deficit of investments for rehabilitation and build-up of production capacities and potential;
- insufficient adaptation to the market conditions of economy;
- defective structure of fuel and energy balance of the state;
- critically high dependency on energy imports from one supplier;
- defective regulatory and legislative support for activities within the fuel and energy complex;
- critically high level of environmental pressure on water and atmosphere within the zones of activities of fuel and energy enterprises.

Thus, due to the listed energy security, political and environmental issues, some authors (D'Anieri 2012; Kudelia 2012) state that the Ukrainian energy system is about to undergo certain transformations. The direction and pace of these transformations remains, however, unclear due to many factors including an unfavourable investment climate, high level of corruption at all levels, lobbying from big business and the current nation-wide crisis (IEA 2012; Matuszak 2012; Zabutyi 2013).

A number of authors in their articles on energy security, energy development, policy analysis and a range of other topics, have marked out the Ukrainian energy system's potentials and challenges (e.g., Anishin *et al.* 2013; Cherp *et al.* 2007; Franke *et al.* 2010; IEA 2006; IEA 2012; Kropatcheva 2011; Matuszak 2012; Milstein and Cherp 2009; Petersen 2012; Plachkova *et al.* 2012): these works will be used and referred to further in Results and Discussion chapters.

And although the case of Ukraine is becoming of a great international interest, there are no academic literature resources highlighting long-term projections for the development of the country's energy system, except for the official governmental document "Updated energy strategy until 2030" (further in text: 'the Strategy'). The Strategy implies three scenarios for the

energy system development: pessimistic, basic and optimistic (MECIU 2012a), all based on questionable scenarios for future economic development and GDP structure (Milstein and Cherp 2009; Zabutyi 2013). Feasibility of the Strategy is questioned by many economic and energy sector experts, who call it “an absolutely unrealistic document”, which does not take into account specificities of the Ukrainian energy system and any possibility of changes or turnabouts (Zabutyi 2013). As the country is currently struggling to overcome the political crisis, the Strategy seems to have been shelved for an indefinite period together with any attempt to establish a new comprehensive plan for the future development of Ukraine’s energy.

2.4. Conclusion

The literature review focused on global to national issues connected with energy systems and energy policies and on the first three objectives of the research (see Paragraph 1.2), providing a basis for development of theoretical framework and further analysis. As far as global energy governance is concerned, three main energy arenas can be marked out: ‘climate change’, ‘energy access’ and ‘energy security’. Primary goals set within each of the contiguous arenas can be contradictory, and thus require careful analysis and planning. At the same time, some authors draw our attention to non-existence of global energy governance as such and point out to the particular importance of understanding of energy systems and building of efficient energy policies at a national level, in order to successfully achieve the global energy aims.

Some authors have identified certain patterns of transformations of states and their national energy systems: a transition from domestic order, survival and revenue imperatives toward economic growth, legitimation and finally conservation. The new energy architecture theory proposes a break up of states according to their energy archetypes: from the countries trying to provide basic energy access to their citizens, to the countries with established energy systems promoting economic growth and sustainable development. In all the theories energy

security issue plays one of the most crucial roles requiring a deep understanding of the country's 'vital energy systems', i.e. the systems whose functioning supports stability and main activities of the nation. At the same time, development of national energy policies and systems is an area of research where many questions are still to be answered. This is due to the fact that each country on the planet has its unique history of formation and transformations of energy systems, unique geopolitical, economic and other conditions, which largely determine the future of its energy sector.

Ukraine, the country chosen for the present research, has a rich energy history, which has not been comprehensively analysed and understood. While the country's energy future has recently become a vividly discussed topic due to the current political crisis, no clear picture can be assembled of who (main stakeholders) and what (main drivers) directs the development of the Ukrainian energy, and what are today's national priorities for this development. Nowadays, in addition to the current crisis, Ukraine faces many other challenges as its energy sector is concerned, including energy security related to the high dependence on natural gas supplies from Russia, gradually growing demand for electricity, outdated power equipment, highly energy-intensive industries, unprofitable nuclear-based power generation and many other issues. The accumulating amount of challenges implies that certain changes are about to occur soon transforming Ukraine's energy systems. In order to understand possible directions of these transformations, I will analyse the past and present of Ukraine's energy, the country's primary and vital energy systems, policies, energy archetype and state imperatives, based on the theories discussed in the literature review and in Theoretical Framework and Methods chapter.

3. THEORETICAL FRAMEWORK AND METHODS

3.1. Theoretical framework

Energy systems and policies are complex due to their close interdependence with economic, political and social systems of a country. Moreover, in the light of historical development, many historically arisen issues and changing institutions influencing energy systems and policies over the years, they acquire unique features and structural complexity (Bending and Eden 1984). From this perspective, they have to be viewed and analysed in an integrated manner, in order to establish a clearer picture of the present and provide a baseline for future projections and development.

“*Energy system*” and “*energy policy*” are intricate concepts, which are not easy to define. In a simplest way, an *energy system* can be viewed as an interrelated network of energy sources and stores of energy, connected by transmission and distribution of that energy to where it is needed (Pramod *et al.* 2012). This definition can help to break energy systems into energy resource-related categories: coal, oil, gas, hydro-, nuclear, renewable etc. A *national energy system*, however, is a much broader collective concept, which implies not only the resource-based energy systems mentioned above, but also respective energy institutions, lobbying parties and actors involved in decision-making as national energy policy is concerned. Each energy system also has certain *vulnerabilities*, i.e. certain weaknesses, which disable the system to cope with selected adverse events (Gnansounou 2008).

According to Bending and Eden (1984), *energy policy* may be considered *ex ante* or *ex post*: in the former case, it is viewed as a set of intentions or objectives to be pursued either as initiatives or as responses to external events; in the latter case, it is seen as “the way in which those objectives have been implemented and as the totality of the decisions which have been made along the way” by all the actors and stakeholders involved. Summing up, energy policy represents decisions affecting the supply of and demand for fuels in all their uses.

Developing countries of the world in different periods in history were undergoing social and economic reforms altering their energy systems while moving from centrally-planned to market-oriented modes of administrative operation, causing conflicts among actors involved (e.g., among a government, energy supply companies, consumers and others) (Yang and Yang 2012). Ukraine's energy sector started being privatized in 1990s and is known to be one of the major arenas for such conflicts for the last two decades. A number of state institutions, industrial actors and other influence groups have been involved in constant arguments, both public and hidden, regarding Ukrainian energy policy (D'Anieri 2012; Kudelia 2012; Kuzio 2012a). However, lobbying and controversy in energy sector is not a prerogative of an independent Ukraine: even during the Soviet times there were tensions “among the appropriate ministries, planning and research institutions and regional interest groups” regarding the development of energy resources (Dienes and Shabad 1979). In this way, Ukraine's energy policy priorities have been largely shaped by certain influential groups directly or indirectly participating in governance of the national energy system (see Figure 3 below).

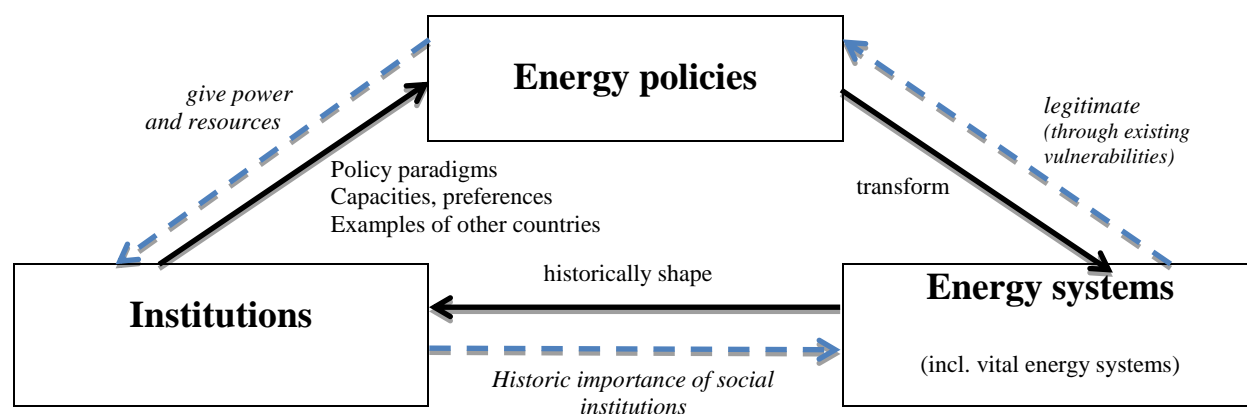


Figure 3. Interactions and connections between energy policies, systems and institutions

The Figure 3 shows a preliminary hypothetical scheme of issues, ideas and institutions, which constitute the process of shaping energy policies in Ukraine. The framework is modified from Leung *et al.* (2014) analysis of energy security policies in China. The straight black

arrows represent visible ‘rational’ connections, while the dashed blue arrows show ‘hidden’ interactions and processes. Following the visible connections, energy systems historically shape corresponding energy institutions, which are driving energy policies, which as a result may transform energy systems. At the same time, vital energy systems have vulnerabilities (Leung *et al.* 2014), which legitimate adoption of certain energy policies. On the first stages of transformation of a state (Dryzek *et al.* 2002; see Table 3), energy policies with basic imperatives (domestic order, survival, revenue, economic growth) are being adopted to support critically important energy systems. The next transformations, however, those following legitimization and conservation imperatives, are legitimating other policies to be pursued directed towards other energy systems, some of which could earlier be perceived as non-critical. Energy policies in turn provide energy institutions with resources, give them power and incentives to continue legitimization of preferred policies, as well as make them insist upon the importance of the vital energy systems and their vulnerabilities. And finally, energy system boundaries are drawn by a number of historically important social institutions, which were/are shaping the system.

Taking into consideration the above facts, framework and theories of development of national energy systems described in the literature review, the analysis will be conducted in respect to each separate energy system of the country (see the Method section) with an intention to answer the following questions:

- How did the energy system developed historically?
- What is the current state of the system?
- How is the system connected/related to other energy systems and major economic sectors of the country?
- How important is the energy system for the nation/society?
- Which institutions govern this energy system and through which policies?

- What are the main vulnerabilities of the system?

Answering these questions will help to build the framework ‘triangles’ for each energy system, thus defining the country’s main systems; identifying main influential groups, stakeholders and institutions related to each system; identifying main policies related to each system; establishing connections between ‘system’, ‘institutions’ and ‘policy’ framework segments. Following the main objectives of the study, the Discussion chapter will provide an integral analysis of all the energy systems rating them according to their importance, distinguishing major vulnerabilities and energy security issues on the national level, most influential actors within the energy sector, and subsequently marking out energy system drivers, policy priorities and showing possible directions of the Ukrainian energy future.

3.2. Method

In accordance with the proposed theoretical framework and thesis objectives (see Section 1.2), the analysis will include the following steps:

- I. Analysis of the historic development and current state of energy sector
 - i. Energy resources and general history of energy
 - ii. Analysis of separate energy systems
 - iii. Current policies and strategies
- II. Identification of main stakeholders, institutions, actors within the national energy system
- III. Identification of Ukrainian energy policy priorities
- IV. Identification of the main drivers for development of the national energy system
- V. Drawing future directions of the Ukrainian energy

In order to distinguish Ukraine’s major energy systems for the analysis, resource-based definition of energy systems proposed in the previous paragraph is used, together with the

IEA's reports and Sankey diagrams (IEA 2006; IEA 2012; www.iea.org/Sankey/). The latter can give a clear understanding of the major energy flows of the country, production and consumption of various forms of energy, as well as help to mark out connection between different economic sectors and energy systems. Figure 4 represents one of such diagrams built for Ukraine. It shows the six primary energy flows: oil, coal, gas, nuclear energy, biofuels and waste and hydro, transformed into heat and electricity, which are subsequently used to identify the country's primary energy systems listed in the Tables 6 and 7 below.

Each of the systems is to be analysed separately according to the questions stated in the framework. A summarizing table of the analysis will look as follows:

Table 6. Template for characterizing the major energy systems of Ukraine

| Energy system | Nuclear | Solid fuels | Gas | Oil | Hydro | Renewable | Electricity |
|-----------------|---------|----------------|-----|-----|-------|-----------|-------------|
| History | | | | | | | |
| Current state | | | | | | | |
| Importance | | | | | | | |
| Connections | | | | | | | |
| Governance | | | | | | | |
| Vulnerabilities | | | | | | | |

In order to rate the systems according to their importance, Dryzek's theory of transformation of a state will be used. Transformations of each system will be followed from the importance in supporting domestic order in the country up to the stages of legitimation and conservation (Table 7). Depending on how 'far' did the system go in its transformations, how deeply embedded it is in the national energy system, its importance will be marked accordingly in the previous table on a scale from 1 (+) to 5 (+++++) based on the criteria described in detail in Table A9 (see Appendix).

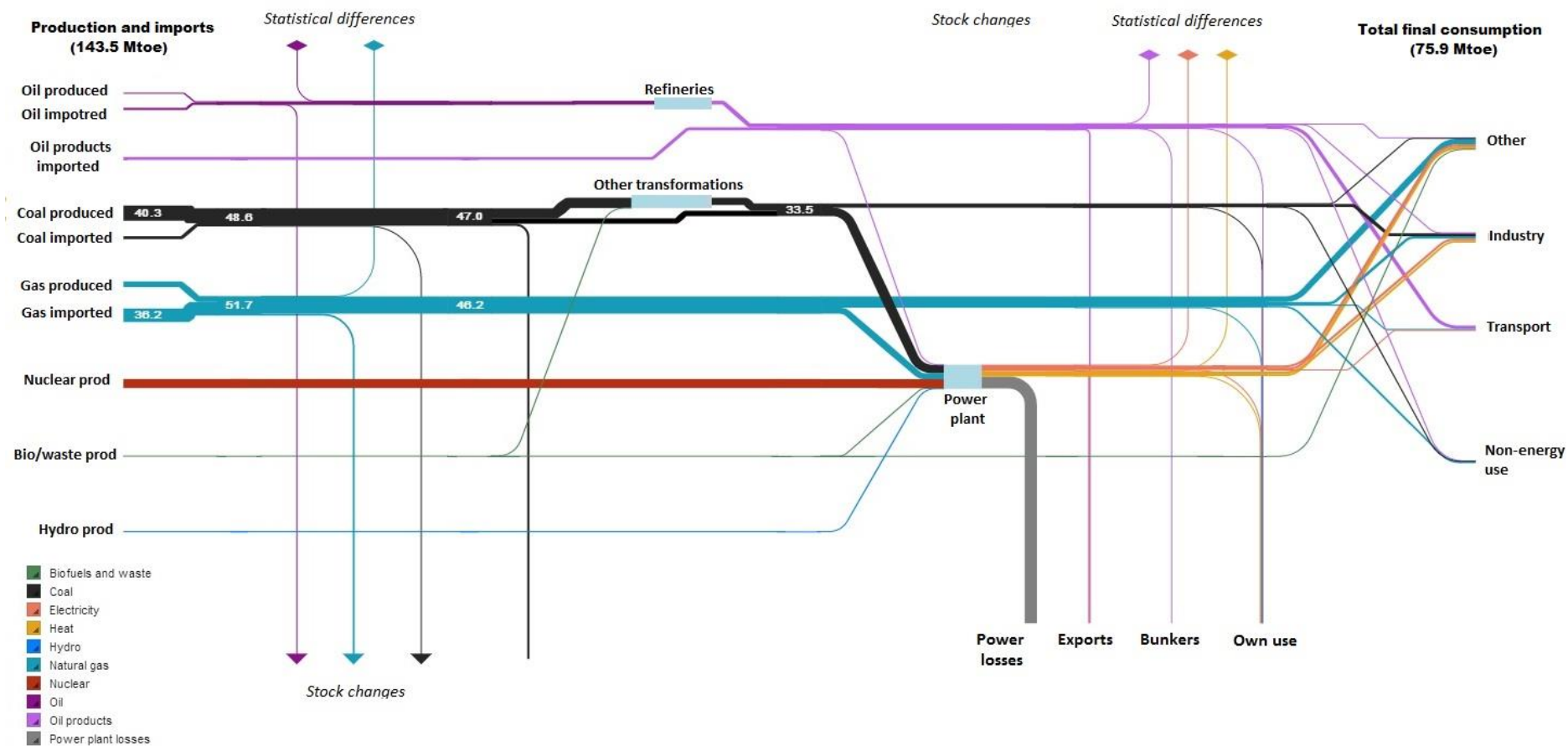
Table 7. A matrix for evaluating the importance of energy systems according to imperatives of a state

| System/Imperative | Domestic order | Survival | Revenue | Economic growth | Legitimation | Conservation |
|-------------------|----------------|----------|---------|-----------------|--------------|--------------|
| 1. Solid fuels | | | | | | |
| 2. Oil | | | | | | |
| 3. Gas | | | | | | |
| 4. Nuclear | | | | | | |
| 5. Hydro | | | | | | |
| 6. Renewable | | | | | | |
| 7. Electricity | | | | | | |

It is important to note that all of the analysed energy systems are directly connected to power production and some of them also to heat production (solid fuels, oil, gas, renewable) due to transformations of energy flows from the primary energy resources to the final consumers in power plants. The electricity system, due to its special characteristics (e.g., impossibility to store electricity) and high importance in both national and international context, will be discussed separately, along with other energy systems following the same framework as stated above. The system of heat supply will be discussed only within the context of the major energy systems responsible for heat production (solid fuels, gas), and thus is regarded to as fully dependent on and interconnected with these systems.

Historic, contemporary analyses and energy systems analysis will then be used to identify main stakeholders, drivers, priorities and possible future transformations of the Ukrainian energy sector in the Discussion chapter. The triangle of interconnections between systems, institutions and policies proposed in the framework (see Figure 3) is to be referred to at all the stages of the analysis. Future scenarios will be built based on identified trends of the energy policy and energy systems' transformations, as well as on the existing political, economic and other uncertainties for the future development of Ukrainian energy sector.

The study is based on a review of more than 60 pieces of English-language and over 25 pieces of Ukrainian, Russian and Soviet academic literature, as well as other resources (national reports, statistical information, newspapers, related videos), which help to keep tracking energy systems' dynamics. The analysis compiles data from various sources, both national (such as the Ministry of Energy and Coal Industry of Ukraine, the Ministry of Environment and Energy Resources of Ukraine, the National Academy of Sciences of Ukraine) and international (such as the International Energy Agency, World Coal Association, World Nuclear Association), and provides insights to the Ukrainian energy from different perspectives: based on the views of internal (national), external (international) experts (e.g., "Updated Energy Strategy of Ukraine until 2030", IEA reports) and author's own findings.



CEU eTD Collection

Figure 4. Sankey diagram for Ukraine, 2011

Source: www.iea.org/Sankey/

4. RESULTS: ENERGY SYSTEMS OF UKRAINE

4.1. Background information

4.1.1. Energy resources of Ukraine

The former “bread basket” of the Soviet Union, Ukraine is a country rich with natural resources, including fertile arable lands, timber, coal, natural and shale gas, graphite, iron ore, uranium ore, manganese, titanium, nickel, mercury, salt and sulphur (MENRU 2012). This has to a great extent defined formation of its primary industries, such as iron and steel production, as well as its energy system with the main primary energy sources being coal and gas fuels (MECIU 2012a).

Geology and resources

Appearance of mineral, water, soil and conventional energy resources is directly connected to geologic structure of the earth. The territory of Ukraine has a complex tectonic structure, which has been formed for thousands of centuries.

Most territory of Ukraine belongs to the East European platform (see Figure 5: Ukrainian Shield), where ancient magmatic and metamorphic rocks appear on the surface or less than 1 km below the surface. The area includes large deposits of iron ore, as well as nickel, titanium, uranium, graphite, mercury, gold, zeolite, kaolin, bentonite and other mineral resources. Main energy resource of the Ukrainian shield is brown coal which is distributed all along the area 1 (see Appendix, Figure A.2, and Figure 6). Volyn-Podolsk plate 3 and Donets fold belt 8 contain large deposits of black coal. The Carpathian fold and thrust belt 4, Dnieper-Donets rift 6, the Black Sea depression 9 and Schythian plate 10 contain many oil and gas deposits. Another energy resource - peat (or turf) - is also found in Ukraine, namely in the north-west of the country within the Ukrainian Shield 1, Kovel salient 2 and Volyn-Podolsk plate 3.



Figure5. Geologic structure of Ukraine

Source: Biletsky *et al.* 2002

Solid fuels

Mining for coal in Ukraine started already in 19th century and led to formation of large industrial areas and centres such as Donbas, the cities of Kryvyi Rih, Mariupol, Zaporizhya and many others in the next decades (Plachkova *et al.* 2012). Coal reserves of Ukraine amount for more than 90% of the country's fossil fuel reserves and 52 billion tonnes in total, 23 billion tonnes of which are considered to be proven and probable (IEA 1996; IEA 2012). A few decades ago Ukraine was producing 240 million tonnes (Mt) of coal annually, while production of coal in 2011 made 82 Mt with 31% share in the national energy mix (IEA 2012; Omelyanovsky *et al.* 2010). The three-fold decline is connected to a number of reasons: substantial depth of occurrence of coal beds, inconvenient geological conditions for mining,

small capacity of the coal beds, outdated mining equipment and technologies etc. However, coal remains an important fuel in both industrial and electricity production sectors.



Figure 6. Coal reserves and main coal basins of Ukraine

Source: Ogarenko 2010

There are three major coal fields on the territory of Ukraine: Donetsk and Lviv-Volyn black coal fields and a Dnieper brown coal field (see Figure 6 above). *The Donetsk basin* is the most important source of coal in Ukraine. It occupies some 50 thousand km² (within Ukrainian borders) and stores large deposits of coke, gas and anthracitic coal. Currently, there are more than 100 production areas in Donbas of an overall capacity of about 50 billion tonnes of coal (Plachkova *et al.* 2012). *The Lviv-Volyn basin* is located to the west of Ukraine and occupies around 10 thousand km² with balance coal reserves making less than 1 billion tonnes (Plachkova *et al.* 2012). The maximum thickness of coal seams reaches 2.8 meters here. The significant depth of coal deposits and their uneven distribution requires application of special technologies such as underground gasification. Without such technologies, e.g. production using conventional methods, only 30% of the basin's coal can be extracted. *The Dnieper brown*

coal basin occupies a vast territory of about 150 km² with coal deposits being spread within Kirovograd, Dnipropetrovsk, Zhytomyr, Zaporizhia, Kyiv, Cherkasy and Vinnytska oblasts (Biletsky *et al.* 2002). Basin's resources are estimated to make 2 billion tonnes. A number of brown coal deposits are also known to be located in Poltava and Kharkiv oblasts, as well as in some of the western regions.

There is a number of current problems related to coal production in Ukraine. These include unfavourable for exploitation geological conditions of most of the reserves, such as high methane content (significant methane content in 90% of the mines), thin coal layers with seams of average thickness of 1.2 meters, significant mining depth more than 0.7 km, possible coal dust outbursts (60% of all mines) and spontaneous coal combustion (22% of all mines) (IEA 2012).

Another type of solid fuels present at the territory of Ukraine is peat. Main reserves of peat fuel are concentrated in Volyn, Rivne and Chernihiv oblasts. An average area of the reserves is 3.3 – 3.5 km² with average fuel volumes of 950 – 1150 thousand tonnes.

Oil and gas

Visible exploitation of the Ukrainian gas and oil resources started in the middle of 20th century (see Figure 19). Main thrust of extraction of the mentioned fossil fuels was seen in 1960's and 1970's (Campbell 2013). Collapse of the USSR in 1991 caused dramatic decline of the country's energy supply levels. Since then production of gas and oil have been fluctuating but never reached the amounts produced in 1960s-1970s during the soviet era. Ukraine is extracting only about 10% of the national demand of oil and less than 25% of that of natural gas (MECIU 2014b; Omelyanovsky *et al.* 2010). As of 2010, only 41% of the national oil and gas resources were estimated to be explored, while the remaining 59% were left undiscovered (Omelyanovsky *et al.* 2010).

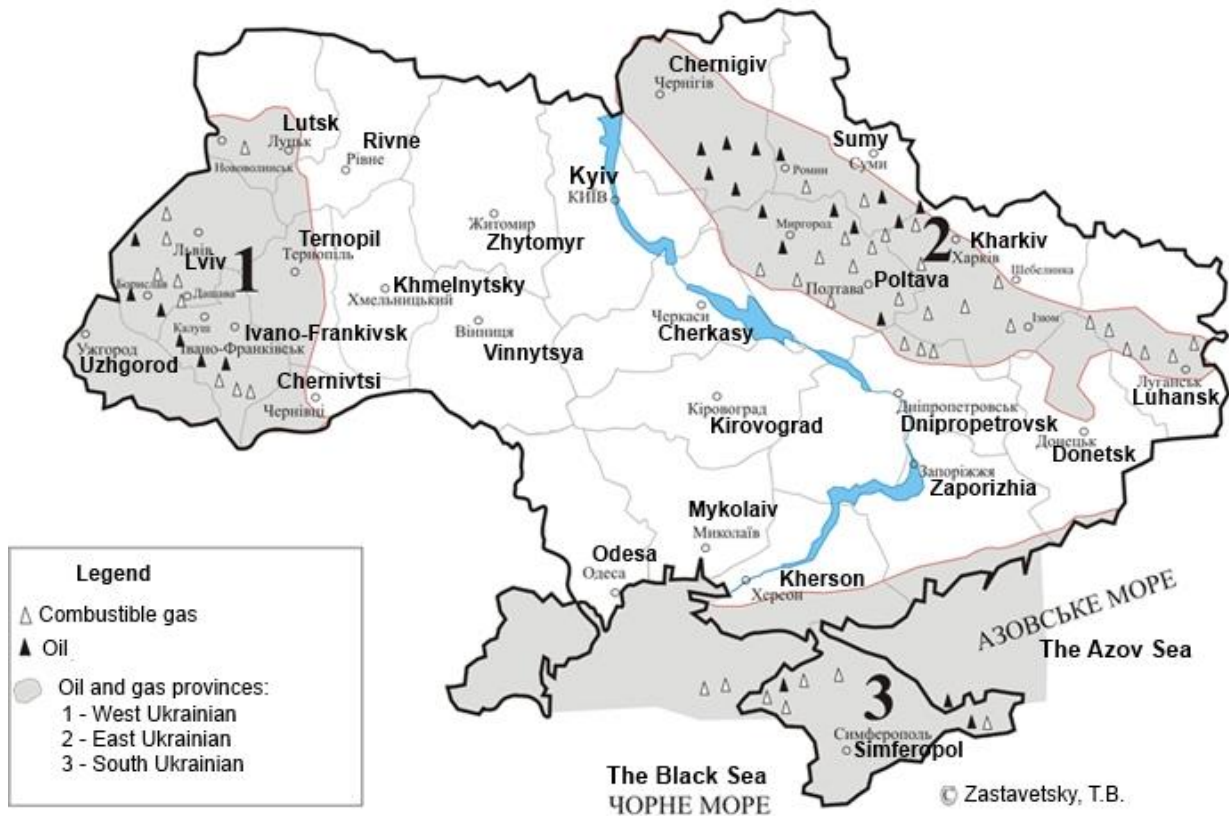


Figure 7. Oil and gas resources of Ukraine

Source: Kondrat and Serednytsky 2013

Most of Ukraine's oil and gas fields are largely depleted with some small reserves remaining at considerable depths of over 4.5 km (IEA 1996). All the gas and oil deposits are concentrated in the following three fields: *Carpathian* (west), *Dnieper – Donets* (east) and the *Black Sea – Crimean* (south) regions, all mapped on Figure 7. More than 80% of oil and gas are being produced at Dnieper-Donetsk oil and gas province, which is the most important hydrocarbon-producing region of the country (IEA 1996). Oil and gas production in the Carpathian region has a history of over 100 years and thus is largely explored, unlike the Crimean region only 5% of which has been explored by 1996 (IEA 1996). Thus, the Black Sea shelf is still expected to hold considerable reserves and become an important source of oil and gas.

There is a whole range of unconventional gas reserves in Ukraine, including shale gas, tight gas and coal bed methane reserves. The term “unconventional” is used to stress that

exploration of the resources in Ukraine is yet on its initial stages. The country ranks third among other European states as shale gas deposits are concerned, after Poland and Norway (Marocchi and Fedirko 2013). Two major shale gas fields are *Yuzivska* (Donetsk and Kharkiv regions, East Ukrainian oil & gas province) and *Oleska* (Lviv and Ivano-Frnkivsk regions, West Ukrainian province). More detailed description of the unconventional gas reserves is given in the Table 8 below.

Table 8. Information on unconventional gas reserves in Ukraine

| Type of gas | Estimated amount of reserves, trillion m ³ | Depth, km | Estimated production cost, \$/1,000 m ³ | Challenges | Investment required (until 2030), billion \$ |
|-------------------------------|---|-----------|--|--|--|
| Gas of the Black Sea | 4 – 13 | > 0.35 | 75-125 | exploration; technology | 10-12 |
| Shale | 1.2-8 | 1-4 | 260-350 | technology, drilling rigs; well siting; reduction of environmental risks | 35-45 |
| Tight | 2-8 | 4-4.5 | 190-280 | exploration; technology | 7-8 |
| Coal bed methane (CBM) | 12-25 | 0.5-5 | 290-410 | exploration; development of infrastructure; technology | 1.5-2 |
| Total: | 17.2 - 54 | | | | |

Data source: MECIU 2012a

During Viktor Yanukovich's presidency (mainly in 2013) a number of agreements were signed regarding development of shale gas basins. The foreign stakeholders interested in production of Ukrainian shale gas include Shell (part of Yuzivska field), Chevron (Oleska field) and Exxon Mobil (Kuzio 2013; Marocchi and Fedirko 2013). The production sharing agreement signed with Shell provided the company with an exclusive right for exploration and tax-exempt industrial production of shale gas on some 1,000 km² area starting from 2017 (Kuzio 2013; Marocchi and Fedirko 2013).

Uranium

Ukraine has a strong raw material base for extraction of uranium with substantial deposits of the ore: around 2% of the world's uranium resources can be found in Ukraine (UATOM 2011). The country is able to fully meet its needs in uranium for the next decades. However, at the moment annual production of uranium makes no more than 1,000 tonnes, which is just above 30% of the amount needed for operation of the existing four nuclear power plants (NPP), with the remaining amount being bought from Russia (Omelyanovsky *et al.* 2010). The extracted ore is then transported to Russia for enrichment and fabrication. In September 2013 construction of the first Ukrainian nuclear fuel fabrication factory was also launched (ZNUA 2013; see Paragraph 4.6.5). Nuclear waste burial, however, remains a critical issue as the country's energy independence and economy are concerned: Ukraine pays Russia as much as 200 million US dollars annually to store and utilize its nuclear waste (UNIAN 2013).

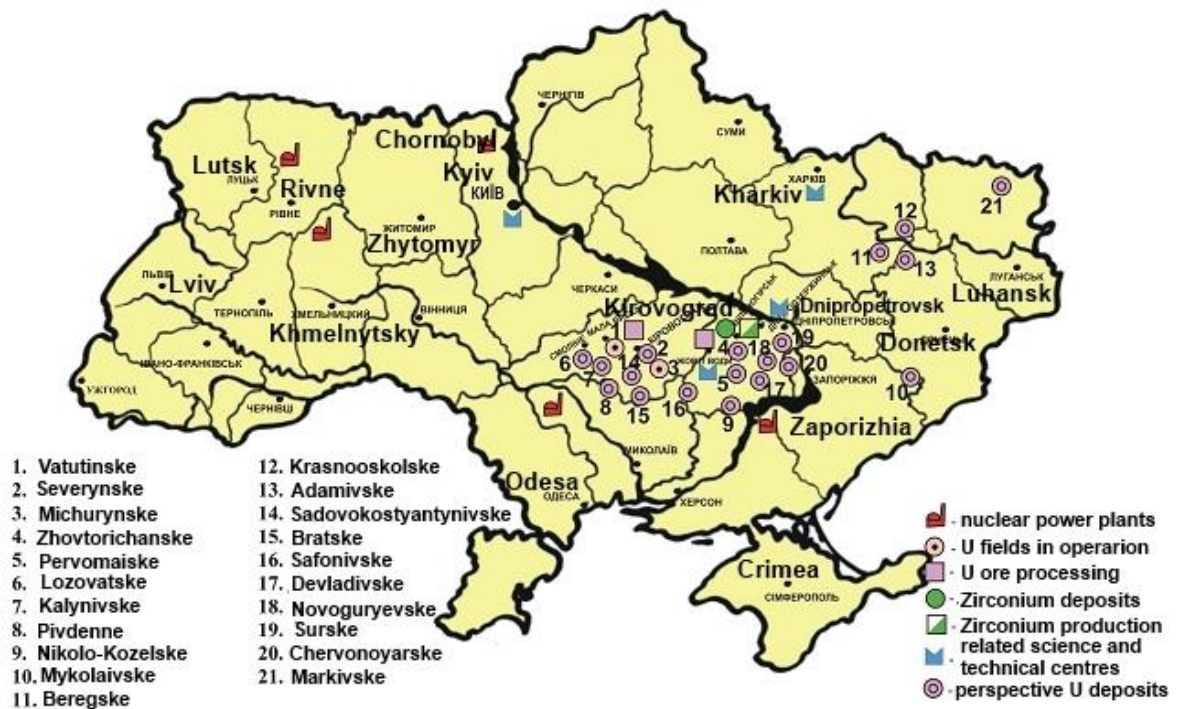


Figure8. Nuclear energy map of Ukraine

Source: UATOM 2011

The four NPP with a total of 15 reactors produce almost half of the country's electricity, which makes the country highly dependent on nuclear energy (WNA 2014). At the same time, Ukraine plans to double its uranium production and achieve 1,880 tonnes (76%) in 2014 out of an overall 2,480 tonnes needed for the NPPs' operation (UNIAN 2013a). The 2020 target for uranium production is 4,800 tonnes/year; 2030 target is 6,400 tonnes/year (WNA 2014).

Practically all of the uranium deposits in Ukraine are located within Kirovograd region (see Figure 8). Overall recoverable uranium resources according to different estimations make from 100,000 to 225,000 tonnes with 65,000 up to 131,000 tonnes regarded as profitable for production (UATOM 2011; WNA 2014). The two uranium deposits which are under operation at the moment are Vatutinske 1 and Michurinske 3. Deposits of Severynske field 2 are kept as a reserve and many other deposits are being under exploration.

Uranium ore fields of Ukraine can be divided into endogenous and exogenous. There are 12 well-explored endogenous fields, which could meet the current needs of the nuclear industry of Ukraine for the next century. Mining for the exogenous deposits is not yet considered to be profitable. However, profitability increases

Renewables

In 2011 the share of renewables in total electricity generation capacity made 11%, out of which non-hydro renewables (solar, wind, biofuels) made 0.1% (MECIU 2012a). The existing hydropower system of Ukraine is well-developed and is comprised of a series of power plants of the Dnieper and Dniester Rivers. At the same time, Ukraine has a large potential for utilization of its other renewable resources for production of both power and heat (see Table 9 below and Figure A.3 in Appendix). Estimations for total potential of renewable energy sources (RES) in Ukraine largely vary and make 25 TWh/year according to (IEA 2012), 196 TWh/year according to (DIFFER 2012), 521 TWh/year according to (Kudrya 2008) and as much as 549 TWh/year according to (MECIU 2012a). For comparison, in 2013 Ukraine

generated 194 TWh of electricity (MECIU 2014b). Southern and east-southern regions of Ukraine, namely Zaporizhia, Kherson, Mykolaiv, Odesa regions and Crimean AR, have significant wind and solar energy potentials (Gonchar 2012; see Appendix, Figures A.3 and A.4). This is due to the fact that the regions are located at or near the shores of the Black and the Azov seas with stronger winds and hotter climate. Among all the seaside regions, Crimea has the highest potential (Gonchar 2012).

Table 9. Estimations of renewable energy resource potentials in Ukraine

| Resource | Technical potential, billion kW·h/year | Annual amount of equivalent fuel (natural gas) substituted, billion m ³ | Regions/areas with the highest potential |
|---|--|--|---|
| Small hydro | 27.7 | 8.7 | westernmost regions (near Carpathians) |
| Wind | 41.7 | 18.0 | south, east-south, west (Carpathians) |
| Solar | 28.8 | 5.2 | southern and central regions |
| Biomass | 162.8 | 17.4 | central, southern, western regions |
| Geothermal | 105.1 | 10.4 | most of potential in southern, northern and westernmost regions |
| Energy stored in environment | 154.7 | 15.7 | central and eastern regions |
| Total | 520.8 | 75.4 | |
| Electricity generated and gas consumed in 2013: | 193.6 | 50.4 | |

Sources: Kudrya 2008; MECIU 2014b; Tytko and Kalinichenko 2010

NASU estimations for renewable energy resources show that four regions of Ukraine could potentially fully substitute their use of traditional energy resources with renewable ones. These regions are: Crimea (302% substitution capacity), Zakarpattia (234%), Kherson (139%) and Chernivtsi (108%) (Kudrya 2008). As an example, Crimea today is largely dependent on energy supplies from the mainland: 100% on coal, 96% on oil, 90% on electricity and 45% on

gas supplies (Gonchar 2012). Thus, there is an enormous potential for application of renewable energy technologies around the country, which is yet untapped and needs to be further developed.

Among the possible biomass sources, which can be used in Ukraine for power/heat generation are: straw, different types of agricultural waste, wood biomass, biodiesel, biogas of different origin, peat and others. According to Volchyn *et al.* (2013), the highest economic potential can be achieved from the use of corn and sunflower production waste, as well as straw (from grains). Waste from agriculture sector can also be used to produce biogas. As agriculture sector of Ukraine leaves significant amount of waste, the recent estimates conducted by the National Biomass Centre show that the waste "... could be used to produce enough biogas to replace 2.6 billion m³ of natural gas per year", which is about 5% of the current gas consumption of the country (IEA 2012; MECIU 2014b). Possible agriculture expansion may bring biogas production potential up to 7.7 m³ natural gas equivalent (IEA 2012). Livestock waste can also be used as biogas fuel and, according to IEA (2012), it can support as much as 4,000 biogas installations.

Application of municipal waste as an energy source is another 'green' option. Estimations show that Ukraine had accumulated more 54 million m³ of solid waste by 2012 and the country's annual waste generation increases by 5-7% every year (Vinnichuk 2012). There are 4,500 official landfills and some 10,000 non-official (Vinnichuk 2012), and at the same time, there are only two waste processing (combustion) plants: one in the capital Kyiv and one in Dnipropetrovsk. The former does not operate at its full capacity and the latter does not operate at all. While waste recovery and combustion could bring economic profits in form of generated electricity and heat, low cost for landfilling and absence of waste processing plants do not stimulate cleaner utilization of waste in the country. Application of waste-to-energy technologies in most of the developed countries advances due to high landfilling prices

and/or provision of incentives for development of the renewable energy sector (Cooper 2013). Thus, implementation of similar policies could help Ukraine to use the free fuel produced in large amounts every year to partially cover its energy demands.

4.1.2. History of energy systems in Ukraine

Temperate climate, luxuriant vegetation, sufficient humidity and fertile soils made the lands of Ukraine very comfortable for living from ancient times. Already in the Middle Ages when Kyivan Rus was established, Ukraine was a centre of Eastern Slavic culture (Channon and Hudson 1995). The state's independence, however, was constantly questioned by the neighbouring countries and Ukraine's territories had been divided up until the XX century.

Although the "coal era" officially started in the 18th century, with the subsequent emergence of the first industries, the present overlook may be important to understand the attitude of the Ukrainians to natural resources and energy, which has been formed for centuries, shaping the landscapes and determining further energy policies of the modern Ukraine.

1 Industrial revolution in Ukraine

One of the main characteristics of the modern era was an industrial revolution, which implied changes in population social structures, prolonged economic growth and revolution of energy in all its forms and variations (Wrigley 2011). As the industrial revolution was rapidly spreading around Britain already in the 18th century and country's energy supply was roughly doubling each half a century (Wrigley 2011), most of the world, including Ukrainian territories, started catching up with Britain many decades, or in some cases even centuries later. Main reasons for this holdup and first steps in establishment of the Ukrainian energy system, as it exists today, are discussed further on.

Role of agriculture in economic growth

By the end of 18th century Ukrainian territories were divided between two empires. Most of Ukraine belonged to the Russian Empire and was broken up into provinces (or so-called “gubernias”), while the western regions was a part of the Austro-Hungarian Empire (Hrycak 2000; see Figure 9 below). Ukraine with its big territories, fertile lands, rich mineral and rock deposits, as well as many other natural resources, was a perfect domain for fast economic growth. Indeed, eastern and southern parts of Ukraine had the largest agricultural output among all other territories of the Russian Empire (Boscia 2010). However, the Ukraine’s huge potential was not fully used due to the social and political order established on the Ukrainian territories after their integration into the two empires.



Figure 9. Ukrainian territories in XVIII – beginning of XIX centuries

Source: Boscia 2010

First of all, most of the Ukrainian population were peasants fixed to allotted lands up until 1861 (year of abolishment of serfdom right). Even in the beginning of 20th century more than 90% of Ukrainians in both Russian and Austro-Hungarian empires belonged to peasantry

(Hrycak 2000). Thus, a free labour market could not be formed and industrial development was limited. Most of the industrial enterprises of the time belonged to landlords or the state, which made market competition practically impossible. Moreover, agriculture by itself could not constitute the only basis for economic growth, which in the end also largely defined economic backwardness of Ukraine in the beginning of 19th century (Hrycak 2000).

Industrial development and urbanization

Coal deposits at the territory of Donbas (eastern Ukraine) are known to be prospected for the first time in 1721-1725 (Bulych 2006). The exploration continued in the end of 18th century with the following commencement of resources' exploitation. On the whole, coal industry of Ukraine is thought to have originated when an iron-smelting factory with simultaneous extraction of coal was built in near *Luhansk* in 1796. In only 50 years coal production at Donbas escalated forty-fold: from 2.5 thousand tonnes in 1810 to 98 thousand tonnes in 1860 (Reshetilova *et al.* 1997). Discovery of high-quality iron ore fields near Kryvyi Rih in 1880s, further expansion of industries and construction of new railways kept raising coal output at Donbas. Before the First World War, as much as 70% of all coal produced in the Russia Empire originated in the Ukrainian Donbas (Lanovyk *et al.* 1994). During the First World War production of coal in the region kept increasing and reached 28.6 Mt in 1916 with as many as 284 thousand workers being involved in coal extraction (Reshetilova *et al.* 1997).

Production of oil in Ukraine started already as early as 1820s, namely near the city of Boryslav in the region of Carpathians (west of the country, Austro-Hungarian Empire). At that time it was the largest region of oil production in Europe and at the beginning of 20th century production its level reached 2.0Mt per year constituting 5% of the world output in 1909 (NAFTOGAZ 2012; Dienes and Shabad 1979). The city of Lviv held the first International Oil Industry Congress in the world in 1877, which resulted in establishment of a regional oil society (NAUKANAFTOGAZ 2014).

The first gas production plant on the territory of Ukraine was built in 1858 in Lviv and used a unique method of extraction of gas from coal (NAUKANAFTOGAZ 2014). The gas was used for city's street lighting purposes. Within the 19th century similar gas production plants spread to other Ukrainian cities, including Kharkiv, Kyiv, Konotop and Odesa (Diyak *et al.* 2009).

Industrialization in the northern and central gubernias of the Russian Empire had advanced much more by the middle of 19th century in comparison to the Ukrainian gubernias of the Empire (Hrycak 2000). Ukraine of this time was a backward agricultural land in both empires. For example, the only big-scale industrial production within the western Ukrainian territories belonging to the Austro-Hungarian Empire was oil and ozocerite (mineral wax) production near Drogobych and Boryslav, which started only in 1850s -1860s (Hrycak 2000).

The industrial revolution came to Ukraine in 1860s-1870s: after cancellation of serfdom in 1861 many Ukrainian territories entered the era of economic growth, which was, however, mainly determined by tsarist economic policy and interests of the two ruling empires. Only certain industrial sectors were being developed on Ukrainian territories: either those which could not be developed in Russian gubernias due to unsuitable environmental conditions (such as sugar industry), or those which were meant to supply Russian and Austro-Hungarian industries with raw and semifinished materials (iron and steel, coal industries). Ready products were mostly manufactured out of the Ukrainian borders. The pricing policy of the Russian Empire was established in a way that raw materials were cheap, while ready-made products were expensive. This made Ukraine's economy highly vulnerable and dependent on imports from the north and the west (Hrycak 2000).

The industrial growth started being particularly evident in 1880s and 1890s as a number of 'new' industrial regions of the Russian Empire entered the stage, including many areas of Ukraine (Munting 1996; see Figure 10 below). This was primarily related to construction of

new railways around the Empire, such as the Ekaterinoslav railway opened in the beginning of 1880s, which allowed the linkage of the iron resources of Kryvyi Rih with the coal resources of Donbas (Munting 1996) and an easy access to the Black Sea harbor cities (e.g., Mariupol). Consequently, the southern Ukraine overtook the long-established iron-producing region of the Urals: by 1900 the southern Ukraine together with Poland territories was producing 52% of the Empire's pig iron (Khromov 1950). Nevertheless, the occurring industrial transformation "... was limited regionally, as well as socially" (Munting 1996).



Figure 10. Industry and agriculture in Ukrainian gubernias of the Russian Empire in 1900

Source: Channon and Hudson 1995

Up until the beginning of construction of the first industrial-purpose railways, industry, unlike trade, had not been playing a big role in development of urbanization in Ukraine. The only exception was the city of *Luhansk* founded in 1795, which became an industrial centre of Ekaterinoslav guberniya owing to the local factory producing cannons and balls for the Black

Sea Fleet (Hrycak 2000). Later on the city will turn into an important coal and gas industrial centre. The riparian cities of Ekaterinoslav (currently: *Dnipropetrovsk*) and *Kherson*, together with the coastal cities of *Mykolaiv* and *Odesa* founded in the end of 18th century, were growing fast in both scale and importance due to their convenient location at the main trade waterways and subsequently turned into large industrial centres. Kherson and Mykolaiv in particular sheltered shipbuilding factories and facilities. As the industrial revolution progressed, a number of industrial centres started emerging. These included Donbas and Dnieper regions (coal, iron and steel, metal-working production), Kryvyi Rih (iron ore production), Nikopol (manganese ore production), Kyiv and Kharkiv (metal-working and machine-building production) and others.

In the western Ukrainian territories industrial revolution was progressing with a slower pace than in those of eastern or central Ukraine belonging the Russian Empire. Development of industrial facilities was mostly financed by foreign capital (Austro-Hungarian, German and other) and included oil extraction and processing, food production, ozocerite extraction, salt extraction, glass production, ceramics, mining, chemical, carpentry industries (Kozyuk *et al.* 2011). As of 1910s, machine building and metal-processing were practically not developed.

As demographic situation is concerned, within 19th century population of the Ukrainian gubernias of the Russian Empire increased three-fold and reached a benchmark of 23.8 million with 15% urban and 85% rural population by 1900 (Pidgorny 2008, Rashin 1956). Further development of industrialization and consequent urbanization were gradually changing the latter distribution. As a result, urban population exceeded rural in 1965.

Energy revolution and electrification

Notwithstanding the immense amount of coal resources distributed within the Russian Empire, large amounts of the black fuel were imported until the first decades of 20th century.

1913 statistical data show that national share of coal as a fuel source was only 30%, while firewood and straw made 70% (Josephson *et al.* 2013). This was due to the lack of available technologies, as well as a lack of knowledge about own energy resources, which had not been extensively explored. At the same time, vast energy potential of the eastern Ukrainian territories was known and thus actively used for the Empire's needs and development.

Electrical energy was recorded to be used for the first time on the territory of Ukraine in 1878 in Kyiv, when a Russian engineer Alexander Borodin constructed four electric lamps as a lighting source for the city's railway workshops (Plachkova *et al.* 2012). A couple of years later, electric streetlights gained popularity among the Kyiv's wealthy citizens who used the newest invention to illuminate their mansions, and later the city's streets. Within the same time period the first power station of a small capacity for general purpose was built in Poltava (central Ukraine) with a following appearance of similar stations in Ekaterinoslav (currently Dnipropetrovsk), Konstantinovsk (Donbas region), Lviv and Odesa. In 1913 the installed capacity of power plants of Ukraine reached 304.3 MW, annual generation of electricity made 543 million kWh and annual electricity consumption per person was equal to 15 kWh (Plachkova *et al.* 2012).

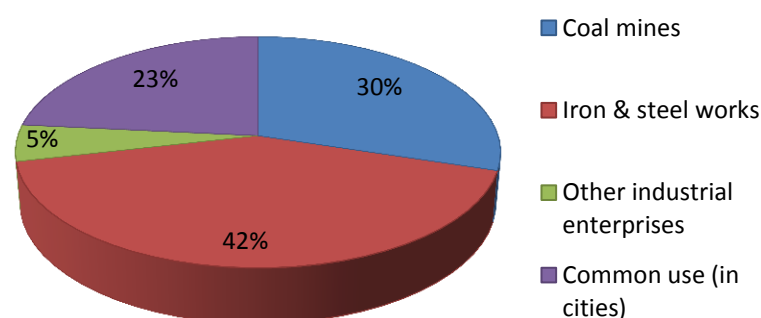


Figure11. Distribution of Ukrainian power plants of capacities more than 1 MW between various sectors of economy in 1913

Source: Plachkova *et al.* 2012

As it is shown in Figure 11 above (also see Table A.1 in Appendix), electricity produced at power plants was mainly used in industrial processes for iron and steel manufacturing, as well as for extraction of coal at coal mines. Access to electricity was still a privilege of urban citizens, while most of the rural areas remained unaltered by the industrial revolution gains.

Emergence of “scientifically-based” planning

During the World War I government and science came together in the Commission on the Study of Natural Productive Forces of Russia (the so-called ‘KEPS’), which was formed in 1915, in order to contribute to the questions of resources exploitation and management (Josphephson *et al.* 2013). The main reason for formation of KEPS was high reliance of Russia on imported manufactured goods and strategic materials from Europe, such as explosives. The war made Russian political and scientific specialists realize that the nation could hardly survive without western technology, which put the whole country at risk and isolation. In this way, during the time of need, when trade from the west was suddenly cut off, KEPS offered its assistance to the nation by chartering the extension of natural resources, conducting research, development and coming up with new manufacturing solutions.

This was happening notwithstanding a certain level of dislike of the Tsarist regime coming from many KEPS scientists and researchers, and many difficulties with logical and funding problems that KEPS experienced during the first years of its existence. At the same time, the Commission played a crucial role in the future postwar developments and the future progress of science and research in the Soviet Union. KEPS surveys, works and inventories were further used in Bolsheviks’ plans for electrification of the USSR by KEPS’ successors: the Council for the Study of Productive Forces (SOPS) and the State Commission for Electrification of Russia (GOLERO). Also thanking to Vladimir Vernadsky, a famous Ukrainian mineralogist and geochemist who was an active member of KEPS, the Ukrainian Academy of Science in Kyiv was formed in 1918. In this way, KEPS “... was the first stage of

‘scientifically-based’ planning that was central to Soviet economic life” (Jospehson *et al.* 2013).

Although the Commission was meant to work on prevention of irrational resource use, many of its members, who later became the members of KEPS’ successor organizations, believed that humans have to exploit and tame natural resources, seeing a raw economic value in nature (Jospehson *et al.* 2013). Thus, Bolsheviks with their primary focus on embracing of big science and technological developments very soon gained a full support of the scientists. The latter started playing an important role in the country’s decision-making in many economic sectors, including energy and resource use.

II Ukrainian SSR: 1917-1991

The October Revolution of 1917 and a civil war caused by the coup d'état had a big influence on the functioning of the existing energy system of the time causing drastic transformations to occur. Before the Revolution scientific research directed toward exploration and exploitation of energy resources in the country was scattered and inconsistent, often undertaken due to initiatives of separate engineer or scientists. After the revolution, namely in 1920s, the country’s power specialists finally gained an appropriate support from the government and were able to implement their progressive ideas on practice.

GOELRO electrification plan

In 1920 V.I. Lenin initiated the development of the first Soviet economic plan for national recovery. It was known as *GOELRO plan* standing for “Gosudrastvennaya komissiya elektrifikatsiya Rossii” (the State Commission for Electrification of Russia) and in Soviet literature is referred to as “... the first in the history of human kind scientific long-term plan for development of the national economy based on electrification” (Ananiev *et al.* 1977). GOELRO plan implied construction of 30 regional power plants (20 thermal and 10 hydro) of a

total capacity of 1.75 GW during the next 10-15 years, development of a powerful machine building industry, reconstruction of agriculture and electrification of railway transport.

The main principles of the plan were:

1. Technical re-equipment of all **economy sectors based on electricity use**. High growth rate of social labour productivity based on electrification of all manufacturing processes and improvement of labour conditions.

2. Ensuring the growth of **heavy industry** on the first place "... as a foundation for development of the whole economy" and in order to strengthen the national defence powers.

3. **High rate of energy sector development** exceeding the rate of industrial development to ensure increasing introduction of electrical energy, maximum meeting of demands of all economy sectors, construction of stand-by power facilities.

4. **Centralization of power generation**. Construction of large modern power plants, which would secure electricity generation for whole regions.

5. Wide **use of** fuels of various quality and **local fuel resources** at the power plants.

6. Wide use of water resources: construction of **hydropower** plants in the regions poor with fuels [at that time, coal resources], construction of hydrological constructions for integrated use of water resources for the needs of power engineering, transport, irrigation and water supply.

7. Construction of power transmission lines and connection of high-capacity power plants with the transmission lines for their simultaneous operation. Establishment of energy systems uniting smaller areas, then larger regions, and as a result, creation of the **united national energy system**.

8. Efficient distribution of power facilities to provide even development of industries within the country. Construction of power plants in the outlying regions of the country, in previously backward regions, establishment of **new industrial centres** (Ananiev *et al.* 1977).

The GOELRO plan served as a prototype for Five-Year Plans developed by Gosplan (the State Committee for Planning) in form of centralized economic plans based on a theory of productive forces emphasizing the primary importance of technical advances for any society. The first national USSR policy directed towards electrification and development of heavy industries dramatically altered the Soviet communist states and resulted in USSR becoming one of the largest political powers of the world by the middle of the XX century. Energy sector thus turned into one of the most important “commanding heights” of the country’s economy, also underpinning its military strength (Dienes and Shabad 1979).

Implementation of GOELRO plan in Ukraine transformed the republic’s infrastructure and because of the vast resources spread all over its territory, Ukrainian SSR became a “bread basket” of the Soviet Union in many senses of this commonly used expression. The corresponding transformations of the Ukrainian energy system are described and discussed further.

Fuel supply in 1940 – 1980

As electrification of the Soviet Union was progressing and industrial production growing, levels of fuel extraction in Ukraine were reaching unprecedented levels. Table 10 shows how oil, gas and solid fuel supply was changing during and after the World War II. Between 1940 and 1970 oil extraction increased 40-fold, gas extraction 120-fold, coal production 2.5-fold. Remaining one of the most important coal republics of the USSR, Ukraine also became one of the Union’s major oil and gas producers during 1960s-1970s. The intense extraction of oil and gas, however, caused a rapid depletion of the resources and a further decline in their production (see Sections 4.2 and 4.3 for more details).

Coal production peaked in the beginning of 1980s at just above 220 Mt and also started its sharp decline afterwards (see Section 4.2). In this way, 1960s-1980s can be referred to as a

‘golden age’ of conventional fuel extraction in Ukraine with a boom of respective energy industries and a rapid development of the country’s energy systems.

Table 10. Fuel extraction in Ukrainian SSR 1940 – 1978

| Type of energy resource | 1940 | 1945 | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 | 1976 | 1977 | 1978 est. |
|---|------|------|------|-------|-------|-------|-------|-------|-------|-------|--------------|
| Crude oil, mln metric tonnes | 0.35 | 0.25 | 0.29 | 0.53 | 2.2 | 7.6 | 13.9 | 12.8 | 11.6 | 10.5 | 9.5 |
| Natural gas, billion m ³ | 0.50 | 0.78 | 1.53 | 2.93 | 14.3 | 39.4 | 60.9 | 68.7 | 68.7 | 67.0 | 64.0 |
| Coal, mln metric tonnes | 83.8 | 30.3 | 78.0 | 126.0 | 172.0 | 194.0 | 207.0 | 216.0 | 218.0 | 217.0 | 211.0 |
| Coking coal, mln metric tonnes | 27.3 | 10.5 | 27.3 | 42.1 | 62.0 | 77.0 | 80.7 | 84.7 | 84.3 | 83.1 | |
| Peat, mln metric tonnes | 3.54 | | 2.93 | | 4.66 | | 4.08 | 4.14 | | | |

Data source: Dienes and Shabad 1979

Energy institutions

As energy systems were growing in both scale and number within the Soviet Union, some large and powerful energy institutions influencing the future of the Soviet energy systems were formed, including the institutions listed in Table 11 below. Among others, a number of specialized machine-building and construction ministries and institutions were involved in energy sector activities (Ananiev *et al.* 1977; Dienes and Shabad 1979). All these institutions were responsible for both production and development of possible alternatives for future energy projects. Thus, they conducted a whole range of activities: from energy-related research, modelling and planning to actual development. Gosplan played a role of a coordinating and decision-making institution incorporating the alternatives into the national

five-year plans. At the same time, high-ranking members of the mentioned above ministries were also often members of Gosplan (Dienes and Shabad 1979).

According to Dienes and Shabad (1979), end of 1970s saw a very intense “... controversy and lobbying among the appropriate [energy] ministries, planning and research institutions and regional interest groups ... than at any time in the post-Stalin years”. The debate had mainly to do with the speed of development, feasibility and adequacy of the growing role of hydrocarbon resources (gas and oil) compared with coal, while nuclear and unconventional energy resources were also growing in application scale and importance. Many research institutions and ministries were either openly or “silently” taking part in the discourse; not surprisingly, many of them were showing loyalty and long-term commitment to the given research fields.

Table 11. Major energy institutions of Ukraine and USSR before 1991

| Name of institution | Date of establishment | Short description |
|---|-----------------------|---|
| Ukrainian Academy of Sciences | 1918 | Established by V. Vernadsky and other Ukrainian scientists |
| USSR Academy of Sciences | 1925 | Energy departments formed shortly |
| Ministry of Oil Industry | 1939 | |
| Ministry of Geology | 1946 | |
| Ministry of Coal Industry | 1948 | formed on the basis of the National Commissariat of Fuel Industry |
| Ministry of Medium Machine Building | 1953 | |
| Ministry of Petrochemical and Oil Refining Industry | 1954 | |
| Ministry of Power Industry and Electrification | 1962 | formed on the basis of the National Commissariat on Power Plants and Power Industry |

| Name of institution | Date of establishment | Short description |
|---|-----------------------|---|
| Ministry of Gas Industry | 1965 | |
| Ministry of Nuclear Energy | 1986 | |
| Ministry of Nuclear Energy and Industry | 1989 | Formed on the basis of the Ministry of Medium Machine Building and the Ministry of Nuclear Energy |
| Ministry of Oil and Gas Industry | 1989 | Formed by unification of the Ministry of Oil Industry and the Ministry of Gas Industry |

Data sources: Ananiev *et al.* 1977; Dienes and Shabad 1979; Ivkin 1999

III Years of independence: 1991 – 2013

In the early 1990s, after the period of a rapid revolution and collapse of the USSR, like most of other post-Soviet states, Ukraine suffered immense output declines, hyperinflation and weakening of its economy. In eight years, between 1990 and 1997, electricity production decreased 1.7 times, domestic natural gas extraction 1.6 times and coal extraction halved (see Figure 12). The economy started recovering only in 2000s; the levels of production, however, never reached those of the late Soviet decades.

The crisis, however, also brought some positive effects: emissions to environment decreased dramatically and had halved by 1997 (see Figure 13). As an ‘economy in transition’, Ukraine became an Annex I party to the UNFCCC Kyoto Protocol, which allowed the country to participate in the international emissions trading and joint implementation under the Protocol. In 1990 Ukraine was the fifth largest contributor to climate change among fourteen Annex I countries, and pledged for 0% stabilization of its emissions until 2012, and -14% reduction until 2020 taking 1990 as a baseline year (IISD 2013).

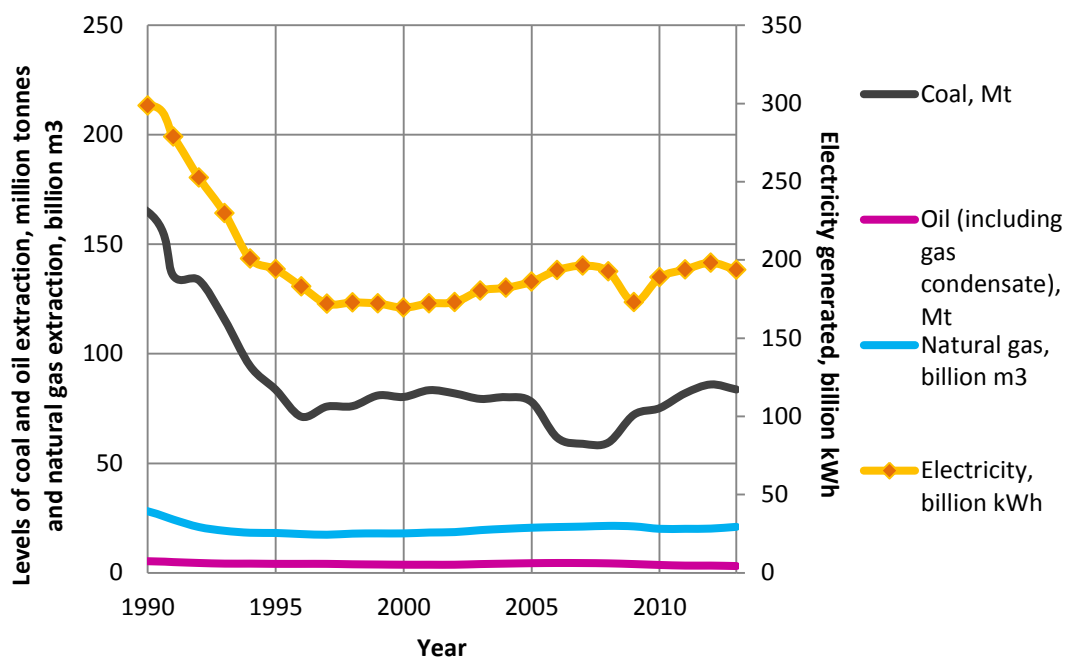


Figure 12. Extraction of coal, oil, gas and generation of electricity
in Ukraine in 1990 – 2013

Sources: MECIU 2014b

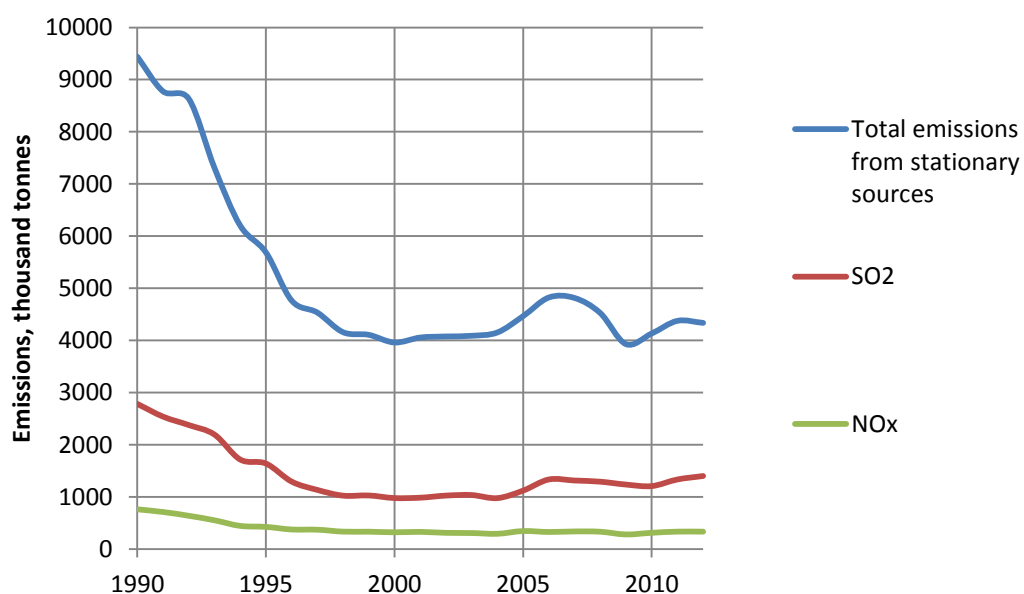


Figure 13. Emissions from stationary sources in Ukraine in 1990 – 2012

Data source: UKRSTAT 2013a

Together with the economic calamity, collapse of the highly centralized Soviet system brought an “institutional void”: weak institutions and state apparatus, which were largely fragmented and lacked technical expertise at all levels (Kudelia 2012; Kuzio 1998). The Soviet legacy also included a strong autonomous network of rapacious elites consisting of four main groups:

- managers of large state enterprises (the so-called ‘red directors’);
- chairmen of collective farms (agricultural lobby);
- komsomol (youth leaders division of the Communist Party of the USSR) who turned into bank entrepreneurs;
- nomenklatura insiders (people holding key administrative positions in various sectors, on both national and regional levels) (Kudelia 2012).

Gorbachov’s economic liberalization policy in 1980s allowed the actors from these groups to come up with a number of rent-seeking schemes and make fortunes, mostly by using state resources and the existing power vacuum (Aslund 2009). The hyperinflation of 1990s, which implied substantial price differentials on commodity and energy products, allowed the business groups to earn rents from foreign trade arbitrage, which strengthened their position in Ukraine’s politics and economy (Aslund 2009; Kudelia 2012). All of Ukraine’s presidents were either directly or indirectly related to these groups and were supporting the informal institutions and schemes created by their predecessors in many economic sectors and activities, including the industrial sector, coal and gas supply and others (D’Anieri 2012; Kuzio 2012b).

The current state of the energy sector of Ukraine can be characterised by high energy intensity, low effectiveness, declining production of gas resources, support of supply-side rather than demand-side policies, poor transparency in terms of control and accountability, large energy consumption subsidies and domination of state entities in energy provision spheres (see next paragraphs).

Ukraine's economy is one the most energy intensive in the world: in 2006, 0.5 toe (and 0.55 toe in 2010) was spent per \$1,000 of GDP, which is almost triple of the EU's energy intensity (0.18 toe/\$1,000) and more than a double of the world's average (0.21 toe/\$1,000) (IEA 2006; Zabutyi 2013). The country also ranks six after the USA, Russia, Canada, Germany and Great Britain in consumption of natural gas worldwide (Omelyanchuk 2010). An overall structure of final energy use in Ukraine is given in Figure 14. Natural gas is a major energy source in the country, while shares of heat power, oil products and electricity make between 15 to 17% of the total final energy use each – almost half of the natural gas share. Ukraine can be considered an energy deficient country, where domestic resources can supply roughly 45% of the national energy needs (Winkler *et al.* 2013).

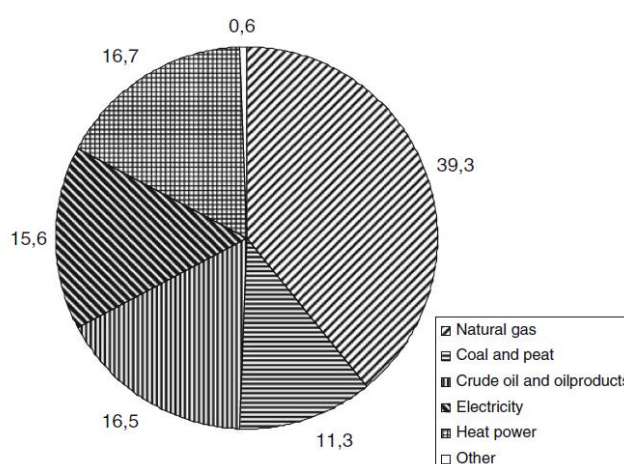


Figure 14. The structure of final energy use in Ukraine, 2010

Source: Winkler *et al.* 2013

As fuel/energy consumption for the needs of power and heat generation is concerned, nuclear, coal and natural gas are the three types of fuel/energy, which take the largest share in the sector - more than 97%, while use of renewable energy at Ukrainian power plants is limited to 3% (see Figure 15 below). Electricity and heat produced at the power plants, together with other types of fuel/energy, go to the final consumers: industries, transportation, public sector,

agriculture and others (see Appendix, Figure A.6 – A.10). Patterns of final consumption and use were described previously in the Sections 4.2 – 4.8.

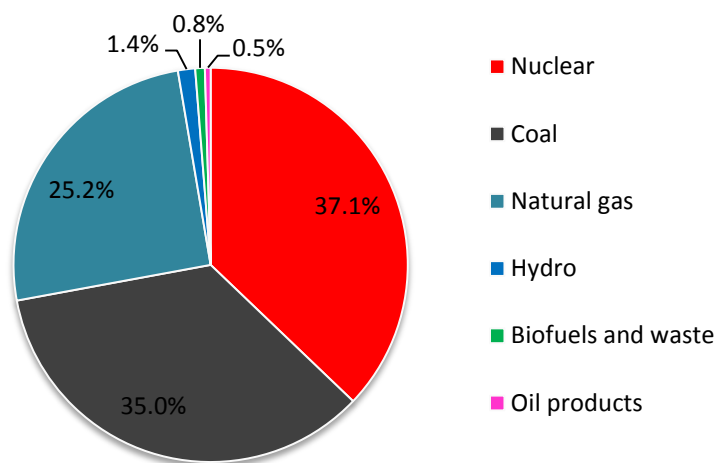


Figure 15. Fuel/energy used at power plants of Ukraine, 2011

Data source: www.iea.org/Sankey

Impact of Ukraine’s energy sector on environment is also becoming larger as industrial production is recovering after the financial crisis of 2009 and country’s energy generation capacities are becoming outdated. The impact is thoroughly estimated by the annual national and regional (oblast) reports “On the state of environment”. The latest national report (MENRU 2012) identifies industrial, power generation and residential sectors as the ones with the highest levels of negative environmental impact. Industrial sector consumes as much as 41% of the country’s total energy resources (MENRU 2012). Thus, eastern part of Ukraine due to a high concentration of industries has some of the highest air, soil and water pollution levels (see Appendix, Figure A.5). The mentioned report also recognizes the urgent need to increase energy efficiency in all economic sectors and enhance energy security of the country by decreasing gas imports, which resonates with the main goals of the “Updated energy strategy until 2030” (MECIU 2012a).

At the same time, in December 2010 Ukraine became a contracting party to the Energy Community Treaty (ECo 2009). The treaty obliged Ukraine to give new commitments on development of the country's domestic energy resources, while compiling with the European legislation, promoting a competitive energy market, developing the energy efficiency potential, ensuring attractive investment conditions for private investments and diversifying the sources of imported energy (EC 2012). For example, one of important EC directives, which Ukraine had to adopt before 1st January 2014, was a directive on reduction of GHG emissions by development of the country's bioenergy potential and technologies, which should comprise a substantial share in the national energy mix by 2017 (Geletuha *et al.* 2014).

4.2. Coal energy system

4.2.1. History

The development of coal mining in Ukraine was started by the Russian tsar Petr I (1672 – 1725), who turned his attention to the samples of the local coal in the Donbas region during his Azov campaign in 1696: “This mineral will be of use, if not to us, then to our descendants” (Plachkova *et al.* 2012). Later on, Petr I started actively pursuing a policy toward development of mining activities in different parts of the Russian Empire, which resulted in discovery of coal deposits in Donets basin in 1721, as well as other deposits near the Rivers Don and Dnieper. In 1722 the tsar signed a decree on the foundation of the Donets coal basin, which later on fuelled the first iron foundry in the region – Lugansk cast iron factory founded in 1799 (Plachkova *et al.* 2012). This event also marked an important milestone in development of energy in Ukraine: the start of transition from firewood and charcoal to coal (see Appendix, Table A.2).

Thus, the western part of Donbas became the first and the oldest centre of coal production in the Russian Empire and already in 1913 it was a source of 87% of all the coal consumed in Russia (EIU and CDCP 1956). Large-scale mining started here already in 1860s, simultaneously with introduction of a coke-smelting process for iron and steel manufacturing (Dewdney 1982). Linked later by railways with a major iron ore centre in Krivyi Rih, as well as with several other towns along the Dnieper bend, the region was quickly developing as an important centre of iron and steel production. For many years Donbas had been practically the only source of good coking coal for the Russian Empire and later the USSR. However, during the World War II Donbas was fully occupied by the Germans and ceased to supply coal for the Soviet consumption, which provided USSR a stimulus for development of other coal areas (EIU and CDCP 1956). Despite the growth of importance of other coal fields in the Soviet Union (in Urals, Kuzbass, Pechora), and many physical difficulties connected with exploitation of Donbas mines (thin and faulted seams, increasing depth of mining), the excellent quality of its coal kept the production at a very high level up until the collapse of the Soviet Union.

Industrial development of the western part of Ukraine started later than of the eastern part due to an absence easily accessible local energy resources up until the beginning of 20th century. A hypothesis about existence of coal resources within the Volyn-Podolsk plate (see Figure 5) was brought forward in 1912 and the first preliminary drilling started only in 1938 (Biletsky *et al.* 2002). Geological surveys showed that the total coal reserves of the Lviv-Volyn basin made 1.75 billion tonnes (Biletsky *et al.* 2002). Exploration of the basin launched with extraction of brown coal after the World War II and by 1960s the work was reoriented into mineral coal production (Plachkova *et al.* 2012). Quality of the coal appeared to be lower than that of the Donetsk basin, which identified its main application as power-generating coal. Development of the Lviv-Volyn basin contributed to improvement of the fuel balance of

western Ukraine, establishment of new industrial complexes and emergence of new urban settlements (e.g., Novovolynsk, Chervonograd).

Intensive exploitation of the Dnieper brown coal basin resources, which were known since the end of 18th century, started after the World War II. Due to the low calorific value of brown coal it has mainly been applied for production of brown coal pellets, which were used by population for various domestic needs. Similarly to the brown coal, peat resources of Ukraine have been used for decades for small-scale power production. Peat was usually turned into pellets and then used as a fuel in local boiler plants located not far from the peat mining sites.

Coal production in Ukraine peaked in the end of 1970s - beginning of 1980s exceeding 200 Mt per year with the highest level of production of 218 Mt, or 302 Mt including coking coal, in 1976 (see Table 10; RC 2003). Until the 1970s, three quarters of the total amount of electricity generated in Ukraine was produced at coal-fired power plants (Plachkova *et al.* 2012). The decline of coal production, which started in the end of the 1970s, was caused by discovery of enormous oil and gas resources in Western Siberia and subsequent change of energy policy priorities. Coal industry started receiving less financial support from the state, which resulted in a gradual deterioration of manufacturing conditions, decrease in labour productivity, escalation of emergency and injury cases, reduction of the overall production and degradation of the social sphere of coal regions and settlements (RC 2003). The easily-accessible coal deposits were also gradually exhausted, which made mining for coal more dangerous and increasingly difficult. During the 1980s, the crisis trends in the coal sector became static, and by the end of the decade coal industry and economic sectors related to it (mining, metallurgy, machine building) had seen an appearance of a whole network of intermediaries, many of which were semi-criminal businesses organized to shift a part of production, and thus respective profits, into a 'shadow' turnover (RC 2003). Consequently, in

1990 coal production in Ukraine dropped to 165 Mt, labour productivity fell down to the level of the 1940s and share of coal in fuel and energy balance of USSR made only 19% in comparison to 66% in 1955 (RC 2003).

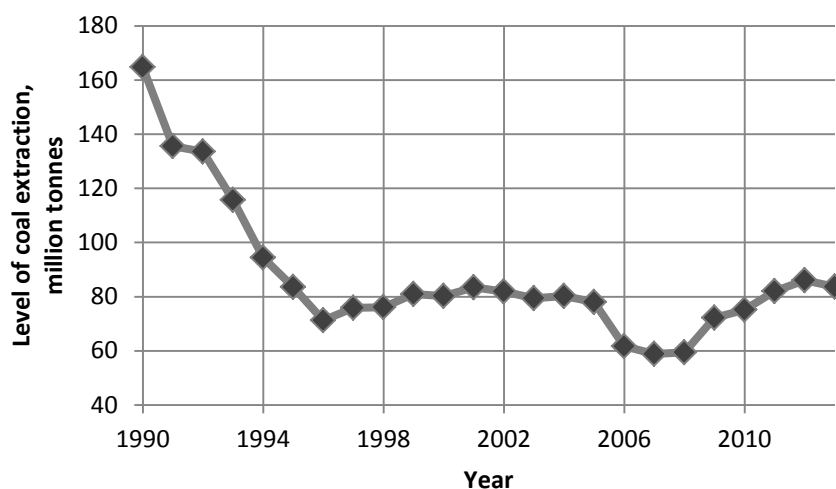


Figure16. Extraction of coal in Ukraine in 1990 - 2013

Data sources: CMU 2001; Kabak and Kornilova 2003; Kondrat and Serednytsky 2013;

MECIU 2014b; Tkach 1997; UKRSTAT 2013b

After 1991, when Ukraine gained its independence and plunged into a long-term economic recession, annual coal extraction decreased even more, down to 50 - 80 Mt during 1990s – 2000s (see Figure 16 above). An overall state of the coal industry stays unsatisfactory and continues worsening since 1980s, as the technical conditions for coal production increasingly become dangerous and ineffective.

4.2.2. Current state

In 2013, Ukraine extracted 84 Mt of coal (24 Mt of coking coal and 60 Mt of energy coal) (MECIU 2014b). Coal is extracted at about 160 mines, out of which about 60 contain high-quality anthracite coal (Kochura 2012). Coking coal is extracted at 46 mines and is in a deficit in the last years due to the positive dynamics of iron and steel production in the country, deteriorating technological conditions at state coal mines and thus decline of total production volumes, small amounts of available domestically low-sulphur coal, which is required for steel

production (Kochura 2012). Thus, on the world energy market Ukraine is both an importer and exporter of coal. Coal is usually imported from Russia and Kazakhstan and exported to a whole range of countries, including European states and Turkey (Ogarenko 2010).

For many years coal energy system and coal industry have been in a crisis condition. Most of the coal industry enterprises are still owned by the state and are highly subsidised; price of coal on the market for many years has been higher than the prime cost of coal production. One of the main reasons for this discrepancy is very high prices for mining equipment and machinery dictated by private companies, which are mostly monopolists in this industrial niche in Ukraine (Ogarenko 2012; see Figure 17 below). According to CR (2003), private subsidiary companies with the help of state executive authorities monopolized both the coal sales market and the market of manufacturing of mining equipment and materials. As a result, the private stakeholders are receiving very high revenues, while mines and the state bear substantial losses and continue to increase subsidies in the sector (Cherkasenko 2012).

Many environmental issues are closely related to the coal sector. Coal industry enterprises are emitting more than 1 Mt of hazardous substances every year, including: 38 thousand tonnes of particulate matter, more than 122 thousand tonnes of sulphur oxides, 150 thousand tonnes of carbon oxides, more than 9 thousand tonnes of nitrogen oxides, more than 450 thousand tonnes of hydrocarbons and other (Plachkova *et al.* 2012). Most of the substances (about 80%) are released into the atmosphere with exhaust gases of boiler plants and drying installations of processing factories using coal as a fuel (MENRU 2012). High level of concentration of coal mining and processing enterprises together with the direct coal consumers (power and heat generation, iron and steel industry) in the eastern and southern regions of Ukraine create deteriorating environmental condition in these areas (see Appendix, Figure A.5).



Main consumers of coal are heat and power generation sector (71% of total coal consumed) and iron and steel industry (21%) (see Figures 18). The former produces electricity and heat used by different sectors of economy, which increases further the share and role of coal in these sectors (see Appendix, Figures A.6 and A.7). Most of the heat generated by combustion of coal, as well as other energy resources, is further consumed by residential and public services sectors (more than 50%) and by chemical, petrochemical, iron and steel, and food industries (more than 30%).

In heat and power generation share of coal as a primary fuel increased from 31% in 1991 to 82% in 2012, largely replacing oil and gas (see Appendix, Table A.3). Share of coal in the fuel balance of five main thermal generating companies of Ukraine (electricity generation only)

currently exceeds 97% (Volchyn *et al.*, 2013). Moreover, in the Ukrainian heat production industry most of the boilers are designed exclusively for coal combustion.

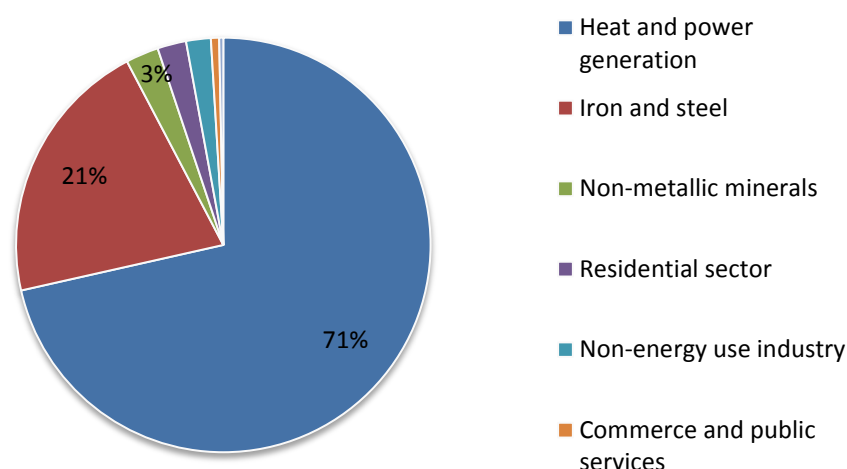


Figure 18. Coal consumption by economic sectors of Ukraine, 2011

(total consumption: 31.2 Mtoe)

Data source: www.iea.org/Sankey/

Metallurgical industry is one of the most important sectors of Ukraine's economy responsible for some 37% of the country's exports (Volchyn *et al.* 2013). Consuming both coking coal and secondary energy resources originating from coal combustion, electricity and heat, iron and steel industry is largely dependent on domestic coal production. Moreover, coal-bound sectors of economy annually create hundreds of thousands of jobs, making the coal energy system also extremely important socially.

Coal is an important strategic fuel for Ukraine and its explored domestic reserves are expected to last for some 200 years at the current rate of production (Volchyn *et al.* 2013). The overall estimated reserves make about 100 billion tonnes, including more than 50 billion tonnes of explored reserves, which makes Ukraine one of the most coal-rich countries in the world (Omelyanovsky *et al.* 2010). Therefore, increasing the use of coal is often seen as one of

required steps towards enhancement of the country's energy security (MECIU 2012a; Volchyn *et al.* 2013).

4.2.3. System governance

The coal energy system is both privately and state-owned with the top governing position belonging to the state entities: to Parliament of Ukraine, Government of Ukraine and the Ministry of Energy and Coal Industry of Ukraine and the National Electricity Regulatory Commission of Ukraine. During the recent decade energy policy of the Ukrainian government has been aimed to adapt coal enterprises to the market environment with an on-going restructuring and privatization of the coal industry. Among the most important recent developments are liberalisation of Ukraine's coal market and "... considerable enhancement of possibilities for private-sector participation" (Cherkasenko 2012). However, as of 2014 the number of state-owned enterprises in the coal sector is very high and makes more than 200, in comparison to 44 in the nuclear energy sector and 30 in oil and gas sector (MECIU 2014a).

The most influential private actor within the coal energy system is DTEK (Donbas Fuel-Energy Company), owned by a businessman and Ukraine's richest man Renat Akhmetov (see Appendix, Tables A.4 and Table A.5). DTEK Holding Ltd is the largest private vertically-integrated energy corporation of Ukraine, created in 2005, and during the last years it has been one of the top Ukrainian and Central European companies by revenue (see Appendix, Table A.5). DTEK is a part of the financial industrial group "System Capital Management" and its enterprises constitute an energy supply chain from extraction and enrichment of coal up to power generation and sale of electricity. The corporation continues to accumulate energy enterprises and businesses: e.g., in February 2014 "DTEK Shidenergo" acquired an access to the interstate electricity transmission lines for export of electricity from Ukraine to Moldova and Belarus (Oblenergo 2014). Operation of all the DTEK's energy assets is generally seen by energy experts as successful: the effective and advanced management, together with

investments in upgrading of energy infrastructure, made coal-mining more competitive and increased effectiveness of coal-based power generation (EURACOAL 2014).

4.2.4. Vulnerabilities

Although coal resources are abundant in Ukraine, there are certain energy security issues connected to disruptions in the coal energy system. Due to the high demand for coal in Ukraine and a whole range of important consumers directly dependent on coal (see next paragraph), any reduction of domestic coal output, or/and increase of demand, causes a deficit of the product and a subsequent need to import it from other, primarily CIS, countries. In 2010, for example, coal output fell to 55 Mt, while consumption increased to 67 Mt. As a result, 3 Mt of power coal and 9.1 Mt of coking coal had to be imported (Kochura 2012).

Coal energy system and economic sectors dependent on it operate inefficiently, use outdated technologies and equipment. The number of technical failures at Ukrainian coal-fired TPPs is very high (see Appendix, Table A.4) and continues to increase. In 2012 an average number of emergency shutdowns was the highest in the history of operation of Ukrainian TPPs (Volchyn *et al.* 2013). From this perspective, the system is extremely vulnerable to possible unexpected interruptions caused by large-scale accidents, breakdowns and other types of failures. Elimination of these by modernization and rehabilitation of existing facilities would dramatically increase system's reliability and durability.

These measures, however, may not be enough to completely ensure safety of the system. Lack of well-trained and educated professionals and a human factor in general, plays a crucial role in functioning of the system. A recent accident at Vuglegirska TPP (Donetsk region), which caused a fire at the plant, its shutdown, destruction of two power units and a death of one of the workers, was caused by an inexperienced worker who breached health and safety rules (UK 2013). Therefore, poor quality of education and training, reduction of staff and

discharge of older experienced personnel caused by sector's privatization, also lead to the growth of technical vulnerability of the system.

4.3. Oil energy system

4.3.1. History

The first extraction of oil in Ukraine took place already in 1771, in the town of Kolomiya (Ivano-Frankivsk region) (Plachkova *et al.* 2012). From the end of 19th - beginning of 20th century oil production was taking place at the Boryslav and Drogobych fields, which produced 2 Mt of oil in 1909 (NAFTOGAZ 2012). However, the fields fell under the Ukrainian SSR only in 1940, after annexation of some of the eastern Polish territories to the USSR, when their oil production level declined to 350 thousand tonnes (Dienes and Shabad 1979).

Oil and gas industries started being intensively developed in Ukraine during the post-war period due to discovery of a number of hydrocarbon resources at the *Carpathians*, in *Dnieper-Donets rift* and in the *Black Sea – Crimean* oil and gas provinces (see Figures 5 and 7, Section 4.1). The new Ukrainian fields exploited during 1950s-1960s included Dolyna field in Ivano-Frankivsk region, Pryluky field in Chernigiv region, Myrgorod field in Poltava region and Akhtyrka in Sumy region. Ukrainian oil production peaked in 1972 at 14.5 Mt and started its steady decline (see Figures 21 and 19 below and Table 10 in Paragraph 4.1.2). According to Dienes and Shabad (1979), Ukraine's contribution to Soviet oil production was never large and didn't exceed 4% of USSR's total oil production. At the same time, Ukrainian crude oil was an attractive resource due to its high quality and convenient location near the European SSR markets. Between 1985 and 2013 oil production declined from 5.8 Mt to 3.3 Mt, and its use as a primary fuel for power and heat generation was minimized.

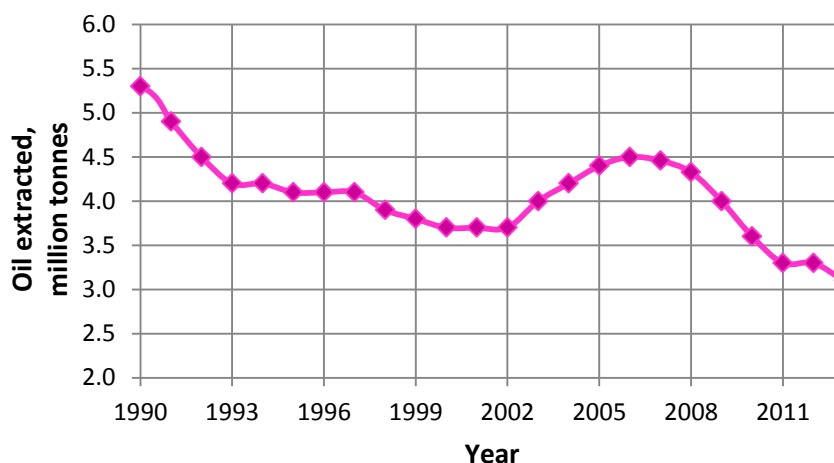


Figure 19. Oil extraction in Ukraine in 1990 - 2013

Data sources: CMU 2001; Kabak and Kornilova 2003; Kondrat and Serednytsky 2013;

MECIU 2014b; Tkach 1997; UKRSTAT 2013b

4.3.2. Current state

While oil demand of Ukraine makes ca. 28 Mt, only 15-18% of the amount is supplied domestically (MECIU 2012b; MECIU 2014b). Oil and gas condensate are supplied to a gas processing plant, Shebelynsky GPP, and six refineries (see Appendix, Table A.6 for more information), which produce a large amount of oil products, including motor gasoline, diesel fuel, stove and fuel oil, oil asphalts, lubricants, liquefied gas, benzene, paraffin and other (QCE 2012). Capacity of the refineries is excessive and makes 51 Mt; however, the capacity is only partially used due to low efficiency of the refineries, which require an urgent modernization, shortage of crude oil and lack of Ukrainian access to Caspian oil (Herasimovich 2008; MECIU 2012b; QCE 2012). Because of unstable foreign exchange rate and significant reserves of “expensive” oil products, local oil producers are less competitive and presence of foreign fuel on Ukrainian oil market increases (Herasimovich 2008).

85-90% of oil imported to Ukraine comes from Russia and Kazakhstan via an existing system of oil pipelines, which is operated by OJSC “Ukrtransnafta” (MECIU 2012b). The system consists of 19 trunk pipelines with a total length of more than 4,700 km, 51 oil transfer

stations, 11 tank farms with reservoirs of the total capacity of more than 1 million m³ and a series of pump units supporting the oil transfer. Flow rate of the Ukrainian pipeline system at its input is 114 Mt per year and at the output 58 Mt per year (MECIU 2012b). Ukraine is an important oil transit country transporting annually more than 15 Mt of oil to Europe (MECIU 2014b).

The consumers of oil and oil products are diverse and include practically all the major sectors of Ukrainian economy. The major oil consumer is a transportation sector, which is responsible for than 68% of oil use (see Figure 20). Agriculture and non-energy use sectors go next with the corresponding shares of 11% and 7%. Oil and oil products is a prevailing type of energy in the following sectors of economy: transport, agriculture and forestry, construction (see Appendix, Figures A.8 – A.10). As an energy fuel, oil also plays an important role in power generation and mining, sectors and a range of other industries, such as iron and steel production and chemical industry.

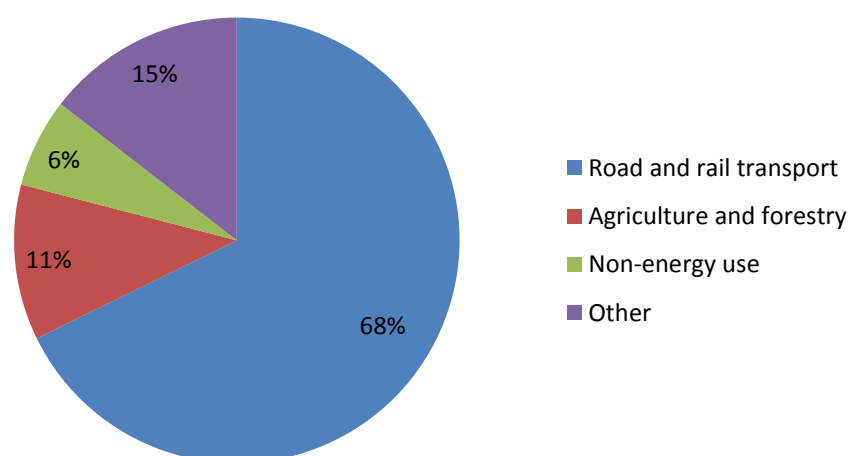


Figure 20. Oil consumption by economic sectors of Ukraine, 2011
(total consumption: 12.4 Mtoe)

Data source: www.iea.org/Sankey/

In power generation sector oil is mostly applied as a secondary fuel. Share of oil as a fuel for TPPs decreased from 20.8% in 1991 to 0.1% in 2012 (see Appendix, Table A.3). It was largely replaced by natural gas and fuel. Two 800 MW oil-gas power units located at Vuglegirska TPP (“Centrenergo”), which are the largest ones among all the units of Ukrainian thermal power plants, have been kept out of operation for more than 15 years due to a very high cost of their operation and power industry overload with high-capacity power units (mostly of NPPs).

As Leung *et al.* (2014) stated, oil plays a unique role in most of the emerging economies of the world, including Ukraine, due to the following reasons:

- 1) it largely dominates such important economic sectors as transportation, food (agriculture) and others, and lacks substitutes;
- 2) its use is growing due to the growth in demand for mobility services;
- 3) its global and national resources are limited.

Oil energy system, unlike any other, has the largest amount of connections to other sectors of Ukrainian economy (see Appendix, Figures A.8 – A.10) and plays the most important role in the transportation sector, which accounts for more than 60% of total oil consumption.

4.3.3. System governance

The key state entities managing the oil sector of Ukraine are the Parliament of Ukraine, the Cabinet of Ministers of Ukraine, the Ministry of Energy and Coal Industry of Ukraine and the National Electricity Regulatory Commission of Ukraine. The latter is responsible for regulation of oil market entities, implementation of pricing and tariff policies, protection of the rights of oil customers, coordination of activities of state authorities in market regulation questions, ensuring efficient functioning of commodity markets (MECIU 2012b). The Ministry of Energy and Coal Industry, in turn, bears a responsibility to establish development priorities

of the oil sector while ensuring legal and normative regulation. The Ministry is also a major decision-maker in various activities taking place in the oil sector (e.g., operation of oil fields) and issues appropriate permissions and approvals for these activities.

The National Joint-Stock Company “Naftogaz” plays a crucial role in the oil sector. Being subordinated to the Ministry of Energy and Coal Industry, it is directly concerned with extraction, transportation and refinement of oil and oil products in Ukraine. The company also runs a number of gas processing plants, which produce liquefied natural gas, motor fuels and other types of oil products from gas, oil and condensate. In 2012 Naftogaz ranked 2nd in the list of top companies in Ukraine and 5th in the top Central European companies by revenue (see Appendix, Table A.5).

4.3.4. Vulnerabilities

The decreasing production of domestic oil (see Figure 17) and its extreme importance for the majority of economic sectors of the country makes the oil energy system highly vulnerable to any interruptions of external supply. In order to enhance the level of oil security, in 2009 the Cabinet of Ministers of Ukraine adopted a Concept of Creating a Minimum Oil and Oil Products Stock by 2020 (MECIU 2012b). Taking into account domestic oil extraction volumes, the stock shall guarantee oil and oil products availability for a period of 90 days.

Ukraine is also highly dependent on oil imports from only two countries, Russia and Kazakhstan, which shows the need of diversification of oil supplies in the future. In order to address this issue, the country is involved in implementation of a project of creation of a new oil transit corridor from the Caspian region to Ukraine and further to European markets, which also allows to bypass the overburdened Turkish straits (MECIU 2012b). The project implies transportation of Azerbaijan oil through the existing oil pipelines to the Georgian harbour of “Supsa”, from the harbour the oil is to be shipped by tankers to the Odesa harbour “Pivdenny” (Ukraine), where it would enter the existing Odesa-Brody oil pipeline and transported to

Poland and further to Europe through the Brody-Plock pipeline, which is yet to be constructed. Implementation of the project shall allow the increase of energy security of Ukraine and other European states, as well as to affirm a role of Ukraine as a reliable oil transit country.

4.4. Gas energy system

4.4.1. History

The birth of gas industry in Ukraine is related to the development of Dashava gas field in 1921 in the western Ukraine (territory of Poland at that time) and construction of the first gas pipeline Dashava-Stryi in 1924 (Diyak *et al.* 2009). In 1940 Dashava gas field located in the Carpathian region was acquired by the USSR from Poland. Ukraine was among the first Soviet republics where gas production was picking up in speed very fast. After the II World War the district of the Carpathians was expanded further by the Soviet Union and more gas fields commenced their operation, including Opary (1940), Ugershko (1946), Bilche-Volitsa (1949) and Rudki (1957) (Dienes and Shabad 1979). As a result, the first international gas exports in the world took place from the territory of Ukraine: in 1945 natural gas started being supplied from Dashava and Opary gas fields to Poland (NAFTOGAZ 2012). In 1948 Dashava field was connected with the republic's capital Kyiv (Diyak *et al.* 2009). As production from the fields was escalating (Table 4.1.2), the Carpathian gas province's importance was growing simultaneously. Due to this, a decision was taken to construct long-distance transmission mains connecting the western Ukrainian gas province with Moscow (completed in 1949), Minsk (1960), Vilnius (1961) and Riga (1962) (Dienes and Shabad 1979).

Development of gas resources switched to the east of Ukraine in 1956 when Shebelinka field in the Kharkiv region started being exploited. Its estimated resources were large: 530 billion m³ (Dienes and Shabad 1979). Two other gas fields, both located in Kharkiv region, were developed in the 1970s: Yefremovka (70 billion m³) and Krestishche (100 billion m³).

These developments were crucial in the view of a steep decline of production at Shebelinka field after 1972. As it was shown in Table 10 (Paragraph 4.1.2) and Figures 21 and 22, natural gas production in Ukraine peaked in 1975-1976 and was steadily declining after up to mid-1990s. Highest level of gas production, namely 68.7 billion m³, was achieved in 1975 (NAFTOGAZ 2012). Since the early 2000s, domestic natural gas extraction has been fluctuating between 18 and 22 billion m³ (see Figure 22).

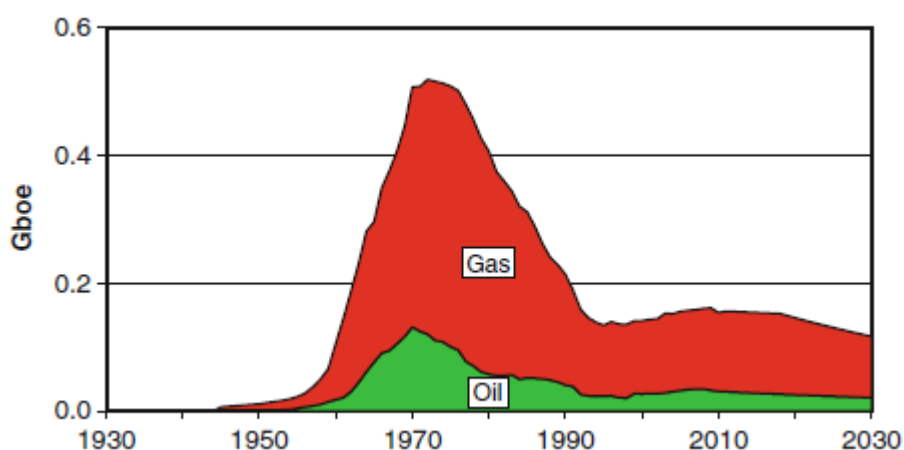


Figure 21. Ukraine oil and gas extraction 1930 to 2030

Source: Campbell 2013

The above mentioned facts made Ukraine “the Soviet Union’s principal gas-producing region in the 1960s and early 1970s” (Dienes and Shabad 1979). Consequently, Ukraine developed a high-capacity gas transmission system with significant gas exports to the east and west of Europe. Thus, in the middle of 20th century natural gas of Ukrainian origin was transported to Russia, Belarus, Latvia, Lithuania, Poland, Czechoslovakia and Austria. During this time a number of influential institutions were also formed, whose task was to deal with natural gas resources exploration, production and transmission. As it will be shown further, these institutions will continue to play an important role in Ukraine’s energy policy throughout the country’s modern history.

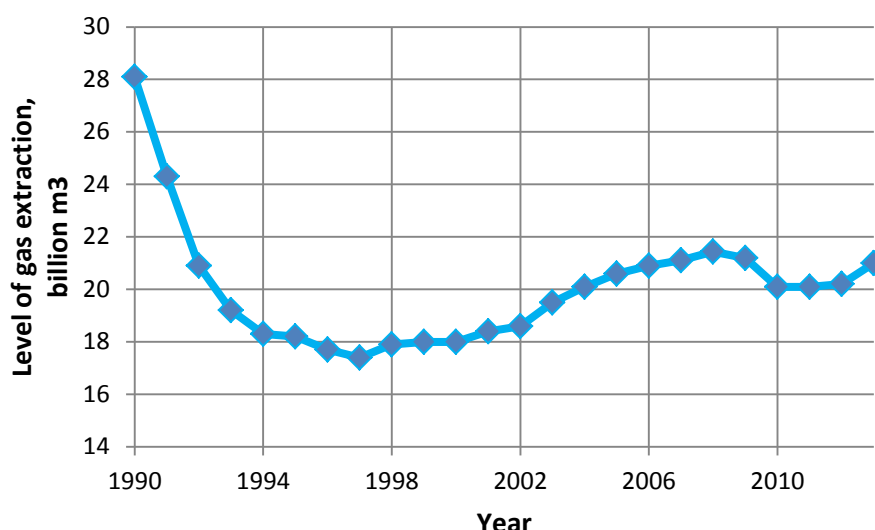


Figure 22. Extraction of domestic natural gas in Ukraine in 1990 – 2013

Data sources: CMU 2001; Kabak and Kornilova 2003; Kondrat and Serednytsky 2013;

MECIU 2014b; Tkach 1997; UKRSTAT 2013b

After the USSR collapsed, Ukraine was left with the enormous legacy: the natural gas transmission pipelines connecting Russia and Europe. This is when Ukraine's vulnerable position as a country highly dependent on the powerful neighbour's natural gas supplies and political decisions started showing up. Many disputes were taking place since the early 1990s regarding gas debts and non-payments for Russian gas. Russia was proposing to remit Ukraine's debt if it surrenders all the nuclear weapons and to delegates a full control of the Crimean Sevastopol naval base to Russia. In order to put pressure on Ukrainian leaders, for the first time Russia used its 'energy power' threatening Ukraine to cut off its gas supplies in 1993 (D'Anieri 2012). Subsequently, Ukraine capitulated and yielded to Russia's demands. The Budapest Memorandum on Security Assurances signed in 1994 between Russia, US, UK and Ukraine claimed that the former three countries "... reaffirm their commitment ... to respect the independence and sovereignty and the existing borders of Ukraine" in return of elimination of all nuclear weapons by Ukraine from its borders (CFR 1994). However, the Russian-Ukrainian gas disputes over Ukraine's gas debts and gas price were never fully eliminated. Russia cutoff its

gas supplies to Ukraine in January 2006 and January 2009, was threatening to do so many more times, and due to the on-going political crisis claimed its intentions to almost double the gas price for Ukraine from the previously set \$268.5 to \$485.5 per 1,000 m³ (BBC 2014; Kramer 2009).

4.4.2. Current state, importance and connections to other systems

In 2013 Ukraine produced 21.0 billion m³ of natural gas, consumed 50.4 billion m³ and transmitted 86.1 billion m³ (MECIU 2014b). Although Ukraine increased its gas production by 4% in comparison to the previous year, the country's domestic gas resources do not allow to meet the high natural gas demand coming from various sectors of Ukraine's economy (see Paragraph 4.4.6). Most of the imported gas originates from Russia (92% in 2013), while 3% is provided by Germany and 2% by Austria (UNIAN 2014).

Ukrainian gas transport system currently serves two main functions: natural gas transportation for Ukrainian consumers and gas transit to European states through the Ukrainian territory. The system is closely linked to gas transport system of Russia, Belarus, Poland, Moldova, Romania, Hungary and Slovakia, and is divided into three corridors by the gas transport directions: Western direction (first corridor), Southern direction (second corridor) and a system of gas transport pipelines "Northern Caucasus - Centre" (no longer used as a transit corridor) (MECIU 2012b). The gas transport system contains some 39,800 km of gas pipelines, more than 1,600 distribution and 74 compressing stations, 13 underground gas storage facilities of a total capacity of more than 32 billion m³ (Plachkova *et al.* 2012). At the intake the system's capacity is 290 billion m³ and its output is 178 billion m³ per year (including 142 billion m³ to the countries of Central and Western Europe) (MECIU 2012b; Paltsev 2014).

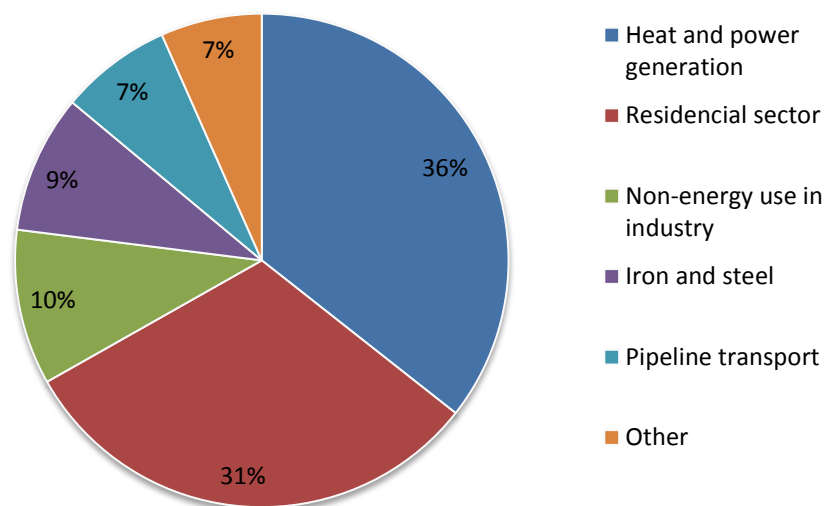


Figure 23. Natural gas consumption by economic sectors of Ukraine, 2011
(total consumption: 45.2 Mtoe)

Data source: www.iea.org/Sankey/

Main natural gas consumers are heat and power generation and residential sectors (see Figure 23). Natural gas is the main fuel used to power CHPPs of Ukraine, which provide electricity and heat for large cities and industries (see Appendix, Figure A.11 for a map and Table A.4 for CHPP examples) (MECIU 2012b). Electricity and heat generation at TPPs and CHPPs is almost fully based on the use of imported natural gas (MECIU 2012b). In the industrial sector, the largest gas consumer is iron and steel industry, followed by non-metallic minerals production (also includes minerals used in metallurgical sector), chemical and petrochemical, mining and quarrying, food, machinery and other industries (see Appendix, Figure A.9). The non-energy use of gas, which is mostly its use as a raw material in petrochemical industry, also represents a substantial share of the overall consumption.

4.4.3. System governance

Key state entities participating in management of the natural gas sector are the Parliament of Ukraine, the Government of Ukraine, the Ministry of Energy and Coal Industry of Ukraine and the National Electricity Regulatory Commission of Ukraine (MECIU 2012b). The Ministry

of Energy and Coal Industry is responsible for establishment of development priorities and ensuring legal regulation in the sector, development of target programmes, improvement of relationships between participants in the market and state monitoring of the gas sector. The latter is responsible for approval and control over license conditions for exercising various commercial activities in the gas market; securing implementation of tariff and pricing policy; promotion of competition in the gas market; approval of such procedure as: access to the unified gas transport system, establishing and reviewing of tariffs; approval of methodologies for tariff calculation of natural gas storage, transport, distribution, supply, injection and withdrawal (MECIU 2012b).

A vertically integrated national oil and gas company of Ukraine NJSC “Naftogaz” carries out a full cycle of activities from gas-related research, gas field exploration, development and production, to gas transit and storage, supply of natural gas to the customers. Production of more than 97% of all oil and gas extracted domestically is carried out by Naftogaz and its subsidiaries (MECIU 2012b):

- Ukgazvydobuvnnya, Ukrtransgaz, Gas of Ukraine – subsidiary companies;
- Uknaftogazkomplekt, Naftogazbezpeka, Ukravtogaz, LIKVO, Naukanaftogaz – subsidiary enterprises;
- Chornomornaftogaz, Ukrspetstrnsgaz – Public JSCs.

To meet its Energy Community obligations, Ukraine is planning to reform its gas sector. One of the reforms implies division of Naftogaz into three independent branches: gas extraction, transportation and supply.

Since 1991 the country’s gas system has always been in the centre of national and international attention due to its importance to various stakeholders and actors involved. Kuzio (2012b) emphasizes on domination of private interests over national interests in energy sector of Ukraine, especially as gas policy is concerned: “in the energy sector ... short term corrupt

gains from the gas trade with Russia have dominated over medium-long term investment in domestic production and energy independence”. Through the time of Ukraine’s independence decisions on gas issues (e.g., gas pricing, establishment of intermediary gas companies) were largely political, rather than economical. Thus, the current political crisis and worsening of political relations between Ukraine and Russia bring insecurity and instability to Ukraine’s gas energy system.

4.4.4. Vulnerabilities

Ukraine’s natural gas system is extremely vulnerable to a whole range of possible interruptions, which are historically caused by political decisions. Ukraine’s energy security is directly connected to the country’s gas sector. The gas system is characterised by heavy reliance on Russia in gas supply, the rising price of imported natural gas, technological and economic barriers to substituting domestic gas-based heating systems with electricity-based ones, energy losses in transit (Milstein and Cherp 2009). Historically, Russia’s attempts to raise gas prices for Ukraine were not successful, because the latter was leveraging its position as an important gas transit player (Nagayama and Horita 2014). However, as the current political tensions between Ukraine and Russia are rising, Russia’s ability to dictate its conditions are becoming as strong as never before. Possible cut offs of gas supply are threatening not only Ukraine, but many other European countries (mostly eastern and Baltic European states), some of which completely rely on Russian gas.

4.5. Hydroelectric power system

4.5.1. History

Development of hydroelectric power in the USSR started in 1920s-1930s: first stations were built in the north-west of the country in the easily developed areas, which were also distinguished by a shortage of fossil fuels required for power generation (Dienes and Shabad

1979). Capacities of the stations did not exceed 100 MW. At the same time, the cheap electricity produced by hydropower plants attracted power-intensive industries, such as aluminium.

The largest of the early Soviet hydropower plants (HPPs) and one of the largest in the world at the time was the first Ukrainian station located at the Dnieper in Zaporizhia (Ananiev *et al.* 1977). The power plant started its operation in 1932, had reached its designed capacity of 560 MW by 1939 and had been expanded to 650 MW by 1950 (Ananiev *et al.* 1977; Dienes and Shabad 1979). Due to the presence of energy-intense industries in Zaporizhia region (manganese ore, iron and steel production), the station was designed to meet base-load requirements and operated up to 5,600 hours per year (Dienes and Shabad 1979).

Further development of the Dnieper hydroelectric potential continued in 1950s. Five new HPPs were built at the river and the original station at Zaporizhia was expanded to serve peak-load requirements. Construction of the six stations was of a major importance to meet the growing electricity demand of the Ukrainian republic (Dienes and Shabad 1979).

4.5.2. Current state, importance and connections to other systems

Hydropower generation takes third place after nuclear and thermal power generation as electricity production is concerned. Installed capacity of Ukrainian HPPs makes more than 10% of the country's total (see Appendix, Table A.7). Public JSC “Ukrhydroenergo”, the country's main hydrogenerating enterprise, currently operates at two main HPP cascades at two rivers: Dnieper and Dniester. There are 103 hydroelectric generators of various installed capacities with the most powerful one of 1,500 MW located at Dniprovsk HPP (MECIU 2012b). Among the hydropower facilities, there are also more than 70 small HPPs and units of a total capacity of more than 100 MW (Plachkova *et al.* 2012). Notwithstanding the large technical potential of Ukraine's hydropower, its current use does not exceed 50% (Plachkova *et al.* 2012).

HPPs include a number of hydro-accumulating power stations (HAPPs), which play an important role in covering peak electricity demand: Kyivska HAPP, Dniestrovska HAPP and Tashlytska HAPP (see Appendix, Figure A.11). Dniestrovska HAPP is one of the largest hydro pumped storage power stations in the world with an installed capacity of 2.3 GW in generating regime and 3.0 GW in pumping (accumulating) regime (Plachkova *et al.* 2012). The HAPP together with two other accumulating plants, Kanivska and Kahovska HAPPs, are currently under construction (MECIU 2012b; Ukrhydroenergo 2014).

Starting from 1996, Ukrhydroenergo using its own funds and a credit from World Bank has been implementing a project of rehabilitation of its HPPs. The project is expected to last until 2018 and result in reconstruction of all existing hydropower units and construction of new ones, which would allow to increase annual power generation from hydro energy by 239 million kWh (Ukrhydroenergo 2014).

As it was mentioned in the history of development of hydropower energy system of Ukraine, the first and largest power plant of its kind, the Dnieper HPP, was built in the important industrial area in Zaporizhia region, in order to provide electricity supply for the local industries, such as manganese ore, iron and steel production (Dewdney 1982). Main purpose of the next HPPs built on the territory of Ukraine was to cover peak demands of the republic levelling the load curve and thus improving reliability of the whole republican energy system. This function of HPPs remained a primary one in the independent Ukraine.

Transformation of hydro energy into electricity at a power plant and consumption of the latter by various sectors of economy makes it impossible to track main consumers of hydropower as such. Therefore, only looking at electricity consumers and keeping in mind specificities of hydropower generation (e.g., the function of covering peak demand), can we identify the closest to hydropower economic sectors. Although industries are intense consumers of electricity, they generally require a stable electricity supply, which can be

provided by NPPs or TPPs, rather than HPPs. In this way, the residential, public, partially transport and agriculture sectors, are the ones most likely to produce the peak demand for electricity and thus are closely related to the consumption of hydropower (see Appendix, Figures A.8 – A.10).

In this way, hydropower plays a very important role in Ukraine's electricity system and is the one renewable system of a relatively large installed capacity. HPPs are designed to cover peak electricity demand, which is impossible for NPPs or large coal-fired TPPs. Large HPPs and hydro-accumulating power plants provide a possibility to reserve water for electricity generation when it is most needed (during peak hours, holidays etc.). Smaller hydropower facilities are also used for flood control.

Moreover, application of hydropower for covering peak demands instead of TPP units allows to save fossil fuel (coal, gas) and in this way to decrease cost of TPP operation. For example, a small-scale Yavirska HPP of an installed capacity of 450 kW allows to save 800 tonnes of coal per year, which could be burnt at a TPP of the same capacity. Together with the fact that electricity produced at HPPs is generally lower than that of TPPs (see Table A12, Appendix), the mentioned practice is crucial in the context of the state of Ukrainian energy system, where thermal power units require a substantial rehabilitation and work with a very low efficiency (Omelyanovsky *et al.* 2010; Volchyn *et al.* 2013).

4.5.3. System governance

Public JSC “Ukrhydroenergo” is a company fully owned by the state, namely by the Ministry of Energy and Coal Industry of Ukraine (Ukrhydroenergo 2014). Therefore, all the HPPs of big capacity are state-owned. The key state entities managing hydropower generation sector are the Parliament of Ukraine, the Cabinet of Ministers of Ukraine, the Ministry of Energy and Coal Industry of Ukraine and the National Electricity Regulatory Commission of

Ukraine. Ukrhydroenergo includes the following eight branches (see Appendix Figure A.11 for a map):

- Cascade of Kyiv HPP and HAPP
- Kanivska HPP
- Kremenchutska HPP
- Dniprodzerzhynska HPP
- Dnieper HPP
- Kahovska HPP
- Dniestrovskaya HPP
- Directorate on Construction of Dniestrovskaya HAPP.

Another large hydropower plant, Tashlytska HAPP, located near the city of Yuzhnoukrainsk belongs to the South Ukrainian energy complex and operates together with the South Ukrainian NPP and a small Oleksandrivska hydropower unit. The main function of Tashlytska HAPP is to cover peak demand in the south-western part of UES of Ukraine and to provide security of operation of the South Ukrainian NPP.

4.5.4. Vulnerabilities

As hydropower is a domestic renewable energy resource and all the necessary equipment and technologies for development of hydropower projects can be produced in Ukraine, energy security vulnerabilities are not significant. At the same time, while the project of rehabilitation of hydropower facilities is on-going, a substantial amount of units and technologies at HPPs is outdated and needs urgent modernisation or total replacement. For example, one of hydropower units operating in Ukraine was constructed in Germany in 1928 and shipped to the USSR in 1958 (Kalynchuk 2011). If such units continue their operation, the chance of their failure and subsequent interruptions of the energy system is unavoidable. The 2009 disaster at Sayano-Shushenskaya HPP in Russia, which was caused by a sudden vibration in the turbine

and resulted in a subsequent explosion of turbine units, widespread power failure, human deaths and environment contamination in the local area, proved that initial deficiencies of power equipment or the smallest inaccuracies during their operation can have the most dramatic results, making even such reliable systems as a hydropower system highly vulnerable.

4.6. Nuclear power system

4.6.1. History

The first nuclear reactors in the USSR were produced for military purposes. 1942 was a year when the first Soviet nuclear project was launched by Stalin's initiative. The project led to development of USSR's first military reactor in 1948, first atomic bomb in 1949 and first in the world attempt to adapt nuclear reactors to generate electricity (Medvedev 1990). Subsequently, already in 1954 USSR launched in operation the first nuclear electric power reactor (Ananiev *et al.* 1977), which determined the country's high priority directed towards nuclear research as one of the ways to maintain USSR's "superpower" status, as well as to provide the energy-poor European SSRs with locally-produced electricity.

At the beginning, nuclear research and all the nuclear projects in the USSR were kept as a "top secret" belonging to military establishment only (Medvedev 1990). In 1950s nuclear projects were designated to be controlled by two institutions: the civilian Ministry of Power and Electrification and by the civilian-military Ministry of Medium Machine Building. The latter was established in 1953 and was responsible for development of nuclear weapons, reactor technologies, fuel reprocessing, burial of nuclear waste and other related issues; the Ministry of Power and Electrification was responsible for operation of power plants, however it could not take part in any decisions as far as reactor systems were concerned (Medvedev 1990). The Ministry of Nuclear Energy of the USSR was created more than three decades later, namely in 1986, and was united with the Ministry of Medium Machine building only in 1989.

The Soviet nuclear energy programme approved in 1956-1957 included development of three different nuclear reactor types (graphite-moderated RBMK, pressurized-water VVER and fast-breeder reactors BN) giving a preference to RBMK reactors, which were relatively easier to construct and represented the only entirely Soviet technology (Medvedev 1990). This implied no need to copy or imitate western reactor models and thus greater energy security for the country. Probability of a major nuclear accident was not of a big concern in the USSR, while a number of foreign specialists were pinpointing certain shortcomings in design of RBMK reactors related to reactor safety already in 1970s (Dienes and Shabad 1979).

Nuclear history in Ukraine started with development of uranium resources in the late 1940s and included uranium ore mining and processing. The works were carried out in highly confidential conditions; environmental safety regulations were poorly followed (UATOM 2011). The city of Zhovti Vody in Ukraine became one of the most important uranium centres in the Soviet Union (see Paragraph 4.1.1. Figure 8: Zhovtorichanske field 4). The city developed rapidly after II World War, with the start of the nuclear era, from 6,522 population in the 1939 census up to 52,000 in early 1977 (Dienes and Shabad 1979). The city gained significant role as uranium mining, milling and processing operations centre.

The first nuclear reactor in Ukraine commenced its operation in 1977 in the city of Prypiat' in the north of the republic. By the end of 1978 two Chornobyl reactors operating at Prypiat' had been among five largest in the USSR (Dienes and Shabad 1979). A few years later Rivnenska, South Ukrainian and Zaporizka NPPs were launched into operation (see Table 11 below) covering the base-load of electricity demand in the Ukrainian SSR. Nuclear power capacity of Ukraine was steadily growing in 1980s as more reactors were being built. The nuclear era, where large fossil-fuel plants are replaced with NPPs, seemed to be approaching fast.

Table 11. Nuclear power reactors in the Ukrainian USSR and beyond

| Power plant, reactor | Location | Type of reactor – Commercial MW | Start date* | Closure date |
|-------------------------|----------------|--|----------------|----------------------------------|
| North | | | | |
| Chornobyl – 1 | Prypiat' | RBMK – 1000 | 1977 | Closed in 1997 |
| Chornobyl – 2 | Prypiat' | RBMK – 1000 | 1978 | Closed in 1999 |
| Chornobyl – 3 | Prypiat' | RBMK – 1000 | 1981 | Closed in 2000 |
| Chornobyl – 4 | Prypiat' | RBMK – 1000 | 1983 | Destroyed after accident in 1986 |
| Chornobyl – 5,6 | Prypiat' | RBMK – 1000 | - | Construction terminated in 1987 |
| North-west | | | | |
| Rivnynska – 1 | Kuznetsovsk | VVER – 440 | 1980 | Scheduled – 2030 |
| Rivnynska – 2 | Kuznetsovsk | VVER – 440 | 1981 | Scheduled – 2031 |
| Rivnynska – 3 | Kuznetsovsk | VVER – 1000 | 1987 | Scheduled – 2017, likely – 2032 |
| Rivnynska – 4 | Kuznetsovsk | VVER – 1000 | 2005 | Scheduled – 2035, likely – 2050 |
| Rivnynska – 5,6 | Kuznetsovsk | VVER – 1000 | - | Construction terminated |
| Khmelnyska – 1 | Neteshyn | VVER – 1000 | 1988 | Scheduled – 2018, likely – 2032 |
| Khmelnyska – 2 | Neteshyn | VVER – 1000 | 2005 | Scheduled – 2035, likely – 2050 |
| South | | | | |
| South Ukrainian – 1 | Yuzhnoukrainsk | VVER – 1000 | 1983 | Scheduled – 2023, likely – 2033 |
| South Ukrainian – 2 | Yuzhnoukrainsk | VVER – 1000 | 1985 | Scheduled – 2015, likely – 2030 |
| South Ukrainian – 3 | Yuzhnoukrainsk | VVER – 1000 | 1989 | Scheduled – 2019, likely – 2034 |
| South Ukrainian – 4 | Yuzhnoukrainsk | VVER – 1000 | - | Construction terminated in 1989 |
| Zaporizka – 1 | Energodar | VVER – 1000 | 1985 | Scheduled – 2015, likely – 2030 |
| Zaporizka – 2 | Energodar | VVER – 1000 | 1986 | Scheduled – 2016, likely – 2031 |
| Zaporizka – 3 | Energodar | VVER – 1000 | 1987 | Scheduled – 2017, likely – 2032 |
| Zaporizka – 4 | Energodar | VVER – 1000 | 1988 | Scheduled – 2018, likely – 2034 |
| Zaporizka – 5 | Energodar | VVER – 1000 | 1989 | Scheduled – 2019, likely – 2035 |
| Zaporizka – 6 | Energodar | VVER – 1000 | 1996 | Scheduled – 2026, likely – 2041 |
| Crimean – 1,2 | Shchelkino | VVER – 1000 | - | Construction terminated in 1989 |

* - commercial operation start date according to WNA 2014

Sources: Dienes and Shabad 1979; Plachkova *et al.* 2012; WNA 2014

Before 1986 the Soviet nuclear programme was perceived to be safe by general public and Chornobyl NPP was considered the best nuclear plant in the USSR with an excellent technical safety record (Medvedev 1990). However, the myth of “the total safety” was shattered by the Chornobyl accident, which happened on 26th April 1986. During the system’s test, reactor No.4 suffered a catastrophic power surge, which led to explosion in its core. Fire from the explosion sent a plume of highly radioactive fallout into the atmosphere polluting more than 53,000 km² (2,300 settlements with 2.6 million population) with radionuclides (Babenko *et al.* 2009). Europe and western parts of the USSR were affected the most by the disaster; this was especially the case for south and south-east of Belarus and northern Ukraine, where levels of radiation reached unprecedented levels (more than 20 mR/h). The area of 30 km radius around the Chornobyl NPP became an ‘exclusion zone’ area.

As it emerged one year after the catastrophe, a number of accidents and unscheduled (emergency) shutdowns took place at the station due to mistakes made by personnel. Moreover, poor quality of pipes and construction work were causing leakages of radioactive water. These problems together with a number of design deficiencies of RBMK reactors and inadequate attitude towards safety issues by the NPP and Soviet management led to the catastrophe, which is often referred to as “world’s worst nuclear disaster” (Meo 2013).

Notwithstanding the Chornobyl accident, a new Five-Year Plan was approved in June 1986 calling for further development of the nuclear power and construction of nearly 40 new reactors around the USSR. And although the plan was unrealistic, the scheduled earlier (in 1983) commissioning of six new units at Khmelnytska, Rivnynska, South Ukrainian and Zaporizka in Ukraine took place between 1987 and 1989 (see Table 11 above). Meanwhile, construction of new reactors in Chornobyl, South Ukrainian and Crimean plants was cancelled. The Crimean NPP in particular, which had been built since 1975, never started its operation:

the construction was terminated in 1987 with a high level of readiness (80% for the first unit and 18% for the second one) (Medvedev 1990).

The Chornobyl accident of caused significant contamination in Europe, as well as a “large public outcry” against nuclear energy and a dramatic fall in new nuclear power construction and developments around the world (apart from a few countries, such as Korea and Japan, due to issues of fossil fuel scarcity and physical constraints on pipeline/transmission) (Csereklyei 2014). Csereklyei (2014) found that the impact of a nuclear accident “... is likely to have a long lasting negative effect in the country where the accident happened, and possibly in countries which were affected by the direct consequences, such as the nuclear fallout”. This true for most of Europe after the Chornobyl disaster. No new nuclear power plants were constructed in Ukraine up to now, and the first plant in Russia was built only in 2006, twenty years later (Csereklyei 2014).

4.6.2. Current state

Nowadays Ukraine ranks 8th in the world as its installed nuclear power capacity is concerned (Shevtsov *et al.* 2013). Its four operating nuclear power plants cover almost 50% of the country’s electricity demand by running 15 nuclear power units: VVER-1000 (13 units) and VVER-440 (2 units), of an overall installed capacity of 13,835 MW (see NPPs on a map in Appendix, Figure A.11). Ten nuclear investment projects are being implemented at the moment worth some 63 billion UAH; they include construction of two new power units (No.3 and No.4) at Khmelnytska NPP, construction of solid nuclear waste recycling facilities, construction of a centralized depository for spent reactor fuel, reconstruction of water supply systems and switchgears and formation of a training centre for the plants’ personnel (ENERGOATOM 2014a).

In the recent years operational lifespan of many nuclear power units is being prolonged, while no new units are being under construction. The first units to continue their operation after

expiration of the critical thirty years of service in 2010 were the two units of Rivnynska NPP. Centralised nuclear waste storages are also being constructed at the moment, namely for three NPPs: Rivnynska, South Ukrainian and Khmelnytska.

Nuclear power sector enterprises dramatically differ in their technical capabilities and condition. On one hand, electricity generation equipment and technologies are being constantly improved, security and efficiency levels of NPPs increased; on the other hand, most of the nuclear industrial enterprises use worn-out equipment and outdated technologies, have no serial orders, thus often operating on the verge of bankruptcy. There are also cases of shutting down of unique processing lines and whole enterprises (e.g. the recent shut down of heavy water production in Dniprodzerzhynsk) (Shevtsovet *al.* 2013).

Shevtsov *et al.* (2013) characterise an overall state of the nuclear sector as “unsatisfactory” pointing out to the failure to comply with 2006-2010 strategic plans, including the necessary development of uranium and zirconium production, preparation to place out of service and launch new units, weak institutional and legislative support. Subsequently, this “... creates real threats to the sustainable functioning of the fuel-energy complex and national security of the country” (Shevtsovet *al.* 2013).

Nuclear energy sector is an integral part of Ukraine’s centralized electricity system and energy market. Its functioning is crucial and in case of its full stop the country would not have enough capacities to meet the national electricity demand. The nuclear system also has certain connections with hydro and renewable energy systems. As it was mentioned in the Paragraph 4.5.3, South Ukrainian NPP operates in coordination with Tashlytska HAPP, while Energoatom also is an owner of a Public Enterprise “Donuzlavskaya VES” created in 2008 to carry out construction and manage operation of wind power plants in Crimea (ENERGOATOM 2014a).

Unlike HPPs, NPPs due to technological specificities can operate only in base-load conditions and are thus covering the basic demand for electricity, which is coming from practically all sectors of economy. The main electricity consumers, also those creating the everyday basic electricity demand, are: residential, commerce and public sectors; iron and steel industry; mining and quarrying industry; rail transport; chemical and petrochemical industry; food industry; machinery and others (see Appendix, Figure A.6).

Thus, nuclear power plays the most important role in Ukraine's base-load power generation being responsible for up to 50% of the country's electricity production. Ukraine ranks sixth in the world (after France, Lithuania, Slovakia, Belgium and Sweden) as such an indicator (nuclear electricity generation) is concerned. Moreover, according to the future projections (MECIU 2012a), the role of nuclear power may continue to grow and strengthen in the next decades if:

- electricity generation from NPPs increases: new nuclear power units are constructed and operational lifetime of the old ones is prolonged;
- national nuclear fuel cycle is organized;
- solutions for treatment of the spent nuclear waste are found;
- security level of the objects of nuclear infrastructure is enhanced (MECIU 2012a).

Moreover, nuclear energy system is an important source of economic revenue for the state. In 2012, Energoatom (see next paragraph for information on the company) was among Ukraine's top 10 companies by revenue with its income of 1.8 billion EUR (see Appendix, Table A.5).

4.6.3. System governance and structure

The nuclear sector of Ukraine is presented by power generation enterprises (NPPs), mining industry complex, various industrial enterprises providing a wide range of services and producing multiple products, and research organizations. Almost all of them, except for

research institutions, are subordinated to the Ministry of Energy and Coal Industry of Ukraine (Shevtsov *et al.* 2013).

The state enterprise “National nuclear power generating company ENERGOATOM” (further in the text: ‘Energoatom’), established in 1996 as a successor of “Goskomatom”, is operating all of the four active NPPs in Ukraine. The company is responsible for production of electricity at NPPs ensuring safety of their operation; it is also responsible for construction of new and rehabilitation of the existing capacities, purchasing of new and taking out of the old reactor fuel, establishment of a national infrastructure for the spent nuclear fuel and nuclear waste treatment, as well as for the physical protection of the nuclear power objects (ENERGOATOM 2014a).

The national regulating authority for nuclear and radiation security is a State Committee of the Nuclear Regulation of Ukraine (“Derzhatomregulyuvannya”). The committee is responsible for 1) establishment of security criteria and conditions for application of nuclear power, 2) issuing of permissions and licenses within nuclear sector, 3) control of nuclear companies in their abidance to nuclear security law and regulations. A head of “Derzhatomregulyuvannya” is assigned by the President of Ukraine. According to Shevtsov *et al.* (2013), there is a number of recorded cases when Energoatom refused to follow recommendations of the Committee due to lobbying of separate authorities and individuals when important decisions are at stake.

All the nuclear industry enterprises and factories related to the nuclear energy sector can be divided into three categories depending on their relation to the Ministry of Energy and Coal Industry:

- a)** a group of 31 state enterprises/companies subordinated to the Ministry (including a uranium mining and processing complex “Shidnyi GZK” in Zhovti Vody, Prydniprovsky

- hydrometallurgical plant and non-ferrous metals factory, state construction enterprise “Atombud” in Chornobyl and others);
- b) two research and design institutions “Energoproekt” in Kyiv and Kharkiv whose state corporate rights are controlled by the Ministry;
 - c) a group of enterprises not controlled by the Ministry, such as a turbine factory “Turboatom” in Kharkiv, Kramatorsk machine-building factory and a number of others.

The National Academy of Sciences (NASU) also plays an important role in nuclear research, specifically concentrating on the issues of nuclear security and physical issues related to the nuclear cycle and related technologies.

Recently, Energoatom officially announced its intentions to fight against corruption within the nuclear sector due to the fact that in the last few years electricity production became unprofitable for the company and it is now making loss instead of return. According to Energoatom, “... this is not only the fault of authorities who saw the nuclear industry as a donor of the national budget and were extracting extra taxes, additional charges and fines; but also of the managers of both the company and its separate divisions” (ENERGOATOM 2014a).

As Shevtsov *et al.* (2013) concluded, the existing infrastructure of the nuclear sector does not correspond to the tasks it has to deal with: the system’s is unclear, disintegrated and unconsolidated, which leads to the impossibility of its effective governance.

4.6.4. Vulnerabilities

The first and primary vulnerability of the nuclear energy system of Ukraine is connected to *energy security*. Domestic production of nuclear fuel for power generation makes only 30%. Most of the fuel and nuclear services (e.g., fuel fabrication and enrichment) are received from Russia. Although a nuclear fuel production and fabrication plant is currently under construction in Ukraine, the project is a 50-50 joint venture between the state-owned company Nuclear Fuel

and Russian-based TVEL (RNA 2012; WNA 2014). Moreover, notwithstanding minor attempts to diversify fuel supply, in 2010 Energoatom signed a contract with Russia, which implies a long-term supply of nuclear fuel for all 15 Ukrainian reactors (WNA 2014).

Similarly, as nuclear waste management is concerned, Ukraine largely depends on Russia in spent nuclear fuel reprocessing (from VVER-440 reactors) and temporary storage of the nuclear waste (from some of VVER-1000 reactors). The latter costs Ukraine more than \$100 million annually. While being capable of storing some of its nuclear waste at NPP sites, Ukraine has recently launched a project of construction of a dry storage facility within the Chernobyl exclusion area (CMU 2014). The project implies storage of spent nuclear fuel from Rivnynska, Khmelnytska and South Ukrainian NPPs, and will significantly increase Ukraine's energy security when the construction is complete. However, due to the long-term nature of nuclear energy projects and contracts, the high level of dependency on Russian services will most likely remain for many years to come.

Chornobyl (1986) and Fukushima (2011) disasters showed that nuclear systems remain vulnerable to a whole range of contingencies: human's mistakes and mismanagement, technological deficiencies, natural disasters and other. Many of these are usually impossible to predict or to prevent fully, leaving a chance of the system's partial collapse and the need to deal with the disaster's detrimental consequences: environmental, social and economic.

And finally, nuclear reactors may become preferred targets for military attack in case of a military conflict. The current crisis in Ukraine, seizure of Crimea by force by Russian troops and the aggravating situation in the eastern regions with on-going local military actions, made the need to enhance the *physical security* of Ukrainian NPPs urgent and necessary. As ENERGOATOM (2014b) reports, at the moment the company is assessing the condition of physical security systems of all its nuclear units and is working on "... new action plans in case any diversion or terrorist attack on nuclear plants or nuclear materials takes place".

4.7. Renewables energy system

4.7.1. History

Ukrainian ancestors started using the energy of water and wind centuries ago, foremost for grinding grains, and later for other industrial purposes. The first records of application of **water** mills in the ancient Rus' are dated 13th century; they had become widespread in Ukraine by 17th century (Plachkova *et al.* 2012). In 17th century the first artificial water basins were also constructed to provide water for intensively expanding water transportation system. This is when the water wheels also started being used to drive bellows, hummers, pumps and other mechanisms, as well as applied in water supply of larger towns. During the Soviet period, simultaneously with large-scale hydropower developments, a large number of smaller hydropower facilities were also constructed. In 1960 about 1,000 *small-scale HPPs* were in operation around Ukraine and their number was planned to be increased up to 3,600 (Plachkova *et al.* 2012). However, in the beginning of 1990s due to appearance of high-capacity NPPs and TPPs, which were producing cheaper electricity, only 50 small-scale HPPs were left in operation. During the years of independence their number increased, although not significantly.

The first **wind** mill constructions which appeared on the Russian territories were most likely copied from German designs, while the southern Slavs (currently the south-west of Ukraine) had earlier adopted an Egyptian windmill prototype (Plachkova *et al.* 2012). The windmills were generally used for flour-milling and in the beginning of 18th century they could be found in thousands in different regions of the Russian empire, as well as of various power capacities from 5 horsepower up to 15 – 20 horsepower; diameter of the wind wheel of the latter made 20 – 24 meters. Archive data suggest that in 1917 an overall capacity of all the windmills located on the modern territory of Ukraine reached 1,400 MW (Plachkova *et al.* 2012).

In 1931 in the city of Balaklava (Crimea) a Ukrainian inventor and a scientist Yuriy Kondratyuk created the first in the world experimental wind power installation for electricity production of a capacity of 100 kW (Ablitsov 2007). Later on he designed a new wind power turbine of a capacity of 1 MW. However, his inventions were never applied: there was no technical facility available at the time to lift the wind equipment up to Ai Petri Mountain (more than 1,000 meters high). The first operational wind power plant appeared on the territory of Ukraine many decades later. In 1994 Ukraine's Government issued a decree "On construction of wind power plants", which resulted in setting up a wind turbine production line at domestic enterprises (SE "Pivdenmash" and a range of military industrial plants), including a 1MW turbine, and a subsequent installation of the first wind turbines at Novoazovska, Donuzlavska, Sakska, Tarhankutska and Truskavetska WPPs (Petrenko 2012). Between 2010 and 2013 an overall installed capacity of Ukrainian WPPs increased four-fold and reached 371.7 MW (UKRENERGO 2014).

Although use of *biomass* as an energy source was wide-spread for many centuries, until recently its use had been limited to direct combustion in an open fire or in furnaces of relatively low efficiency (Plachkova *et al.* 2012). In Ukraine bioenergy and *solar* resources started being applied for heat/power generation and fuel production only in late 1990s – 2000s, while geothermal and some other perspective resources are yet to be developed. In 2011 one of the world's largest photovoltaic SPPs in the world was launched in the city of Perovo, Crimea, with an installed capacity of 100 MW (PVResources 2013). Installed electric capacity of Ukrainian solar installations saw a 70-fold increase in the last four years: from 8.1 MW in 2010 to 563.4 MW in 2013 (UKRENERGO 2014). A number of institutions have also been conducting research on application of renewable energy in Ukraine. One of them is the Institute for Problems of Material Science located in Crimea and operating since 1955. The Institute has

the only heliocentre in Ukraine and within the whole ex-Soviet space, which works on research related to development of new materials for solar industry (FIPMS 2013).

4.7.2. Current state, importance and connections to other systems

The role of RES in Ukraine's energy system has been visibly increasing in the last years, as new renewable projects launch and their installed capacity grow. Government incentives, commitments given to the EC and international financial support are among the important factors promoting the advancement of RES in the country. Energy of RES is used for electricity, heat and fuel production, although yet the most common use in Ukraine is connected to the former.

Electricity generation from RES doubled between 2012 and 2013 and made 0.64% of the total electricity production (or 1.3 billion kWh out of 193.6 billion kWh) in the last year (MECIU 2014b). As it is shown in Table 12 below, installed electric capacity of renewable plants is constantly growing and by July 2013 the number made 981.2 MW of solar, wind, small hydro, biogas and biomass power plants, which is more than 1.5% of the total installed power capacity of the country (IMEPOWER 2013; UKRENERGO 2014).

Table 12. Installed capacities of renewable power plants in Ukraine by July 2013

| Type of power plant | Installed capacity, MW |
|---------------------|------------------------|
| Solar PV | 569.5 |
| Wind | 330.4 |
| Small hydro | 74 |
| Biogas and biomass | 7.3 |
| Total | 981.2 |

Source: IMEPOWER 2013

A number of new renewable projects are currently under development. Among them is construction of a wood chip-fired power plant of 18 MW capacity, which shall become the first of five biomass-fired plants (total capacity: 50 MW) located in the north of the country (IMEPOWER 2013). The project is to be developed under the large-scale investment

programme sponsored by the European Bank for Reconstruction and Development (EBRD) and the Clean Technology Fund (CTF, World Bank Group), and implemented by the Ukrainian EIG Engineering. Other projects include:

- ✓ expansion of Ukraine's largest wind park in the city of Botievo (Zaporizhia oblast) by 105 MW (sponsored by DTEK Wind Power);
- ✓ expansion of Novoazovska WPP (Donetsk oblast) by 57.5 MW (financed by EBRD);
- ✓ installation of turbines of 21 MW total capacity at Beregova and Stavki WPPs (Kherson oblast);
- ✓ construction of 4.2 MW SPP in Odesa oblast (financed by EBRD);
- ✓ construction of a plant for production of straw fuel pellets with capacity of 60,000 tonnes per year in Kryvyi Rih (a joint project between the Ukrainian agricultural holding KSG Agro and a Polish company Polish Energy Partners);
- ✓ construction of the first biogas production facility in Ukraine producing 5.8 million m³ of gas annually and generating both electricity (1.5 MW installed capacity) and heat (financed by EBRD) (IMEPOWER 2013).

Source: IMEPOWER 2013

In 2008 Ukraine introduced a “green” tariff for electricity: a feed-in scheme with fixed prices, which guarantees grid connectivity to all renewable installations (Roelfsema *et al.* 2014). The feed-in tariffs are high in comparison to world major economies and make 42 c€/kWh for solar PV and 11c€/kWh for wind (see Appendix, Figure A.4.7.2 for electricity tariffs), which makes it highly profitable to invest in the renewable energy projects and can explain the latest dramatic increase in installed renewable electric power capacity. According to Roelfsema *et al.* (2014), the green tariff policy may lead to 8% share of renewable electricity (excluding electricity produced by large hydropower plants) in country's energy mix in 2020.

At the same time, political unrest together with administrative, bureaucratic and other barriers still restrict growth of the renewable industry (Kurbatova *et al.* 2014; Roelfsema *et al.* 2014).

Several policy instruments are already adopted in Ukraine to establish and regulate the green electricity market. The policy documents include Cabinet of Ministers of Ukraine (CMU) Decree on the Programme of State Support for Alternative and Renewable Energy and Small Hydro and Thermal Power, Energy Strategy of Ukraine Until 2030, Law of Ukraine on Alternative Sources of Energy, CMU Decree on Approval of the Granting of Preferential Loans for Investment Projects on Energy Saving Technologies for Production of Alternative Energy Sources, CMU Decree on Production and Use of Biogas, a Tax Code of Ukraine and some others (Trypolska 2012). Although the policy and legal papers define the general energy use from RES, there is no clear national target for a total consumption from RES (Trypolska 2012). At the same time, the current legislation guarantees grid access for renewables. The SE “Energoynok” (wholesale electricity market of Ukraine) is obligated to purchase the electricity produced by use of RES, which was not sold directly to electricity-distributing companies or consumers.

4.7.3. System governance

The state institutions governing renewable energy sector are: Parliament and Government of Ukraine, National Electricity Regulatory Commission and State Agency on Energy Security and Energy Saving (Kurbatova *et al.* 2014; see Appendix, Table A.8 for detailed descriptions of the state institutions’ responsibilities). A number of laws are governing the market of green energy and renewable sector, including the Law of Ukraine “On Electric Power Industry”, “On Alternative Sources of Energy”, “On Energy Saving” and “On Alternative Fuels”.

While large HPPs are controlled by the state, small-scale hydropower facilities are generally privately sponsored and owned. Adoption of the ‘green tariff’ scheme started giving certain incentives for further development of small-scale hydropower (HPPs of up to 10 MW

installed capacity) as an attractive renewable resource for power generation. However, hydropower investors face a whole number of issues connected to such developments, including difficulties with purchasing of land and connection to the grid, high prices for the use of water and others (Kalynchuk 2011).

4.7.5. Vulnerabilities

Most of RES are potentially vulnerable to climate changes (in long term), while the energy efficiency and production from RES are constrained by environmental conditions. For example, use of solar energy for heat or electricity generation is limited to cloud cover and atmospheric turbidity, hydroelectric power – to local hydrology and weather patterns, wind power – to variations in atmospheric pressure, wind velocity and direction, ambient temperatures and air density. On one hand, use of RES is promoted as a way to decrease a magnitude of climate change; on the other hand, climate change will most likely affect the prospects for the use of RES in the future (Nikolova 2010).

Moreover, implementation of renewable projects in Ukraine started only recently. Thus, the country does not have enough experience or capabilities in running renewable energy plants, as well as in production of related energy equipment or development of its own renewable technologies. Therefore, many new RES projects are associated with foreign investment and application of foreign technologies (see previous paragraph), which to a certain degree affects the country in terms of energy security. However, such impacts are relatively minor if compared to energy security issues Ukraine has to face in natural gas supply and nuclear sectors.

4.8. Electric power system

“Communism is Soviet power plus electrification of the whole country”

(V.I. Lenin)

4.8.1. History

As Dienes and Shabad (1979) stated, “electrification and economic modernization have long proceeded hand in hand”: electric power became an efficient instrumental in a rapid rise of labour productivity due to many conveniences associated with its use (easy to manipulate, versatile, easy to transport etc.). The first uses of electricity on the territory Ukraine, described earlier in Paragraph 4.1.2, took place in the end of 19th century. Large-scale development of Ukraine’s electricity system started with the famous GOLERO plan (for more details, see Paragraph 4.1.2), which implied technical re-equipment of all economy sectors based on the use of electricity, electrification of all manufacturing processes, centralization of power generation, construction of large power plants securing electricity generation for whole regions, use of local fuel resources at the power plants, and finally, creation of the united national energy system (Ananiev *et al.* 1977). From the perspective of the present, the GOELRO intentions can be seen as successfully implemented: the United Energy System (UES) of Ukraine combines in itself the relative diversity of use of different energy resources for power generation and a vast electrification of the country (currently, almost 100%), which made electricity a crucial resource for the national economy.

According to the distribution of primary energy resources (see Paragraph 4.1.1), Ukraine’s electricity generation capacities differ between regions. The eastern regions, rich with coal and mineral resources, are mostly dependent on coal and hydrocarbon resources for both power generation (see Appendix, Figure A.11) and functioning of their industries (especially metallurgy). The westernmost regions located near Lviv-Volyn coal basin also use coal for electricity generation. The USSR’s main legacy for the regions without substantial

coal, gas or oil reserves is nuclear power generation capacities, and large-scale hydropower capacities on Dnieper and Dniester rivers. Two big exclusions are: the capital Kyiv and neighbouring regions, accommodating a number of TPPs and CHPPs for production of electricity and heat; Crimean Autonomous Republic, which is almost fully dependent on electricity supply from Ukraine's mainland. Although a construction of a NPP in Crimea was planned and started being implemented, the project was terminated after the Chornobyl nuclear disaster (see Paragraph 4.6.1, Table 11).

The role of TPPs (both TPPs and CHPPs) in power generation changed dramatically in the last decades. Before the collapse of the Soviet Union they were responsible for most of electricity generated and largely exceeded NPPs in annual electricity production. The importance of TPPs soon started its decline and since the second half of 1990s NPPs and TPPs produces about the same amount of electricity on the annual basis:

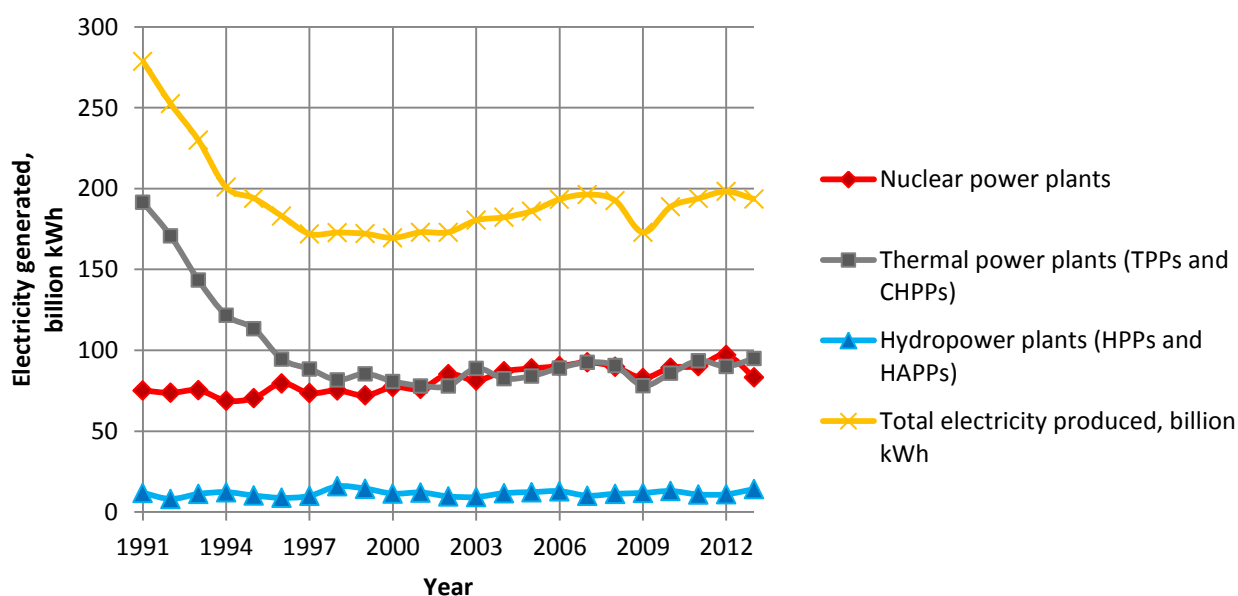


Figure 24. Electricity generation energy mix in Ukraine in 1991 – 2012

Sources: MECIU 2014b; UKRSTAT 2013b

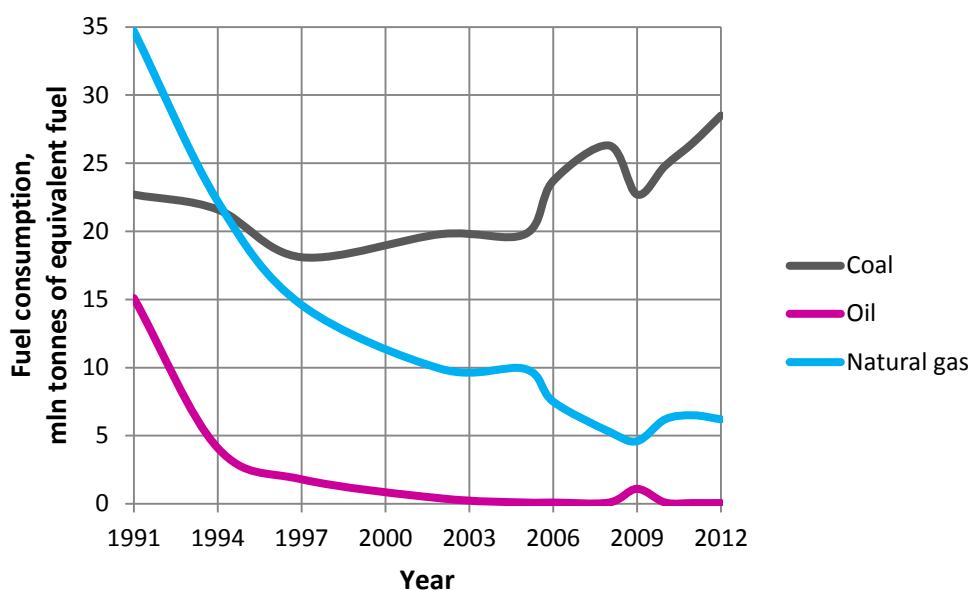


Figure 25. Change of the structure of energy resources in electricity and heat generation at TPPs and CHPPs in Ukraine in 1991-2012

Data source: Volchyn *et al.* 2013

Energy mix at the Ukrainian thermal power plants (both TPPs and CHPPs) has also changed dramatically since 1980s – early 1990s. In 1991 natural gas, coal and oil were used as primary energy sources at the plants with natural gas being a dominant fuel among the three (see Figure 25). However, as the Ukrainian economy saw decreasing levels of extraction of all the three resources and the Russian-Ukrainian disputes on gas supplies launched after the collapse of the USSR, coal has gradually replaced gas in power and heat generation, while oil stopped being used as a primary energy source at TPPs in the early 2000s (see Appendix, Table A3).

During 1990s Ukraine underwent a range of substantial reforms and became the first country among the other ex-Soviet states to liberalise its electricity sector (DIFFER 2012; see Paragraph 4.8.3 for more details).

4.8.2. Current state, importance and connections to other systems

The total installed electricity generation capacity in Ukraine is 54.4 GW, or 1.2 kW per capita (2013), which compares to for instance 0.9 kW/cap in Poland and 2.0 kW/cap in Germany (EIA 2011; UKRENERGO 2014). Thermal and nuclear power generation capacities constitute the basis of the UES of Ukraine making 54.5 % and 25.4% of the total installed power capacity of the country accordingly (see Appendix, Table A.7; Volchyn *et al.* 2013). At the same time, as it is shown on Figure 22, TPPs (including CHPPs) and NPPs produce about the same amount of electricity, namely more than 45% of the country's total electricity generation annually. Hydropower and hydro-accumulating power plants take 10.0% of the overall capacity while generating about 5.5% of electricity (Volchyn *et al.* 2013). Normally, hydropower capacities are used to cover peaks and half-peaks of electricity demand (during the busiest hours of the day), while thermal and nuclear capacities are designed to work in base-load conditions without substantial interruptions. However, units of thermal power plants have been often used as manoeuvre equipment to cover the peak loads, which causes fast wearing of the energy equipment and results in reduction of reliability of the whole energy system (Omelyanovsky *et al.* 2010; Volchyn *et al.* 2013).

The average capacity factor – share of the installed capacity that is in actual operation over the year – is low (38% in 2009, in comparison to 66% in Indonesia), which is due to the existing overcapacity, poor status of transmission grid and associated lack of electricity export possibilities, inefficient power generation at thermal power plants and high cost of fuel inputs (DIFFER 2012; MECIU 2012a). The residual lifetime of Ukraine's thermal and nuclear capacities is limited and makes 2-5 years for some of TPPs, while any nuclear units require an extension of operational lifetime within the next 10 years (see Table 11). Therefore, while no new thermal or nuclear plants are being constructed at the moment, a large number of generation capacity has to be replaced in the near future.

In 2013 Ukraine generated 193.6 billion kWh of electricity, out of which 147.3 billion kWh (76% of the total) was consumed within the country, 9.8 billion kWh (5% of the total) was exported and the remaining 36.4 billion kWh (19% of total) was used for own needs of power generating units or lost during transmission (MECIU 2014b). Ukraine is a net exporter of electricity and its main export markets are Belarus, Poland, Hungary and Slovakia (UKRENERGO 2014; for transmission lines see Appendix, Figure A.11). Electricity for export is produced only at one TPP, a coal-fired Burshtynska TPP, characteristics of operation of which were brought to the western European standards. Burshtynska TPP belongs to the PJSC “DTEK Zahidenergo” and is disconnected from the United Energy System of Ukraine (Volchyn *et al.* 2013).

The consumption of electricity is fairly evenly divided between domestic industries and households: industries consume 48% of all electricity, while residential, commerce and public sectors are responsible for 45% of the total consumption. Iron and steel sector is the most electricity-intensive industry among all consuming almost 20% of the total and followed by mining and quarrying (8%) and rail transport (5%) (see Appendix, Figure A6).

4.8.3. System governance

The key state entities managing the electricity sector of Ukraine are the Cabinet of Ministers of Ukraine, the Ministry of Energy and Coal Industry of Ukraine, the National Electricity Regulatory Committee and the State Agency for Energy Efficiency and Energy Conservation (MECIU 2012b; see Figure 24 below). State management of electricity sector (establishment of development priorities and ensuring legal regulation of fuel and energy complex) is entrusted to the Ministry, while the Regulatory Committee is responsible for regulation of activities of all the entities, which are natural monopolies in electricity sector, and for promotion of competition in electricity generation and supply. The Energy Efficiency Agency implements state policy in the sector and is responsible for control of efficient use of

energy resources and promotion of increasing use of renewable and alternative fuels in the energy balance of Ukraine (MECIU 2012b). The National Energy Company “Ukrenergo” is a natural monopoly in the field of electricity transmission, responsible for coordination of development and maintenance of electric networks in the country and creation of reliable parallel operation of the Ukrainian electricity system with electricity systems of other countries (MECIU 2012b).

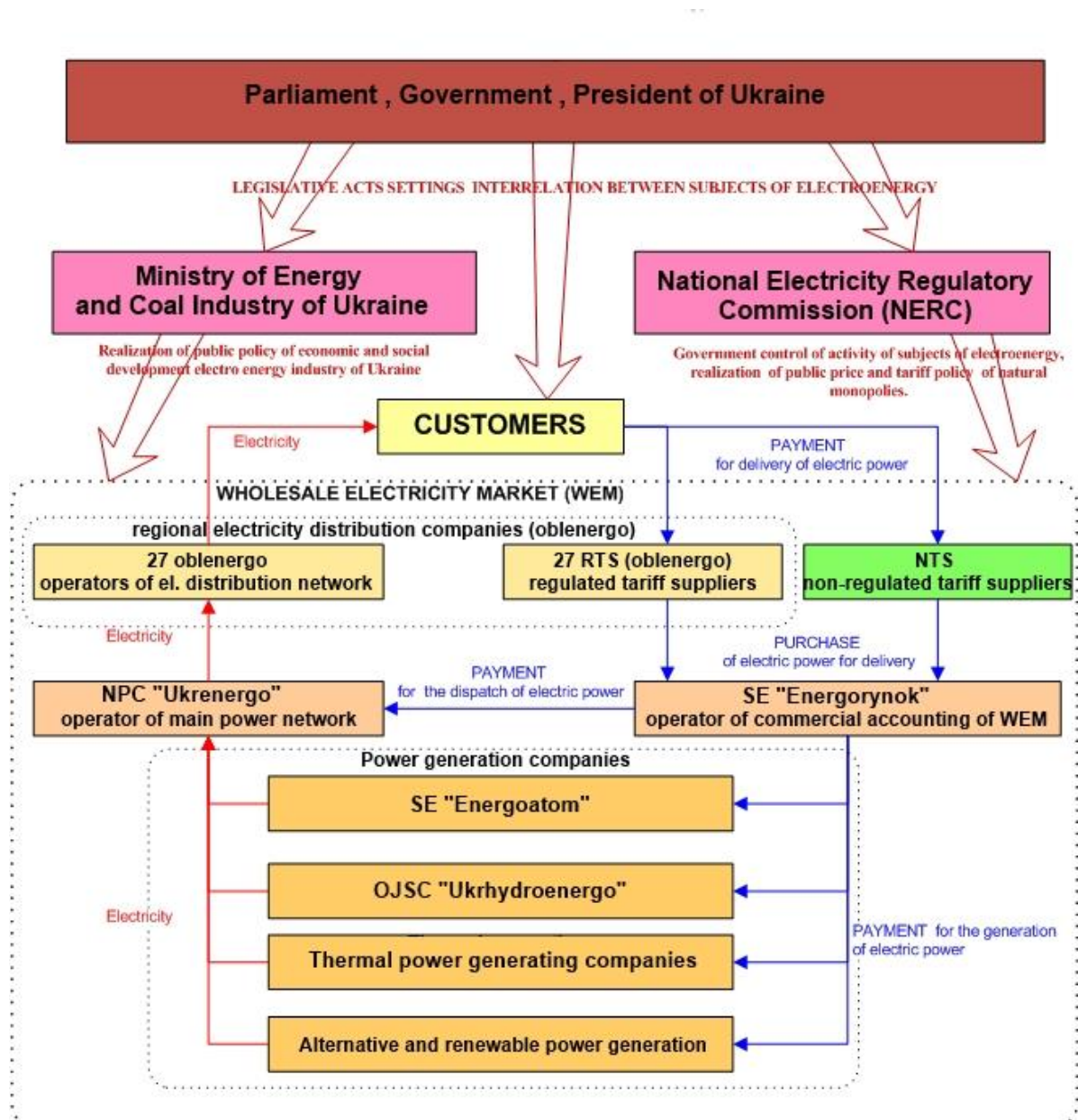


Figure 26. Structure of electricity market and electricity system governance of Ukraine

Source: Ukrenergoexport 2010

The Law on Electricity adopted in 1997 fixed the structure of the Ukrainian electricity market. The wholesale electricity market is based on a single buyer/seller model, where a state-owned company SE “Energorynok” is the only buyer responsible for purchasing all the electricity generated by licensed power plants with a capacity of over 20 MW, and wind power generators regardless of size (DIFFER 2012; MECIU 2012b). All electricity generators (same conditions regarding their size as mentioned previously apply) are, in turn, obliged to sell their produced electricity to “Energorynok”. Generators of electricity, which operate large-scale HPPs (“Ukrhydroenergo”) and NPPs (“Energoatom”), sell their electricity at regulated tariffs, while TPPs sell to a competitive bidding platform where the prices are established on a daily basis (DIFFER 2012). From this perspective, the market of electricity is not completely liberalised and prices remain dependent on generation source (see Appendix, Figure A.12 for latest electricity tariffs).

After the electricity is purchased by “Energorynok” from more than 50 generating companies, it is then being sold to 27 oblenergos (regional power distribution companies) and independent suppliers at a blended rate (see Figure 26; Appendix, Figure A.12 for WEM price). Oblenergos are responsible for distribution, supply and electricity services for end-users, as well as they sell electricity to consumers at end-user tariffs regulated by NERC (DIFFER 2012). The end-user tariffs as of 1st May 2014 for the city of Kyiv made: 1.30 UAH/kWh (7.9 EUR cents/kWh) for industrial sector; 0.36 UAH/kWh (2.2 EUR cents/kWh) for transportation sector; and 0.29 – 0.96 UAH/kWh (1.7 – 5.9 EUR cents/kWh) for residential and public sector, depending on the amount of electricity consumed per month (Kyivenergo 2014; NERC 2014).

4.8.4. Vulnerabilities

Electricity system is directly connected to primary energy resources used for electricity generation, and thus, any interruptions in fuel supply (natural gas, coal) may dramatically affect the system. As it was shown in Section 4.2, most of energy coal used at power plants is

produced domestically; therefore, external interruptions are unlikely to affect electricity production at TPPs of Ukraine. At the same time, CHPPs (the plants producing both heat and power) largely depend on natural gas supplies and the gas energy system, which is highly vulnerable in terms of energy security (see Section 4.4).

Another energy security risk is related to ageing of the electricity transmission lines, as well as production facilities, including most of TPPs, HPPs and NPPs. 95% of all the TPPs and HPPs reached the end of their designed lifespan, which increases the number of failures at the plants (see Section 4.2) and decreases their reliability (Volchyn *et al.* 2013). Large investments are required to keep up the current levels of production and improve the system's reliability.

Moreover, electricity consumption per capita in Ukraine is very high, mostly due to low efficiency of the system starting from electricity production, transmission and ending up with its consumption by industries and households. According to the Strategy (see next Section), electricity consumption is expected to double by 2030 (MECIU 2012a), which would make both the supply and demand sides to face immense challenges, also increasing vulnerability of the system if no energy efficiency policies are adopted in the nearest future.

4.9. Current strategies and policies

According to IEA (2012), "... Ukraine needs a transformation of its energy sector to a more efficient, secure and sustainable energy system" by conforming to the following key energy policy priorities:

- untapping its enormous energy efficiency potential;
- expanding development and production of indigenous energy sources;
- modernising its energy supply chain;
- ensuring regulatory reform and ensuring full implementation of EC provisions;
- phasing out subsidies for gas, coal and electricity consumers;
- enhancing policy-making and implementation of energy policy measures;

- delivering energy sector structural reform.

Practically all of these priorities are reflected in the “Updated Energy Strategy of Ukraine Until 2030” (or *the Strategy*), which targets to secure the country’s energy supply by increasing the indigenous coal and gas extraction, diversification of fuel supplies, liberalisation of energy market, as well as by improving energy efficiency of the national energy system (MECIU 2012a). The Strategy provides three scenarios for the future development of the Ukrainian energy system, a pessimistic, baseline and optimistic, all of which imply gradual increase in GDP (annual increase of 3.8%, 5% and 6.4% according to the scenarios). The expected results of the Strategy are the following:

- increase in domestic **coal** extraction up to 115 Mt, maximal privatization of the coal sector, increased efficiency of mining (see Figure 27);
- increase in domestic **gas** extraction up to 40 – 45 billion m³ per year ensuring 90% of the national demand (see Figure 27);
- meeting the growing **electricity** demand (the demand is forecasted to increase 1.5-fold by 2030) by rehabilitation of the existing TPPs, extending the operational lifespan of the existing NPPs, attracted investments for modernization of the electricity system, and after 2018 commissioning of new generating capacities (new NPP, HPP and TPP units, construction of new **renewable power** plants) (see Figures 27 and 28);
- cutback of state expenditures and **phasing out subsidies** in energy sector;
- introduction of national programmes on **energy efficiency** and subsequent reduction of specific energy use in the economy by 30 – 35% by 2030;
- attraction of investments to **reform energy sector**; establishment of competitive markets; attraction of private investors by increase of prices of energy resources; intensification of control over monopolies; long-term stabilization of regulatory framework.

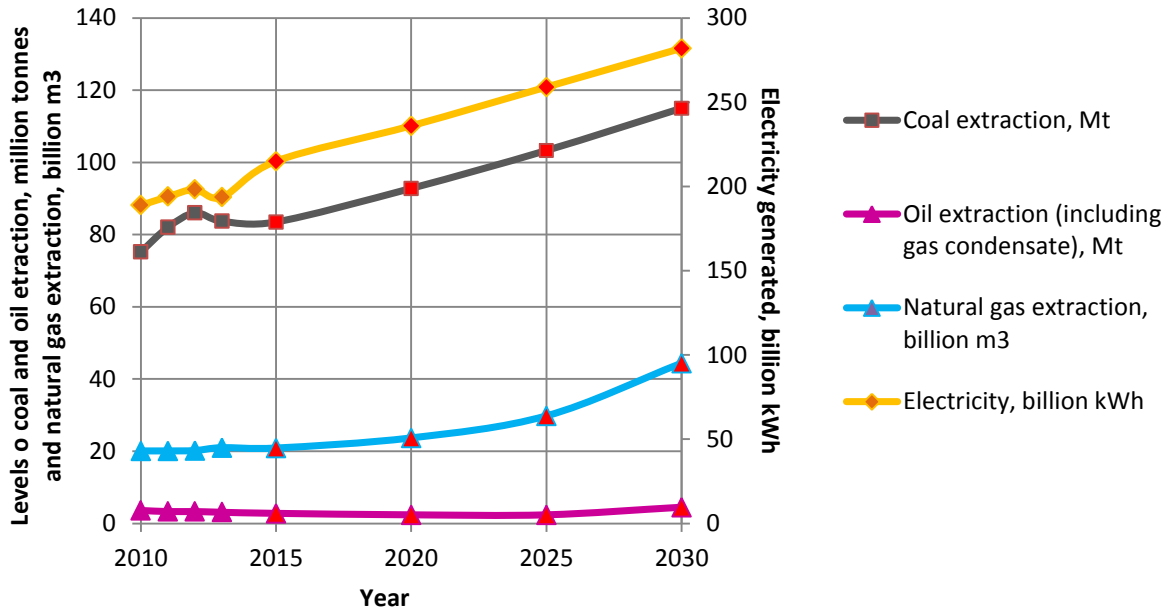


Figure 27. Extraction of coal, oil, gas and generation of electricity in Ukraine in 2010 – 2013 (factual data) and 2015 – 2030 (the Strategy ‘baseline’ scenario projections)

Data source: MECIU 2012a; MECIU 2014b

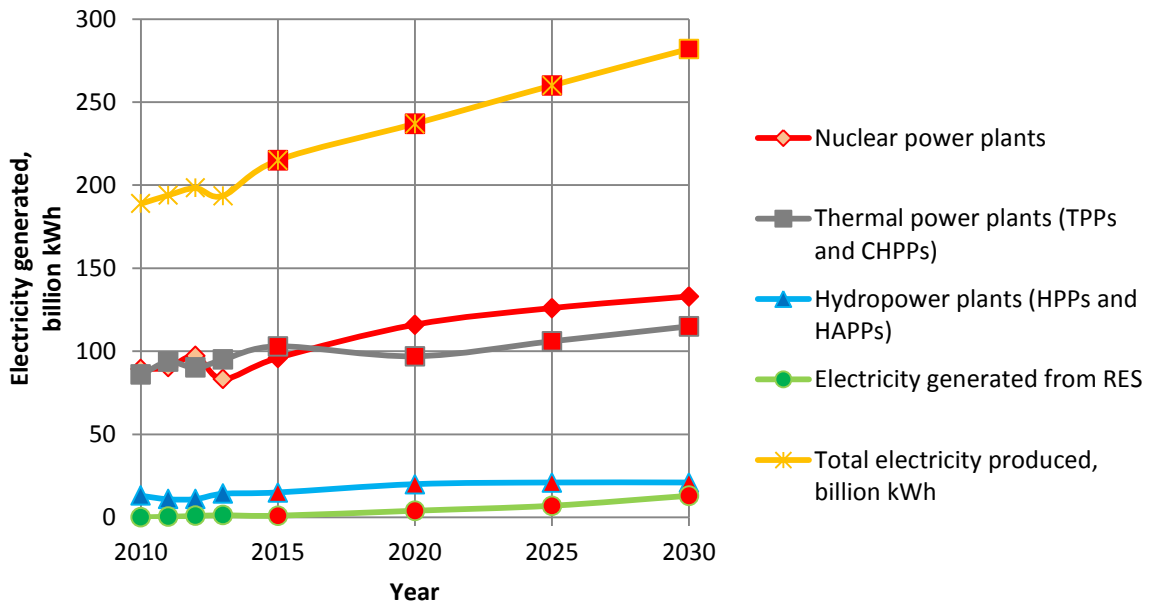


Figure 28. Electricity generation energy mix in Ukraine in 2010 – 2013 (factual data) and 2015 – 2030 (the Strategy ‘baseline’ scenario projections)

Sources: MECIU 2012a; MECIU 2014b; UKRSTAT 2013b

Figures 27 and 28 provide factual 2010 – 2013 data (for 1991 – 2013 data, see Figures 12 and 22) and projected by the Strategy 2015 – 2030 data on extraction of domestic resources, electricity production and energy mix in the sector of power generation. Instead of the projected growth of electricity generation, the current trend is rather opposite: power production level saw a 2.3% decline in 2013 in comparison to 2012 (MECIU 2014b) and due to the current crisis, it may continue to decrease in the nearest future. Similar patterns can be observed for coal extraction, while natural gas and oil extraction levels do not significantly deviate from the line drawn by the Strategy's plans. In electricity generation energy mix, difference between power production levels from NPPs and TPPs is relatively small, which according to the Strategy may be the case until 2015. The set by the baseline scenario 2015 level of electricity generated from RES was exceeded already in 2013, and made 1.3 billion kWh in comparison to the 1.0 billion kWh projected for 2015 (MECIU 2012a; MECIU 2014b).

The Strategy was approved by the Cabinet of Ministers of Ukraine in July 2013 and provoked many debates and critics in political and scientific circles. According to Gonchar (2012), the Strategy should be based on reliable economic data and the strategy of economic development of the country, which at the moment simply does not exist. Some energy experts called the Strategy "... an absolutely unrealistic document", which does not take into account specificities of the Ukrainian energy sector, any possible economic, political or other changes, energy strategies of other countries (e.g., Russia, EU) and does not provide reliable data on the national energy balance (Zabutyi 2013). Many questions also arose in respect to the 'overoptimistic' plans on construction of new TPP and NPP units, as well as the small share of renewables in the country's projected electricity mix in 2030 (only 10% of the total installed capacity, including large HPPs), (DIFFER 2012; Gonchar 2012; Zabutyi 2013). Gonchar (2012) concludes that the document should be viewed as recommendations for future development rather than an actual energy policy strategy.

4.10. Chapter findings

Ukraine is a country rich with many mineral and energy resources, exploration and exploitation of which started many decades ago. Under the Russian and Austro-Hungarian Empires (end of 18th – beg. of 20th century), Ukrainian territories were mostly producing raw and semi-finished materials for the empires' needs, while the ready-made products were imported, making the territories highly insecure in economic terms. The first large-scale industries were sugar production and shipbuilding; agriculture was playing an important role for Ukraine's economy for centuries. The industrial revolution drove increasing levels of coal extraction in 18th century and resulted in establishment of major industrial centres, primarily in the eastern and southern Ukrainian territories rich with iron ore, manganese and other resources.

Intensive exploration of Ukraine's domestic energy resources (coal, gas, oil) took place in 1950s – 1980s. The Soviet's policy of extensive centralized electrification of the USSR republics resulted in establishment of the United Energy System of Ukraine integrating the country's energy systems and determining the main flows of energy supplies, often interconnected with energy systems of other Soviet republics. As a result, together with the independency in 1991, Ukraine received an enormous energy legacy from the USSR in face of influential state energy and energy-related institutions, large NPP, TPP and HPP capacities, energy-intensive industries and related institutions, as well as many issues connected to energy security, which is especially evident in the Ukraine-Russia relations. The legacy has been determining energy policies throughout the contemporary history of the yet 'incomplete' (Kudelia 2012) Ukrainian state.

Summary of the analysis of Ukraine's energy systems is provided in Table 13 below. Except for the energy security issues, Ukrainian energy system is highly vulnerable in both short- and long-term due to ageing of its power plants (TPPs, NPPs, HPPs); use of outdated

technologies for fuel extraction, power and heat generation and in industries; depletion of domestic oil, gas and coal resources; inefficient structure and governance of energy sector, which allows many possibilities for rent-seeking. One of the latest national energy policy documents attempting to address these issues is the “Updated Energy Strategy of Ukraine until 2030”, which is, however, according to many experts needs many further improvements, if not a complete revision.

Table 13. Results of analysis of energy systems of Ukraine

| Energy system | Coal | Oil | Gas | Hydro | Nuclear | Renewables | Electricity |
|-------------------------------------|---|---|---|--|--|---|---|
| History | History of extraction and industrial use from 19 th century (Donbas); well-established infrastructure and institutions; increasing use of coal at TPPs | Extensive oil production in 1960s-1970s, decline in production since 1972; well-developed infrastructure and institutions | Principal gas producing region of USSR in 1960-1970s; high capacity gas transmission lines developed; established infrastructure and institutions | First HPP in 1932 as source of electricity for industries; growing capacities up to 2000s, | First NPP in 1970; well-established infrastructure and institutions (incl. research, machine-building); capacities and production increased since 1991 | Use of water and wind energy for centuries; first windpower installation in the world (1931); development of RES since 1990s-2000s (wind, solar, hydro) | First use and first power plant in the end of 19 th century; electrification during Soviet times (TPPs, HPPs, NPPs); highly centralised system |
| Current state | Use of outdated equipment and technologies; low efficiency; regular failures; state subsidies | Domestic production meets 15-18% of demand; functioning refineries and transmission pipelines | Manipulatory topic on political agenda; high dependence on one supplier | Most of equipment and technologies outdated; ongoing rehabilitation of HPPs | 15 operating units at 4 NPPs, operational lifespan of NPPs prolonged, no new NPP units are under construction | Amount of wind and solar installations annually growing; green tariff incentives, yet not profitable | TPPs and NPPs main generators; Ukraine – net exporter of electricity; substantial inefficiencies from power generation to final consumption |
| Connections to other systems | Public and residential sectors, iron and steel industry, chemical and petrochemical industry and others | Transportation sector, connections to practically all sectors of economy | Public and residential sectors, iron and steel industry, non-metallic, chemical and petrochemical industry | Public and residential sectors, transport, agriculture, industries | Majority of economic sectors (public and residential, industries); hydro and renewable energy systems | Local businesses, industries consuming electricity/heat | Connected to all energy systems reviewed; consumption evenly distributed between public & residential and industrial sectors |

| Energy system | Coal | Oil | Gas | Hydro | Nuclear | Renewables | Electricity |
|------------------------|---|---|--|--|---|--|--|
| Importance | Extremely important for metallurgy (coking coal), electricity and heat production (energy coal) | Oil used in most of economic sectors (no substitution), specifically important for transportation; revenues from oil transmission | Revenues from gas transmission; extremely important for residential sector (heat production), metallurgy; gas used in most of sectors of economy | HPPs and HAPPs produce 10% of country's electricity, cover peak electricity demand | Extremely important, NPPs produce half of Ukraine's electricity, cover basic electricity demand, bring large economic revenue | Local importance for electricity/heat production; electricity from RES makes less than 1% of country's total; important for Crimea regions without own conventional resources (e.g., Crimea) | Extremely important for normal functioning of the economy and society |
| Governance | State-governed, influential private stakeholders (e.g., SCM Holdings Group) | State-governed, most of oil production controlled by state | State-governed, most of gas production controlled by state | State-governed, large-scale HPPs and HAPPs state-owned | State-governed, all nuclear enterprises are state-owned | State-governed, mostly private owners of RPPs, electricity produced from RES purchased by SE "Energorynok" | Power plants both state and privately owned, single buyer/seller model of wholesale el. market |
| Vulnerabilities | <i>Energy security</i> (coking coal imports) <i>Technical failures</i> (outdated technologies and equipment) <i>Human factor</i> (impacts of privatization, need of new generation of specialists, better training) | <i>Energy security</i> (more than 90% of imported oil of Russian origin) | <i>Energy security</i> (more than 70% of consumed gas of Russian origin) | <i>Technical failures</i> (outdated equipment and technologies) | <i>Energy security</i> (dependence on Russia in fuel extraction, enrichment, fabrication, technical services, nuclear waste storage, NPP equipment) <i>Technical failures</i> (often unpredictable) <i>Target for military attack</i> | <i>Change in climatic conditions</i> (unpredictable changes, global warming etc.) <i>Energy security</i> (use of imported equipment and services) | Combined vulnerabilities of all the previous six energy systems + <i>Technical failures</i> related to ageing transmission lines |

5. DISCUSSION AND ANALYSIS

The analysis of energy systems of Ukraine conducted in the previous chapter can give a better understanding of functioning of the whole national energy system of the country: define its strengths and weaknesses, pinpoint the existing and required energy policy priorities, and identify key drivers impelling the system's development. The collected data and information show the current trends within Ukraine's energy systems, providing a baseline for development a number of future scenarios. Thus, the current chapter will take a closer look at the national energy system of Ukraine as a complex and integrated structure, by bringing the data from the previous chapter together and aiming to address the primary aims and objectives of the thesis (see Paragraph 1.2).

5.1. Vital energy systems and their vulnerabilities

5.1.1. Identifying Ukrainian VES

In order to identify VESs, i.e. most important energy systems supporting the basic conditions for normal functioning and stability of the nation (domestic order and survival), Dryzek's theory of state imperatives can be used (see Paragraph 2.2.1). Table 14 below represents ranking of the seven energy systems, described in detail in the previous chapter, according to the six imperatives of a state: from domestic order to conservation. Based on this, Ukraine appears to be highly dependent on the following VESs:

- 1) **electricity** system;
- 2) **nuclear** energy system;
- 3) **natural gas** energy system;
- 4) **coal** energy system;
- 5) **oil** energy system.

Table 14.Rating* of Ukraine's energy systems according to the six imperatives of a state

| Imperative/ System | Domestic order | Survival | Revenue | Economic growth | Legiti- mation | Conser- vation | Total |
|-----------------------|-------------------|----------|---------|--------------------|-------------------|-------------------|------------|
| Coal | +++++ | +++++ | +++++ | +++++ | ++ | + | 23+ |
| Oil | +++++ | +++++ | ++++ | +++ | ++ | + | 20+ |
| Gas | +++++ | +++++ | +++++ | +++++ | ++ | + | 23+ |
| Nuclear | +++++ | +++++ | +++++ | +++++ | ++++ | ++ | 26+ |
| Hydro | ++++ | ++++ | +++ | +++ | +++ | ++ | 19+ |
| Renewables | ++ | ++ | ++ | + | + | + | 9+ |
| Electricity | +++++ | +++++ | +++++ | +++++ | ++++ | ++ | 26+ |

* see Appendix, Table A.8 for detailed description of the rating system

The vast electrical networks and the complex centralized electricity system created during the Soviet times as a part of the Union's electrification policy, became a foundation for further development of Ukraine's economy and the most fundamental asset of the nation. The system is directly connected to all of the other energy systems discussed in the work, as well as to most of economic sectors of the country. The extensive use of nuclear fuel, coal and natural gas for power and heat generation (see Figure 26) unavoidably makes the corresponding energy systems also vital. It appears, however, that renewable energy systems of Ukraine, including large hydropower, due to overcapacity of UES of Ukraine and existing substitutes (e.g., covering peak demand by hydropower can be substituted by gas-fired and coal-fired power units) cannot be perceived as supporting critical functions of society. Therefore, their importance on the national level is lower than that of other energy systems. Although oil is not currently used in Ukraine as a primary fuel for production of electricity, the oil energy system plays a crucial role for normal functioning of society (transportation, agriculture, defence and internal security) and lacks substitutes.

At the same time, according to Leung *et al.* 2014 (see Paragraph 2.2.3), support of critical functions of a society is not the only essential characteristic of VES. The system also has to consist of elements (natural resources, technical infrastructure, institutions), which are strongly

connected to each other, more than to the elements outside the system. The previous analysis showed that the elements of the discussed energy systems are indeed strongly interconnected, mostly because of historic peculiarities related to each of the systems.

Most of the technical infrastructure and influential energy institutions were created during the Soviet times (before 1990s). The electric power system of Ukraine was designed a complex and highly integrated structure, requiring its constant coordination and precision of operation. Since the system is highly centralized, there is a number of powerful institutions managing it and supporting its infrastructure and normal operation, headed by SE “Ukrenergo”. Similarly, SE “Energoatom” is supporting the functioning of the nuclear energy system, NJSC “Naftogaz” of the oil and gas energy systems.

5.1.2. Vulnerabilities

Each of the VESs is susceptible to a range of possible interruptions, which may result in failure of their functioning. As it is shown in Table 15 below, Ukraine’s dependency on energy imports, mainly from Russia, can lead to a number of interruptions affecting energy systems and economic sectors on different scale: from European to local. The natural gas energy system appears to be the most susceptible one, while coal and renewables’ energy system the least sensitive.

According to the three perspectives on energy security (see Table 5), the vulnerabilities of the natural **gas energy system** of Ukraine can be viewed from the ‘sovereignty’ perspective. The system has rigid historic roots associated with the escalating role of natural gas for Ukraine’s economy during 1960s-1970s, when the levels of extraction of indigenous gas were extremely high and natural gas of Ukrainian origin was not only used within the domestic borders but also transported to other Soviet republics. The multiple interconnections of the Ukrainian gas system with other countries developed decades ago and created the vulnerable infrastructure highly reliant on a single ‘malevolent agent’.

Table 15. Susceptibility of Ukrainian energy systems to externally-caused interruptions

| Scale | Description | Ukrainian energy system involved | Examples of interruptions | Economic sectors of Ukraine most affected |
|-----------------|--|--|--|--|
| European | externally-caused interruptions affecting the nation itself and other European nations | natural gas | cut-off of Russian gas supplies to Ukraine and Europe | residential, power and heat generation, industries |
| National | externally-caused interruptions affecting the whole nation | natural gas oil nuclear electricity | cut-off of Russian oil supplies; cut-off of enriched nuclear fuel supplies from Russia | all sectors |
| Regional | externally-caused interruptions affecting separate regions of the country | coal | cut-off of coking coal imports from Russia and Kazakhstan | iron and steel industry |
| Local | externally-caused interruptions affecting local territories and communities | renewables | termination of renewable energy projects supported by European companies | local power generation and local businesses |

The **nuclear energy system** combines the ‘sovereignty’ and the ‘robustness’ perspectives. On one hand, the use of nuclear power for electricity generation is often viewed as a way to enhance the national energy security by decreasing imports of fossil fuels and/or hydrocarbons. Indeed, because of the large designed installed capacities of NPPs, they can largely replace coal- or gas-fired power plants and provide a substantial amount of electricity, produced domestically, which also has a positive effect on environment. On the other hand, many issues and questions remain: where will the nuclear power technologies, equipment, enriched and fabricated fuel be coming from? where will the nuclear waste be stored? Only a few countries in the world have the so-called ‘complete nuclear cycle’: from nuclear fuel

extraction, enrichment and fabrication to the nuclear waste storage and burial. These include Russia, France, the US and a few others. Ukraine is, however, not in the list.

Historically, the nuclear system of Ukraine has been tied to Russian manufacturing capacities: while turbines for NPPs have been produced in Ukraine (at the power machine-building factory “Turboatom”, Kharkiv), all of the existing Ukrainian NPP reactors are of Russian production. As termination of designed lifespan of the Ukrainian NPPs approaches, new nuclear units have to be constructed, if the national energy policy continues to promote further use of nuclear power in the country’s energy mix (see Section 4.9). However, due to the absence of available technologies and production lines for construction of new reactors, enrichment of nuclear fuel and a number of other related maintenance services, Ukraine will have to cooperate with the countries which could provide the required services, i.e. with the world’s self-sufficient nuclear states mentioned above. Establishment of Ukraine’s own full nuclear cycle to ensure the country’s utter nuclear security, although is theoretically possible, would contravene with the Budapest Memorandum (CFR 1994) and require immense investments. Thus, the ‘sovereignty’ of Ukraine’s nuclear energy system leaves many questions to be answered.

At the same time, the Chornobyl accident played a substantial role in Ukraine’s energy future. Construction of a number of nuclear units was postponed or terminated because of the disaster (see Table 11). Among the unfinished NPPs is the Crimean NPP: a power station, which could significantly decrease dependency of the Crimean peninsula on electricity supplies from the mainland. The accident also resulted in adoption of stricter nuclear regulations not only in Ukraine but worldwide and “... gave rise to a fundamental worldwide change in approach when it comes to safety” (ENS 2006), which made the nuclear energy system more robust to possible failures. However, no protection policy mechanisms caused by such a major accident, such as switching to the use of more abundant resources and/or upgrading energy

infrastructure (see Table 5), were implemented in Ukraine afterwards. Moreover, the importance of the nuclear power increased since the collapse of the USSR, and according to the recent energy strategy, it may continue to be a major contributor to the country's energy balance in the future.

The **coal energy system**, unlike gas, oil or nuclear, appears to be less susceptible to external influence, due to the high levels of domestic coal extraction. Good-quality coking coal is the only resource, which Ukrainian metallurgy industry, and thus partially Ukrainian economy, is dependent on in terms of external supplies. Ukraine ranks 6th among the world's major coking coal importers shipping in 10 Mt of coking coal annually (WCA 2014). In case of any interruptions, however, the consequences are unlikely to be of a national scale, but rather affecting certain regions (such as Donbas, Kryvyi Rih) and stakeholders (e.g., Renat Akhmetov's "Metinvest"). Although the country's economy will be affected, the national energy system is unlikely to suffer from interruptions in coking coal supplies.

One of the largest vulnerabilities of the **Ukrainian energy system** is also its technical unreliability. The system is highly susceptible to failures, accidents and major inefficiencies, and requires an extensive upgrading. At the same time, the system's robustness cannot be in a constant decline. The increasing amount and scale of technological failures and understanding that the domestic fuel resources will eventually run out shall provoke the subsequent implementation of protection mechanisms and as a result enhance not only robustness but also resilience of the whole system and infrastructure. This transition, however, may take many decades to be accomplished.

5.2. Energy system drivers

5.2.1. Driving forces

Based on the analysis of the energy systems, the following drivers leading development of Ukraine's energy system can be distinguished:

1. High economic burden of the **coal** sector. Reforms are needed: privatization, eliminating subsidies, higher efficiency of production. Current plans to increase coal extraction, which will not, however, offset gas imports and the eventual retirement of the ageing nuclear capacities.

2. Tremendous pressure to change usage of **natural gas** imported from Russia.

3. Currently appeared interest to support **renewables** energy system (high feed-in tariffs). Some of largest RES potentials, however, are located in areas highly affected by the current Ukraine-Russia conflict: Crimea (solar), eastern regions (wind).

Together with these drivers, there are forces impeding development and transformation of Ukraine's national energy system:

1. Absence of pressure to change **oil** supply system.

2. Absence of short-term (5-10 years) pressure to change **hydroelectric** and **nuclear** energy systems.

3. Absence of own capacity to maintain and expand **nuclear** energy system, which is a backbone of the country's electricity system. The capacity can only be supported by an outside actor (such as Russia).

4. Absence of pressure to change **electricity** energy system and the electricity market scheme.

Therefore, the current major driver is related to the most susceptible VES – the gas energy system, and Ukraine's high dependency on Russia in gas supplies. At the same time,

there seem to be no short-term interest to decrease gas consumption or dramatically reduce gas supply from Russia, due to the widespread usage of gas in various economic sectors of Ukraine, the historically-formed convenient connections of Ukraine's gas system to those of Russia and Western Europe, lobbying stakeholders and institutions promoting the gas policy and other reasons.

Similarly, there is an absence of a short-term interest to change electricity, nuclear or hydroelectric systems, which notwithstanding the ageing infrastructure and equipment, are still to operate for another decade or more. Since Ukraine has never produced enough oil / oil products to meet its national demand, the historically formed oil supply system, together with a whole range of related stakeholders and institutions, is unlikely to be transformed in the nearest future. The coal sector, however, requires urgent modernization and restructuring, in order to increase profitability and security of coal production. This is especially important if Ukraine is to follow the Strategy's scenarios implying a gradual increase of domestic coal production. The latter policy, however, will not affect the utter significance of gas and nuclear energy systems in the country, but will only allow to partially meet the projected growing electricity demand.

5.2.2. Policy interests and stakeholders

The discussed driving forces appear due to interactions within the “Energy system – Institutions – Energy policy” triangle (see Section 3.1), where historically established energy institutions and major stakeholders in the energy sector play an extremely important role in shaping energy policies and this driving the system in a certain direction. The current Ukrainian energy system is a ‘dainty morsel’ for revenue seekers. As it was shown on the example of the coal sector, the opportunities for rent-seeking in the energy sector are huge and are estimated to make billions of dollars annually. Thus, it is not surprising that “... rather than try to change the system, dominant political motivation has been to gain control of the system and the rents it generates” (D’Anieri 2012).

Notwithstanding the privatization (e.g., coal sector) and liberalization (e.g., electricity market) processes taking place within some of Ukraine's energy systems, the centralized system of governance has not changed since the Soviet times. The state still plays a decisive role in energy sector governance and management of resources. Therefore, one of the ways to control the sector and its revenues is to have a legislative or executive power in the country (the Parliament, the Cabinet of Ministers, the Ministry of Energy and Coal Industry). Another influential state entity is the National Electricity Regulatory Commission. Not only it regulates the electricity supply, but also implements pricing and tariff policies in the country, including those for the oil market. Figure 29 below shows other major stakeholders involved in electricity generation and supply in the country, according to the energy systems analysed previously.

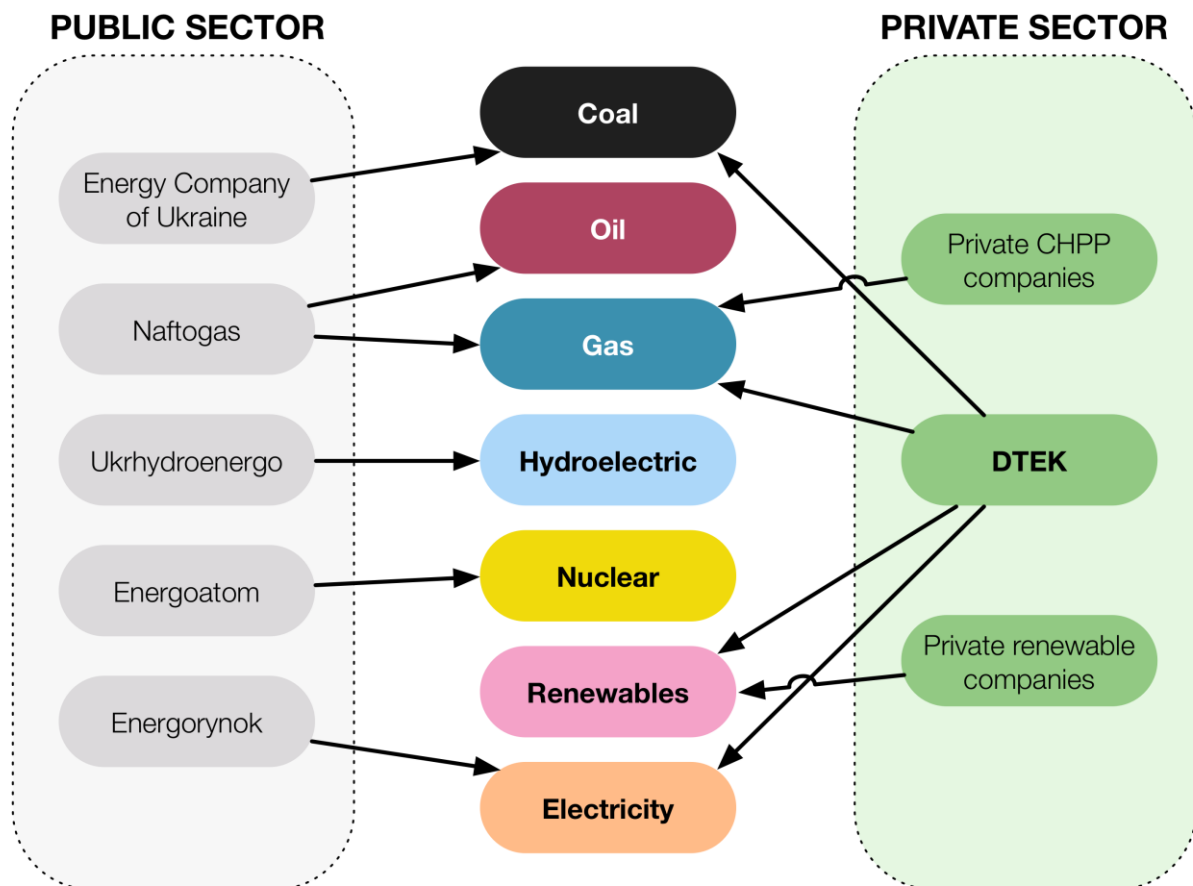


Figure 29. Major stakeholders in electricity generation and supply activities in Ukraine

Thus, there is a mix of state and private ownership in the sector. The most outstanding actor in the private sector is DTEK (owned by Ukraine's richest man R. Akhmetov), the company with big shares in coal, gas, electricity and renewables energy systems in relation to power generation and supply. As far as installed electric power capacity is concerned, the shares of state-owned and privately-owned electricity generating companies are almost equal: the *state* owns NPPs (nuclear), large HPPs (hydro) and some of TPPs (coal-fired) and CHPPs (gas-fired), while *private* entities own most of TPPs, CHPPs and renewable (solar, wind and small hydro) capacities. State and private companies interact and make certain agreements to receive a profit.

Decisions in the country are in the end taken not according to the national interests, but to the interests of key financial and industrial groups or family clans (e.g., see Paragraph 4.2.2 for coal industry rent-seeking scheme). For example, Ukraine's only electricity exporter, DTEK, sells electricity generated at its coal-fired Burshtynska TPP to the wholesale market for a high price and purchases it from "Energorynok" for a much lower wholesale price *legally* bypassing the Law "On electric power industry" and paying for it 30% less than other industrial enterprises (Kosharna 2013). Such schemes make the state-owned enterprises (including "Energoatom", "Hydroenergo") less profitable, unable to carry out the needed rehabilitation and renovation works, and thus the companies are forced to take up immense loans (Kosharna 2013) to continue their operation. The existing schemes also promote more extensive use of coal and gas for power generation, largely substituting the use of renewable energy resources.

As it was stated in the previous chapter, a number of Ukrainian companies belong to the top companies in Central Europe according to their revenue (see Appendix, Table A5). These include:

Table 16. Top energy market stakeholders in Ukraine according to revenue they generate

| Energy sector | Name | Activity | Owners |
|--------------------|-----------------------------------|--|---|
| Coal | <i>“Coal of Ukraine”</i> | coal mining and processing | state |
| Oil and gas | <i>“Naftogaz”</i> | extraction, transportation, refinement and production of gas, oil and oil products | state |
| | <i>“Ukrtatnafta”</i> | oil refinery | privately-owned (Ukrainian and Russian owners) |
| | <i>“Galnaftogaz”</i> | gasoline supplier and retailer | privately-owned (Ukrainian owner) |
| | <i>“Gazprom Sbut Ukraine”</i> | major supplier of natural gas | privately-owned (by Russia’s “Gazprom”) |
| | <i>“Alliance Oil Ukraine”</i> | oil refinery | privately-owned (Russian, Kazakhstan owners) |
| Nuclear | <i>“Energoatom”</i> | nuclear power generation | state |
| Electricity | <i>DTEK</i> | Ukraine’s largest electricity producer and distributor | privately-owned (Ukrainian owner) |
| | <i>“Energorynok”</i> | national electricity market | state |
| | <i>“Centrenergo”</i> | electricity producer (three TPPs) and distributor | state |

Sources: Deloitte 2013; KyivPost 2011; Podolyanets 2014; SCM 2014

The energy sectors listed in the table correspond to the five VESs of the country, identified in the previous section: electricity, nuclear, gas, coal and oil systems. Table 17 also shows that while coal, nuclear and electricity sectors are either state-owned or have private Ukrainian owners, oil and gas companies are largely privately-owned by foreign entities. This takes us back to the question of energy security, which proves to be the most topical issue in gas and oil sector. At the same time, the number of top-revenue oil and gas companies is much higher than for any other energy sector, which shows that the sector is among those that bring a large profit and is attractive for foreign investors (Russia, Kazakhstan, Belarus). On the contrary, the coal sector is largely owned by the state and it is a much less profitable business, especially as far as coal mining and processing is concerned.

5.3. Energy policy priorities

Analysis of the energy systems of the country and of the Strategy helps to identify the following empirically observable energy policy priorities:

1. Maintaining **stability**, through support of the existing system with large opportunities for illicit revenues
2. **Avoidance of** unpopular **reforms** (e.g., increase of energy prices for households)
3. **Privatization** of energy systems, while keeping centralized governance
4. Achieving **energy security in the ‘easiest’ way**: by expanding the existing capacities and the existing infrastructure (increased use of coal, nuclear power)

The priorities are mostly short-term and do not take into account a whole number of long-term trends, which Ukrainian energy system is tied up to: the depletion of domestic gas and coal resources, ageing of power plants (TPPs, NPPs, HPPs) and the whole energy infrastructure, gradual growth of oil and gas prices, deteriorating environment (see Appendix, Figure A5), renewable technology development, and others. The priorities also dramatically differ from the ones suggested by the IEA (2012) (see Section 4.9). This means that the historically-established energy systems, institutions and stakeholders play a larger role than international-given agendas in defining national energy priorities.

The stated priorities also correspond to the drivers discussed in Paragraph 5.2.1, which do not imply any urgent changes in structure or operation of the energy system in short-term. Similarly, the issue of achieving energy security, although stands as a high priority in many official talks and documents, is planned to be achieved at the lowest possible cost: by maintaining participation of the same stakeholders in the future, by minimal changes and maximal expansion of the existing infrastructure.

5.5. Future scenarios of Ukraine's energy

In order to project the future of Ukraine's energy, the current trends and uncertainties have to be taken into account. The trends vary from national (e.g., depletion of domestic gas) to international/European (e.g., EU becomes less dependent on Russia) to global (e.g., decline in cost of renewable energy technologies) and will affect Ukraine's energy system, no matter which scenario is reviewed.

Since the thesis has been written in the time of big political changes and the Ukraine-Russia 2014 political crisis, the outcome of the situation remains unclear and difficult to predict. Because Russia's influence on the current Ukraine's energy system is extremely large, the major important uncertainty as the current crisis is concerned, is whether the relationship with Russia will normalize in the future or it will become hostile. The role of Crimea as an area with large potential for development of renewable resources, as well as for shale and natural gas developments (see Figure 7 and Table 8), could potentially become significant. However, at the moment Crimea's share in electricity generation and energy supply in Ukraine is minor, and thus the peninsula's status is not taken into account the scenarios. Other uncertainties and current trends are shown on the Figure 30.

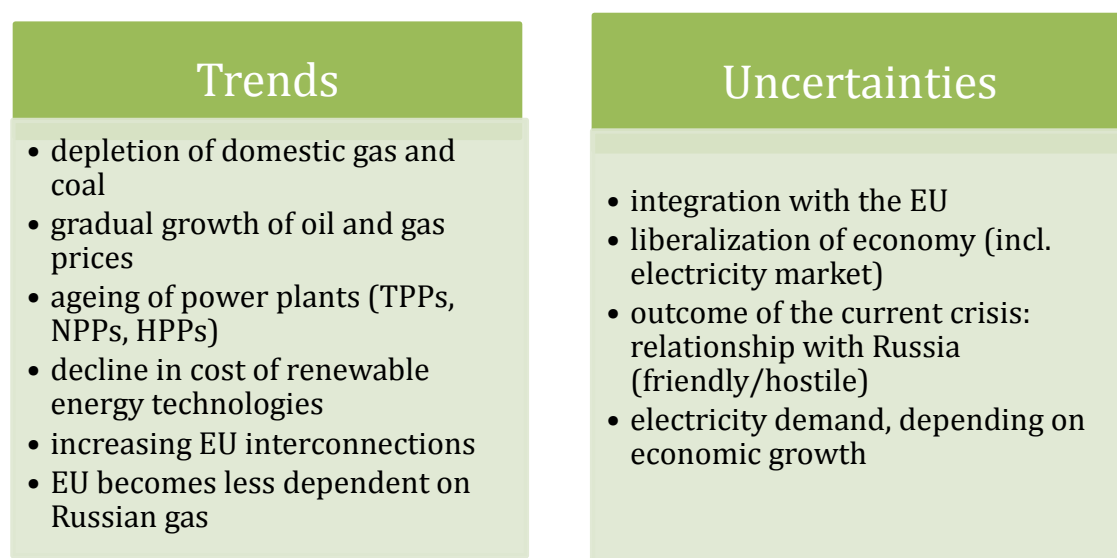


Figure 30. Trends and uncertainties for development of Ukraine's energy sector

The four scenarios discussed further below take into account a certain mix of uncertainties, which could potentially make up respective circumstances in shaping Ukraine's energy system and policies. These include two European integration scenarios (one with hostile and one with friendly relationship with Russia), a scenario with hostile relationship with Russia and no European integration, and finally, a "business as usual" scenario where energy markets continue to be controlled by the state and relationship with Russia normalizes.

Scenario 1

Economic growth, integration with EU, liberalization of economy, hostility with Russia

- Privatization and vertical de-integration in all energy systems. Competitive system, external energy suppliers present in energy markets. Development of private energy monopolies.
- Privatization and vertical de-integration of electricity sector.
- EU standards on environmental measures for energy supply, energy efficiency.
- Reduced export-oriented industrial production, some of heavy industries are bankrupt, reduced industrial energy consumption.
- Coal sector seriously weakened.
- Rehabilitation, renovation of the existing infrastructure and facilities.
- Ukraine will desperately try to find substitutes for Russian gas and decrease consumption of natural gas in the country by electrification of domestic heating systems and taking other measures. Agreement with European countries on development of the Odesa-Brody pipeline.
- Ukraine will try to find substitutes for Russian oil.
- Ukrainian NPPs for some time still receives services, enriched nuclear fuel from Russia according to the existing long-term agreements.

- Phasing out nuclear power in longer term, no new NPPs or nuclear power units constructed.
- Development of own energy resources: renewables, shale gas.
- Diversification of energy supplies, elimination of energy dependency on Russia.

Scenario 2

Economic growth, integration with EU, liberalization of electricity market, friendly with Russia

- Privatization and vertical de-integration in all energy systems. Competitive system, external energy suppliers present in energy markets. Development of private energy monopolies.
- Privatization and vertical de-integration of electricity sector. Electricity market governed by the EU Internal Energy Market ensuring a secure, competitive and environmentally sustainable market in electricity.
- Bringing operational characteristics of Ukraine's power plants to EU standards and increasing export of electricity to the west.
- EU standards on environmental measures for energy supply, energy efficiency. Rehabilitation of energy-intensive industries, such as iron and steel production.
- Coal sector seriously weakened.
- Opening the economy for foreign capital and investments: renewable projects, shale gas development, energy efficiency projects.
- Rehabilitation, renovation of the existing infrastructure and facilities.
- Keeping the current system of Russian gas supply and transmission.
- Agreement with European countries on development of the Odesa-Brody pipeline.
- Cooperation with Russia on nuclear energy. Common nuclear projects on construction of new power plants in Ukraine using the productive power of both countries.

- Development of own nuclear waste storage facilities (e.g., at Chornobyl).
- Partially keeping dependency on Russian fuel (gas, oil, enriched nuclear fuel) supplies, although at a lower level due to liberalisation of economy.

Scenario 3

Economic decline, no integration with EU, state-controlled markets, hostile with Russia

- Trying to maximally keep the existing energy infrastructure, electricity market structure.
- Reduction of export-oriented industrial production, reduced industrial energy consumption.
- Growing role of coal in the country's energy balance.
- Desperately trying to find substitutes for Russian gas and attempt to decrease consumption of natural gas (e.g., by electrification of domestic heating systems and taking other measures).
- Agreement with European countries on development of the Odesa-Brody gas pipeline.
- Use of the existing Ukraine-Europe gas transmission pipelines in reverse mode.
- Ukraine will try to find substitutes for Russian oil and coking coal.
- Ukrainian NPPs still receive services, enriched nuclear fuel from Russia according to the existing agreements.
- Phasing out nuclear power in longer term, no new NPPs or nuclear power units constructed.
- Import of electricity after phasing out NPPs.
- Increasing use of renewable energy resources.
- Foreign investments in shale gas extraction projects for both domestic use and export.
- Decreased/eliminated dependency on Russian energy imports by diversification of supplies.

Scenario 4

Economic decline, no integration with EU, state-controlled markets, friendly with Russia

- Keeping the existing energy infrastructure and electricity market structure.
- Keeping the current system of Russian gas supply and transmission. Increasing role of natural gas in the national energy system and industrial sector.
- Oil, coking coal, enriched nuclear fuel primarily of Russian origin.
- Carbon lock-in.
- Cooperation with Russia on nuclear energy. Common nuclear projects sponsored by Russia on construction of new NPPs in Ukraine using the productive power of both countries.
- Increasing energy dependency on Russia.

The scenarios show that relationship with Russia will be playing a major role in the question of Ukraine's energy security. Normalization of the relationship after the crisis would allow the currently existing gas and oil lobbying groups to continue their influence on Ukraine's energy sector and promote further use of gas throughout the country's economy, as well as keeping the Russia-EU gas transmission system operating. The convenience of such a situation would be very favourable for Russia in long-term, as well as for the EU in shorter term, while the latter is developing alternatives and new infrastructures substituting the use of Russian gas. On the other hand, establishment of hostile relationship with Russia in the future would push Ukraine towards diversification of its energy imports (especially gas, oil) and thus enhance the country's energy security.

The future role of nuclear energy system in Ukraine will also to an immense extent depend on the Ukraine-Russia relationship. Establishment of long-term cooperation between the two countries in nuclear power development would allow Ukraine to ensure it can meet its

electricity demand in the future, when the current NPPs come to an end of their service. Thus, if relationship with Russia normalizes, the two countries could cooperate to implement a whole range of nuclear projects, combining the productive and manufacturing powers they have since the Soviet times. Deterioration of Ukraine-Russia relationship would mean that Ukraine will have to look for other ways to meet its electricity demand in the future: either by developing new NPPs using some of the equipment, enriched fuel and services of non-Russian origin (e.g., French) or by dramatically changing its electricity mix with an increased role of renewables and domestic energy resources (shale gas, coal). The former is unlikely to happen due to the extremely high investments required to launch new nuclear power projects, which Ukraine will either not be able to afford (in case of Scenario 3, where economy is in decline) or will not be urged to (in case of Scenario 1, where economy is in improving and many alternatives for nuclear power generation can be found, including import of electricity from other countries).

The role of coal in the national energy balance is likely to grow under the scenarios of hostilities with Russia, especially under the Scenario 3, where Ukraine has to look urgently for Russian gas substitutes, and where energy markets are controlled by the state. The latter implies lobbying from the existing stakeholders, energy clans and interested groups, who would try to maximally keep the existing energy infrastructure and promote further use of coal as a major domestic abundant energy resource.

Integration with the EU and subsequent liberalization of Ukraine's economy and electricity market would bring a competitive energy system with external energy suppliers present in the country's energy markets. This would lead to development of private energy monopolies and at the same time diversification of energy imports, in case of both normalization and deterioration of Russia-Ukraine relationship. While Ukraine's electricity supply system is currently characterized by overcapacity and use of outdated technologies, integration with the EU will lead to the need to modernize the system, bring operational

characteristics of Ukraine's power plants to EU standards, which would allow to use the capacities efficiently and to increase export of electricity to the EU countries. This, however, will not be the case anymore when Russia-Ukraine relationship worsens and Ukraine has to phase out its large nuclear power capacities (Scenario 2). Closer ties with the EU and a simultaneous economic growth would also provide Ukraine with a chance to upgrade its energy system, infrastructure and rehabilitate energy-intensive industries, while actively developing own renewable resources and energy efficiency potential.

Development of RES is likely to proceed fast under the Scenarios 1, i.e. in case of economic growth and hostile relationship with Russia, which would urge Ukraine to look for different alternatives to meet the growing electricity demand and change the energy mix simultaneously. Economic growth, however, would simultaneously imply growing pressure on environment in the next decades, notwithstanding implementation of RES projects. The situation is likely to improve and stabilize in longer term, when all the possible energy efficiency measures are taken and energy mix changes in favour of the use of less or non-polluting energy resources.

6. KEY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This thesis examines and explains the establishment and development of energy systems and energy policies in Ukraine, and analyses primary drivers for their development through time. In order to carry out the research, a theoretical framework was proposed and applied, which allowed to follow and explain the process of establishment of the national energy system and policies. The framework implied analysis of the country's separate energy systems (coal, oil, gas, hydroelectric, nuclear, renewables, electricity) by answering the questions on historical development of each system, its current state, its connections to other systems and economic sectors, its importance for the nation/society, major institutions and stakeholders involved in its governance and management. The systems were then viewed in an integrated manner as parts of the national energy system.

The framework draws from the recent Global Energy Assessment concept of vital energy systems and the idea that institutional interests (historically established institutions and major stakeholders) play an important role in shaping energy supply chains and affect national energy policies and energy systems through the “Energy systems – Institutions – Energy Policies” triangle. The results of the research show that a number of vital energy systems, institutions and actors were historically formed in Ukraine, and that through the existing strong interconnections they largely affect the country's energy policy priorities and are driving the further development of Ukraine's national energy system.

The stated research aim and objectives were achieved through the historic and contemporary analysis of Ukraine's energy sector. Looking further into the past, rather than only at the present situation, allowed to understand better the current and future challenges of Ukraine's energy sector, to clarify why the national energy strategy prioritizes certain aspects (e.g., development of nuclear and coal sectors) while considerably disregards others (energy security, role of renewables). A comprehensive integrated historic analysis of establishment of

Ukraine's national energy system and of formation of the national energy policies has never been done previously. Thus, the current thesis represents an attempt to lay a foundation for such an analysis, which in perspective could help to build future energy policies and strategies of Ukraine, taking into consideration the current issues and challenges, as well as the historically established ties and connections between energy systems, different economic sectors, institutions and stakeholders.

6.1. Key findings

- ❖ **Main historic drivers** and driving forces for development of Ukraine's energy system:
 - presence of abundant energy resources (coal on the east, natural gas on the west), extraction of which started in the end of 19th – beginning of 20th century;
 - establishment of energy-intensive industries (such as iron and steel production) and large industrial centres starting from the end of 19th century, which required continuous fuel supplies;
 - the Soviet policy of nationwide electrification, which implied the use of local resources for power generation, electrification of all manufacturing processes, establishment of a centralized power supply system and a united energy system;
 - growing role of natural gas and oil for Ukraine's and USSR's economy in 1950s – 1970s, growing importance of Ukraine as a natural gas producer and a gas transit-state;
 - growing role of nuclear power generation in Ukraine's and USSR's electricity mix in 1970s – 1980s;
 - international and public pressure to terminate construction of new nuclear power plants and units after the Chornobyl disaster (1986);
 - Gorbachov's policy of economic liberalization in 1980s, weakening of institutions and state apparatus, increasing possibilities for rent-seeking schemes, formation of corrupt elites at the “public-private interface”;

- pressure from Russia in regard of unpaid gas bills and threats of cutting off gas supplies since early 1990s;
- establishment of closer political and economic ties with the neighbouring western, EU and other countries since 2000s (with certain temporal fluctuations).

❖ **Vital energy systems** of Ukraine: electricity, nuclear, natural gas, coal, oil.

❖ Energy systems most susceptible to externally-caused interruptions (directly affecting national **energy security**): natural gas, nuclear, oil.

❖ Main **current drivers** and driving forces for further development of Ukraine's energy system:

- tremendous political and economic pressure to change usage of natural gas imported from Russia;
- high economic burden of the coal sector and need of reforms: privatization, elimination of subsidies, modernization;
- currently appeared interest to support and develop renewables energy system.

❖ Current forces impeding development and transformations of the energy system:

- absence of pressure to change oil supply system, electricity energy system or electricity market structure;
- absence of short-term pressure to change hydroelectric and nuclear energy systems;
- absence of own capacity to maintain and expand nuclear energy system;

❖ **Major stakeholders** in Ukraine's energy sector (according to influence and revenues):

- 1) "Naftogaz" (state-owned, oil and gas sector);
- 2) DTEK (privately owned, coal-, gas-, wind-based electricity generation, electricity supply and export);

- 3) “Energoatom” (state-owned; electricity market of Ukraine);
- 4) “Energoatom” (state-owned; nuclear power generation).

❖ **Main energy policy priorities** (unofficial):

- keeping stability, mainly through support of the existing energy system with large opportunities for illicit revenues;
- maximal avoidance of unpopular reforms;
- privatization, while keeping the Soviet’s centralization system of governance;
- achieving energy security in the ‘easiest’ way: by expanding the existing capacities and existing infrastructures (increased use of coal, nuclear power).

❖ There is a constant **interaction** between energy systems, historically-established energy institutions and energy policies, which drive the national energy system in a certain way.

❖ **Future** of Ukraine’s energy system:

- Hostile relationship with Russia is likely to result in phasing out the use of nuclear power for electricity generation, development of own energy resources (shale gas, renewables), diversification of energy supplies and thus enhanced energy security.
Friendly relationship with Russia is likely to result in Ukraine’s long-term nuclear power future;
- Integration with EU means for Ukraine liberalization of energy markets with subsequent declining role of coal in energy balance, growing role of renewables and significantly improving the state of the existing energy systems and infrastructure, diversification of energy supplies;
- The ‘business as usual’ scenario implies a further declining energy security and slowing down of development of renewables.

6.2. Conclusions and recommendations

The geographic and historic conditions, together with the recent foreign policy of Ukraine, created an apparent choice between Russia and the European Union (West) in economic, political and other terms. This is especially topical in the view of the current crisis, which shall soon make Ukraine to make a decisive choice: to go either of the ways, although not necessarily breaking relations with another side, or to find a way out by itself not following any of the sides. The choice will have a direct impact on the country's economy and the way its energy system will develop.

The 'business as usual' scenario could potentially become the most deteriorating one for the country's energy sector: a weak rule of law, energy infrastructure falling into decay and increasing dependency on Russia in many energy-related issues. In the scenario the central role in Ukraine's energy market remains belonging to state and quasi-state actors, which further facilitates Russia to continue using energy as a lever to coerce Ukraine into following its rules. Cooperation with EU and Russia simultaneously is one of the best options, which could help Ukraine to modernize and reform its energy sector, while diversifying energy imports and exporting own energy products (such as electricity). Achieving this, however, is an immensely difficult task, requiring long-term planning and strong political governance; but if managed properly can be accomplished. A full integration to the EU may leave Ukraine in a hostile relationship with Russia for decades and lead to the necessity of phasing out nuclear power capacities, while turning from a net electricity exporter to electricity importer. Ukraine's energy security will, however, dramatically improve in this situation.

The thesis' findings can also help to identify and summarize the main priorities, which shall guide the energy policy of Ukraine in the future:

1. Improving energy security (diversification of energy imports, use of renewables, decreasing natural gas consumption nationwide)

2. Improving energy efficiency from fuel extraction to power and heat generation to final energy use
3. Market reforms in energy sector (privatization, state incentives for energy security, efficiency, environmentally-sound energy projects)
4. Elimination of vulnerabilities (technical modernization, education and training)
5. Increasing transparency (access to data, information, decisions)

These are long-term priorities, many of which go into big contrast with the existing energy schemes and preferences of the major energy sector stakeholders. This means that the path towards sustainable and secure energy system for Ukraine implies a whole number of transitions, many challenges to deal with and many more years to go through.

6.3. Implications for future research

The present research can potentially be used as a theoretical basis to carry out further studies on the topic of development of energy systems and energy policies in Ukraine, as well in other countries. The thesis had a number of limitations, which shall be taken into consideration:

1. The work is theoretical and requires practical insights and opinions on the issues discussed.
2. The findings are to a big extent generalized. Further research requires a comprehensive analysis of all the energy systems (including the heat energy system), energy flows and final energy consumers.
3. Notwithstanding the fact that data used in the work were taken from official state reports, documents and scientific papers, their validity can be questioned due to the non-transparent schemes present throughout the country's energy sector.

4. Some of required data could not be found, acquired or calculated due to technical and other issues. These include historic data on export of electricity from Ukraine, historic data on final energy consumption patterns, full information on energy sector stakeholders and on transformations of energy institutions through time (e.g., of gas and oil institutions, how they transformed between 1980s and 2000s).
5. The recent political and economic crisis and its possible impact on the future of Ukraine's energy sector could not be taken into account due to many uncertainties and the quickly changing situation in the country. The consequences of the crisis, such as annexation of Crimea by Russia, together with the region's Black Sea oil and gas province and a large renewable energy potential, can be followed and studied separately, in order to complement the research in the future.
6. The data used in the work include data from Crimea, as an autonomous republic of Ukraine (i.e., before 16th March 2014).

Reference List

- Ablitsov, V. 2007. *Galaktyka "Ukrajina". Ukrajinska diaspora: vydatni postati* [The Galaxy "Ukraine". Ukrainian diaspora: eminent figures]. Kyiv: KYT.
- Ananiev, G.D., Baryshev, V.A., Mhitaryan, S.G., Neporozhnyi, P.S., Steklov, V.Y., Stolyarov, A.V., Yaganov, M.P. 1977. *Elektrifikatsiya SSSR: 1967 – 1977* [Electrification of USSR: 1967 – 1977]. Moscow: Izdatelstvo "Energiya".
- Anishin, A.S., Piriashvili, B.Z., and Chirkin, B.P. 2013. Trends and prospects in ensuring energy resources in Ukraine. *Studies on Russian Economic Development* 24 (1): 84-98.
- Aslund, A. 2009. How Ukraine became a market economy and democracy. *Post-Soviet Geography and Economics* 42 (5): 313 – 328.
- Babenko, L.A., Jenkovszky, L.L., and Pavlovych, V.N. 2009. Prospects of safe nuclear energy in Ukraine. In *Progress in high-energy physics and nuclear safety*, eds. V.Begun et al., 293-318. Springer Science+Business Media B.V.
- Barca, S. 2011. Energy, property, and the industrial revolution narrative. In *Ecological Economics* 70: 1309-1315.
- BBC. 2014. *Ukraine rejects Russia Gazprom gas price hike*. URL: <http://www.bbc.co.uk/news/business-26902522> [consulted on 14th May 2014].
- Bending, R. and Eden, R. 1984. *UK energy: structure, prospects and policies*. Cambridge: Cambridge University Press.
- Bhattacharyya, S.C. 2011. Overview of global energy challenges. In Bhattacharyya, S.C. *Energy economics: concepts, issues, markets and governance*, 419-439. London: Springer.
- Biletsky, V.S., Boiko, V.S., Zolotko, O.A., Saranchuk, V.I., Panov, B.S., et al. 2002. *Girnychiy encyclopedychnyi slovnyk*. [Mining dictionary]. Vol.3. Donetsk: Shidnyi Vydavnychiy Dim.

Boscia, L.N. 2010. *Ukraine under the empires and the 19th century periods*. URL: http://www.personal.psu.edu/lmb5048/blogs/louis_boscia_ukr_100_final_project/2010/02/ukraine-under-the-empires-and-the-19th-century-periods.html [consulted on 5th February 2014].

Bulych, Y. 2006. *Energetyka Ukraini: istoriya stanovlennya i suchasnyi stan* [Energy sector of Ukraine: history of establishment and current state]. URL: <http://www.ji.lviv.ua/n41texts/bulych.htm> [consulted on 10th February 2014].

Cabinet of Ministers of Ukraine (CMU). 2001. *Postanova "Pro zatverdzhennya programy UKRAJINSKE VUGILLYA" vid 19 veresnya 2001 roky, №1205* [Decree "On approval of the programme UKRAINIAN COAL" of 19th September 2001, No.1205]. URL: <http://zakon4.rada.gov.ua/laws/show/1205-2001-%D0%BF> [consulted on 13th May 2014].

_____. 2014. *Rozporyadzhennya "Pro nadannya dozvolu na rozroblennya proektu zemleustroyu shchodo vidvedennya zamalnyh dilyanok" vid 23go kvitnya 2014 r. No.399-r* [Decree "On granting permission for land development project on land allotment" of 23rd April 2014 No.399-r]. URL: <http://zakon1.rada.gov.ua/laws/show/399-2014-%D1%80> [consulted on 14th May 2014].

Campbell, C.J. 2013. *Campbell's atlas of oil and gas depletion*, 159-161. URL: <http://www.springer.com/energy/fossil+fuels/book/978-1-4614-3575-4> (Consulted on 7 November 2013).

Carbon Capture and Storage Association (CCSA). 2013. *Why CCS?* URL: <http://www.ccsassociation.org/why-ccs/> [consulted on 7th November 2013].

Castles, F.G. 1985. *Terra incognita Australis: a search for new directions in comparative policy analysis*. *Government and Opposition* 20/3: 384.

Central Intelligent Agency (CIA). 2013. *The world factbook: Ukraine*. URL: <https://www.cia.gov/library/publications/the-world-factbook/geos/up.html> [consulted on 12th February 2014].

Channon, J. and Hudson, R. 1995. *Historical atlas of Russia*. London, New York, Victoria, Ontario, Auckland: The Penguin Group.

Cherp, A., Adenikinju, A., Goldthau, A., Hughes, L., Jansen, J., Jewell, J., et al. 2012. Chapter 5: energy and security. In *Global energy assessment – Toward a sustainable future*, 325 – 383. Cambridge: Cambridge University Press.

Cherp A., Antypas, A., Cheterian, V., and Salnykov M. 2007. *Environment and security: transforming risks into cooperation. The case of Eastern Europe (Belarus – Moldova – Ukraine)*. URL:

http://www.envsec.org/publications/ENVSEC.%20Transforming%20risks%20into%20cooperation.%20The%20case%20of%20Eastern%20Europe_English.pdf [consulted on 7th November 2013].

Cherp, A., Jewell, J., and Goldthau, A. 2011. Governing global energy: Systems, transitions, complexity. *Global Policy* 2(1): 75-88.

Cherp, A. and Jewell, J. 2011. The three perspectives on energy security: intellectual history, disciplinary roots and the potential for integration. *Current Opinion in Environmental Sustainability* 3(4): 202-212.

Cherp, A. and Jewell, J. 2013. Energy security assessment framework and three case-studies. In *International handbook of energy security*, eds. M. Trombetta and H. Dyer, 146-173. Cheltenham Glos, UK: Edward Elgar Publishing.

Cooper, J. 2013. *Ukraine: from European bread basket to clean technology pioneer*? URL: <http://www.waste-management-world.com/articles/print/volume-12/issue-3/regulars/iswa-comments/ukraine-from-european-bread-basket-to-clean-technology-pioneer.html> [consulted on 19th March 2014].

Council on Foreign Relations (CFR). 1994. *Budapest Memorandums on Security Assurances*, 1994. URL: <http://www.cfr.org/arms-control-disarmament-and->

[nonproliferation/budapest-memorandums-security-assurances-1994/p32484](#) [consulted on 13th May 2014].

Csereklyei, Z. 2014. Measuring the impact of nuclear accidents on energy policy. *Ecological Economics* 99: 121 – 129.

D'Anieri, P. 2012. Ukrainian foreign policy from independence to inertia. *Communist and Post-Communist Studies* 45: 447 – 456.

Deloitte. 2013. *Top 500: Central Europe 2013*. URL: <http://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/ce-top500-2013.pdf> [consulted on 7th May 2014].

Demirel, Y. 2012. Energy and energy types. In Damirel, Y. *Energy: Production, conversion, storage, conservation, and coupling*, 27-70. London: Springer.

Dewdney, J.C. 1982. *USSR in maps*. London, Sydney, Auckland, Toronto: Hodder and Stoughton.

Dienes, L. and Shabad, T. 1979. *The Soviet energy system: resource use and policies*. Washington, D.C.: V.H. Winston & Sons.

DIFFER. 2012. *The Ukrainian electricity system – a brief overview*. URL: http://www.differgroup.com/Portals/53/images/Ukraine_overall_final.pdf [consulted on 17th February 2014].

Diyak, I.V., Osinchuk, Z.P., and Savkiv, B.P. 2009. *Gazova galuz Ukraini: stanovlennya, dosyagnennya, osobystosti* [Gas industry of Ukraine: establishment, achievements, personalities]. Kyiv: Svit Uspihu.

Dryzek, J.S., Hunold, C., Schlosberg, D., Downes, D., and Hernes, H.-K. 2002. Environmental transformation of the state: The USA, Norway, Germany and the UK. *Political Studies* 50: 659-682.

DT News. 2014. *Stand-off in Ukraine*. URL: <http://dt.bh/stand-off-in-ukraine/> [consulted on 12th February 2014].

The Economist Intelligence Unit and the Cartographic Department of the Clarendon Press (EIU and CDCP). 1956. *The USSR and Eastern Europe*. London: Oxford University Press.

ENERGOATOM. 2014a. Place NNEGC “Energoatom” in the energy market of Ukraine. URL: http://www.energoatom.kiev.ua/en/about/about_nngc/ [consulted on 18th April 2014].

_____. 2014b. *V Ukrajinі vdoskonalyujut systemy fizychnogo zahystu atomnyh elektrostancij* [Ukraine is improving its physical security systems at nuclear power plants]. URL: <http://www.energoatom.kiev.ua/ua/press/nngc/38810-v-ukraini-vdoskonalyuyut-sistemi-fizychnogo-zahystu-atomnih-elektrostantsiy/> [consulted on 14th May 2014].

Energy Community (EC). 2009. *Protocol concerning the accession of Ukraine to the Treaty establishing the Energy Community*. URL: www.energy-community.org/pls/portal/docs/728177.PDF [consulted on 11th November 2013].

Energy Information Administration (EIA). 2011. *International energy statistics: total electricity capacity*. URL: <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7> [consulted on 14th May 2014].

_____. 2013. *International energy outlook 2013 with projections to 2040*. URL: [http://www.eia.gov/forecasts/ieo/pdf/0484\(2013\).pdf](http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf) [consulted on 29th October 2013].

European Association for Coal and Lignite (EURACOAL). 2014. *Country profiles: Ukraine*. URL: <http://www.euracoal.com/pages/layout1sp.php?idpage=269> [consulted on 11th May 2014].

European Commission (EC). 2012. *Seventh joint EU-Ukraine report: implementation of the EU-Ukraine Memorandum of Understanding on Energy Cooperation during 2012*. URL: ec.europa.eu/energy/international/bilateral_cooperation/doc/ukraine/20130225_mou_progress_report7_en.pdf [consulted on 2nd November 2013].

European Nuclear Society (ENS). 2006. *Chernobyl: the accident scenario and its global impact*. Issue No.12 (April 2006). URL: <http://www.euronuclear.org/e-news/e-news-12/presidents-contribution.htm> [consulted on 26th April 2014].

Ezeh, A.C., Bongaarts, J., and Mberu, B. 2012. Global population trends and policy options. *The Lancet* 380 (9837): 142-148.

Florini, A., and Sovacool, B.K. 2009. Who governs energy? The challenges facing global energy governance. *Energy Policy* 37 (12): 5239-5248.

Franke, A., Gawrich, A., Melnykovska, I., and Schweickert, R. 2010. The European Union's relations with Ukraine and Azerbaijan. *Post-Soviet Affairs* 26(2): 149-183.

Frantsevich Institute for Problems of Material Science (FIPMS). 2013. *IMPS NASU*. URL: <http://www.materials.kiev.ua/science/home.jsp> [consulted on 15th May 2014].

Geletuha, G.G., Zheliezna, T.A., and Drozdova, O.I. 2014. *Energetychnyi ta ekologichnyi analiz tehnologiy vyrobnytstva energiyi z biomasy* [Energy and environmental analysis of biomass energy supply technologies]. Analytical report No. 8 prepared for the Bioenergy Association of Ukraine. URL: <http://www.uabio.org/img/files/docs/position-paper-uabio-8-ua.pdf> [consulted on 17th May 2014].

Global Energy Assessment (GEA). 2012. *Global Energy Assessment – Toward a Sustainable Future*. Cambridge: University Press. Cambridge UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. URL: <http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA-Summary-web.pdf> [consulted on 28th October 2013].

Gnansounou, E. 2008. Assessing the energy vulnerability: case of industrialised countries. *Energy Policy* 36 (10): 3734 – 3744.

Goldthau, A., and Sovacool, B.K. 2012. The uniqueness of the energy security, justice, and governance problem. *Energy Policy* 41: 232-240.

Gonchar, M. 2012. Chastka VDE v energobalansi vyznachyt tehnologichnyi potentsial Ukraini [Renewable energy share in energy balance with identify technological potential of Ukraine]. *Dzerkalo Tyzhnia* of 2012/08/06. URL: <http://ua-energy.org/post/22974> [consulted on 5th March 2014].

Herasimovich, V. 2008. *Ukrainian oil refinery sector review*. Center for Social and Economic Research. URL: <http://www.case-ukraine.com.ua/u/publications/e9c7feea5be204cd8cc69fc00904b15f.pdf> [consulted on 15th May 2014].

Hrycak, Y.J. 2000. *Narys istoriji Ukrajiny: formuvannya modernoji ukrajinskoji natsiji XIX-XX st.* [Outline of the history of Ukraine: establishment of the modern Ukrainian nation in XIX-XX centuries]. 2nd ed. Kyiv: Geneza.

IMEPOWER. 2013. *Ukraine renewable energy newsletter*. Issue No.27 of 19th October 2013. URL: <http://imepower.files.wordpress.com/2013/10/ukraine-renewable-energy-newsletter-27.pdf> [consulted on 17th May 2014].

Institute for Energy and Transport (IET). 2012. *Solar radiation and photovoltaic electricity potential: country and regional maps for Europe*. URL: <http://re.jrc.ec.europa.eu/pvgis/cmapi/eur.htm> [consulted on 15th May 2014].

Intergovernmental Panel on Climate Change (IPCC). 2005. *IPCC special report on carbon dioxide capture and storage*. Report prepared by Working Group III of the Intergovernmental Panel on Climate Change. URL: http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf [consulted on 4th November 2013].

_____. 2013. *Climate change 2013: The physical science basis. Working Group I contribution to the IPCC 5th assessment report - changes to the underlying Scientific/Technical Assessment.* URL: http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_All.pdf [consulted on 28th October 2013].

International Energy Agency (IEA). 1996. *Energy policies of Ukraine: 1996 survey.* Paris: OECD/IEA.

_____. 2006. *Ukraine: Energy policy review 2006.* Paris: OECD/IEA. URL: <http://www.iea.org/publications/freepublications/publication/ukraine2006.pdf> [consulted on 7th November 2013].

_____. 2011. *Are we entering a golden age of gas?* Special report prepared by the International Energy Agency. URL: <http://www.worldenergyoutlook.org/goldenageofgas/> [consulted on 30th October 2013].

_____. 2012. *Energy policies beyond IEA countries: Ukraine 2012.* International Energy Agency and Organisation for Economic Co-operation and development. URL: http://www.iea.org/publications/freepublications/publication/UK_Summaryplus.pdf [consulted on 28th October 2013].

International Energy Agency/Global CCS Institute report to the third Clean Energy Ministerial (IEA and GCCSI) 2012. *Tracking progress in carbon capture and storage.* URL: <http://www.iea.org/publications/freepublications/publication/IEAandGlobalCCSInstituteTrackingProgressinCarbonCaptureandStoragereporttoCEM3FINAL.PDF> [consulted on 7th November 2013].

Ivkin, V.I. 1999. *Gosudarstvennaya vlast SSSR: visshie organi vlasti i upravleniya i ih rukovoditeli 1923 – 1991* [USSR national governance: supreme governance and management bodies and their heads]. Moscow: ROSSPEN.

Jewell, J. 2012. *Global energy security in long-term de-carbonization scenarios: assessment framework, indicators, and preliminary results*. URL: http://www.exeter.ac.uk/energysecurity/documents/ese_resources_May2012/Jessica_Jewell.pdf [consulted on 1st May 2014].

Jewell, J., Cherp, A., and Riahi, K. 2014. Energy security under de-carbonization scenarios: an assessment framework and evaluation under different technology and policy choices. *Energy Policy* 69: 674 – 648.

Kabak, A.Y. and Kornilova, O.M. 2012. Ekonomiko-statystychnyi analiz palyvno-energetychnogo kompleksu Ukrainy protyagom 2001 – 2010 rokiv [Economic and statistical analysis of the fuel and energy complex of Ukraine for the time period of 2001 – 2010]. In *Visnyk Dnipropetrovskogo Universytetu imeni Olesya Gonchara*. URL: <http://vestnikdnu.com.ua/archive/201264/kabak.html> [consulted on 16th May 2014].

Kalynchuk, D. 2011. Mali GES – velyki nadiyi [Small HPPs – big hopes]. *Tyzhden UA* of 28th October 2011. URL: <http://tyzhden.ua/Economics/34111> [consulted on 12th May 2014].

Khromov, P.I. 1950. *Ekonomicheskoe razvitie Rossii v XIX – XX vv.* [The economic development of Russia in 19–20th centuries], p.195. Moscow: Gosudarstvennoe izdatelstvo politicheskoy literaturi.

Kish, G. 1960. *Economic atlas of the Soviet Union*. Michigan: The University of Michigan Press.

Kochura, V. 2012. Coal market of Ukraine: Analysis and development background. *GeoScience Engineering* 58 (1): 17 – 23.

Kondrat, R.M. and Serednytsky, L.M. 2013. Vydobuvannya nafty ta gazu [Extraction of oil and gas]. In *Naftogazova galuz' Ukraini: postup i osobystosti* [Oil and gas sector of Ukraine: history and personalities]. Kyiv: Publishing Centre "Logos Ukrainia".

Kosharna, O. 2013. *Hto “zachyshchaje” energorynok pid Ahmetova* [Who cleans up the energy market for Akhmetov]. Publication for the National Society of Journalists of Ukraine. URL: <http://nsju.org.index.php/article/1278> [consulted on 15th May 2014].

Kozyuk, V.V., Rodionova, L.A., et al. 2011. *Istoriya ekonomiky ta ekonomichnoji dumky: vid rannih cyvilizacyi do pochatku XX st.* [History of economy and economic thought: from the early civilizations to the beginning of 20th century]. Kyiv: Znannya.

Kramer, A.E. 2009. Russia cuts off gas deliveries to Ukraine. *New York Times* of 1st January 2009. URL: http://www.nytimes.com/2009/01/02/world/europe/02gazprom.html?_r=0 [consulted on 14th May 2014].

Kropatcheva, E. 2011. Playing both ends against the middle: Russia's geopolitical energy games with the EU and Ukraine. *Geopolitics* 16 (3): 553-573. URL: <http://dx.doi.org/10.1080/14650045.2011.520863> [consulted on 6th November 2013].

Kudelia, S. 2012. The sources of continuity and change of Ukraine's incomplete state. *Communist and Post-Communist Studies* 45: 417 – 428.

Kudrya, S. 2008. *Renewable energy development in Ukraine*. URL: <http://www.energy-community.org/pls/portal/docs/326201.PDF> [consulted on 6th March 2014].

Kurbatova, T., Sotnyk, I., and Khlyap, H. 2014. Economical mechanisms for renewable energy stimulation in Ukraine. *Renewable and Sustainable Energy Reviews* 31: 486 – 491.

Kuzio, T. 1998. Ukraine: a four-pronged transition. In *Contemporary Ukraine: dynamics of post-Soviet transformation*, ed. T.Kuzio, 165 – 180. New York: M.E. Sharpe Inc..

_____. 2012a. Twenty years as an independent state: Ukraine's ten logical inconsistencies. *Communist and Post-Communist Studies* 45: 429 – 438.

_____. 2012b. The Ukrainian immobile state two decades after the disintegration of the USSR. *Communist and Post-Communist Studies* 45: 413 – 415.

_____. 2013. *Shale gas could drive Ukraine's European integration*. URL: www.alaskadispatch.com/article/20130617/shale-gas-could-drive-ukraines-european-integration [consulted on 10th March 2013].

Kyivenergo. 2014. *Taryfy na elektrychnu energiyu (krim naseleennya)* [Electricity tariffs (except for residential sector)]. URL: <http://kyivenergo.ua/ee-company/tarifi> [consulted on 14th May 2014].

KyivPost. 2012. *Top Ukrainian companies by revenue: Deloitte's Picks, 2011*. URL: http://www.kyivpost.com/media/images/data/images/01-32_KyivPost_38-9/original.jpg [consulted on 7th May 2014].

Lanovyk, B.D., Matysyakevych, Z.M., Mateiko, R.M., et al. 1994. *Ukrajina i svit: istoriya gospodarstva vid pervisnoji doby i pershyh tsyvilizatsij do stanovlennya industrialnogo suspilstva* [Ukraine and the world: the history of economy from the first eras and first civilizations to the establishment of industrial society]. Kyiv: Geneza.

Leung, G.C.K., Cherp, A., Jewell, J., and Wei, Y.-M. 2014. Securitization of energy supply chains in China. *Applied Energy* (2014).

Marocchi, T. and Fedirko, T. 2013. *Shale gas in Poland and Ukraine: a great potential and an uncertain future*. A business report for the Portal on Central and Balkan Europe. URL: <http://www.pecob.eu/shale-gas-pl-ua> [consulted on 19th March 2013].

Matuszak, S. 2012. The oligarchic democracy: the influence of business groups on Ukrainian politics. *OSW Studies No.42 (September)*. Warsaw: Ośrodek Studiów Wschodnich im. Marka Karpia.

Medvedev, Z.A. 1990. *The legacy of Chornobyl*. New York, London: W.W.Norton & Company Inc.

Meo, N. 2013. 'It was like a science-fiction movie': Chernobyl – site of the world's worst nuclear accident revisited. *The Independent* (of 7th November 2013). URL:

[http://www.independent.co.uk/news/world/europe/it-was-like-a-sciencefiction-movie-
chernobyl--site-of-the-worlds-worst-nuclear-accident-revisited-8925141.html](http://www.independent.co.uk/news/world/europe/it-was-like-a-sciencefiction-movie-chernobyl--site-of-the-worlds-worst-nuclear-accident-revisited-8925141.html) [consulted on 24th March 2014].

Milstein, D. and Cherp, A. 2009. Energy security and the environment in Eastern Europe: the case study of Ukraine. In *Energy and Environmental Challenges to Security*, ed. S.Stec and B.Baraj, 237 – 249. Springer Science + Business Media B.V.

Ministry of Energy and Coal Industry of Ukraine (MECIU). 2012a. *Onovlennya energetychnoji strategii Ukrajinu na period do 2030 roku* [Updated energy strategy of Ukraine until 2030]. URL: <http://mpe.kmu.gov.ua/fuel/doccatalog/document?id=222032> [consulted on 16th October 2013].

_____. 2012b. *Statement on security of energy supply of Ukraine*. URL: <http://www.energy-community.org/pls/portal/docs/1676177.PDF> [consulted on 7th November 2013].

_____. 2014a. *Perelik derzhavnyh pidpryjemstv, ustanov, organizacij ta objednan', shcho nalezhat' do sfery upravlinnya Ministerstva energetyky ta vugilnoji promyslovosti Ukrajinu, stanom na 01.02.2014* [List of state enterprises, entities, companies and unions, which belong to the governance sphere of the Ministry of Energy and Coal Industry of Ukraine, as of 1st February 2014. URL: http://mpe.kmu.gov.ua/minugol/control/uk/publish/article?art_id=244927080&cat_id=194359 [consulted on 4th May 2014].

_____. 2014b. *Statystychna informaciya za sichen-gruden 2013 roku* [Statistical information on January-December 2013]. URL: http://mpe.kmu.gov.ua/minugol/control/uk/publish/article;jsessionid=8C461104BD66157B67E24B5F2C90CDE1.app2?art_id=244907076&cat_id=35081 [consulted on 10th May 2014].

Ministry of Ecology and Natural Resources of Ukraine (MENRU). 2012. *Natsionalna dopovid pro stan navkolyshnyogo pryrodnogo seredovyscha v Ukraini u 2011 roci* [National report on the state of environment of Ukraine in 2011]. Kyiv: Ministry of Ecology and Natural Resources of Ukraine. URL: <http://www.menr.gov.ua/media/files/NacDopovid2011.pdf> [consulted on 5th November 2013].

Munting, R. 1996. Industrial revolution in Russia. In *The industrial revolution in national context*, ed. M. Teich, and R. Porter, 329-349. Cambridge: Cambridge University Press.

NAFTOGAZ (National Joint-Stock Company of Ukraine “Naftogaz”). 2012. *History of oil and gas industry*. URL: <http://www.naftogaz.com/www/3/nakweben.nsf/0/69CDD708EEFC16B4C22570D8003432CC?OpenDocument&Expand=1&> [consulted on 10th February 2014].

Nagayama, D. and Horita, M. 2014. A network game analysis of strategic interactions in the international trade of Russian natural gas through Ukraine and Belarus. *Energy Economics* 43: 89 – 101.

National Electricity Regulatory Commission (NERC). 2014. *Taryfy na elektroenergiyu, shcho vidpuskajetsya naseleunnyu* [Electricity tariffs for residents]. URL: <http://www.nerc.gov.ua/?id=4787> [consulted on 14th May 2014].

NAUKANAFTOGAZ. 2014. *About us: history*. URL: http://www.naukanaftogaz.com/index.php?option=com_content&view=article&id=10&Itemid=14&lang=en [consulted on 23rd March 2014].

New York Times (NYT). 2014. *In taking Crimea, Putin gains sea of fuel reserves*. URL: http://www.news-journal.com/news/world/in-taking-crimea-putin-gains-sea-of-fuel-reserves/article_7cf73cdb-0f5b-5b39-94c1-a8e296a580cc.html [consulted on 18th May 2014].

Nikolova, S. 2010. *Vulnerability of renewable energy production to climate change*. Workshop on vulnerability of energy systems to climate change and extreme events, 19

– 23 April 2010, International Centre for Theoretical Physics. URL: http://cdsagenda5.ictp.trieste.it/html_trees_links/1201801804/participants_presentations/Nikolova-Vulnerability_Renewable_Energy.pdf [consulted on 29th April 2014].

Oblenergo. 2014. *DTEK Shidenergo kupyla 1,1 GVt potuzhnostei dlya eksportu elektroenergiyi* [DTEK Shidenergo purchased 1.1 GW of capacities for export of electricity]. URL: <http://www.oe.if.ua/showarticle.php?id=2621> [consulted on 11th May 2014].

Ogarenko, Y. 2010. *Problemy vugilnoyi promyslovosti Ukrainy ta vykydy parnykovykh gaziv vid dobutku j spozhyvannya vugillya* [Challenges of the coal industry of Ukraine and greenhouse gas emissions from production and consumption of coal]. Report prepared for the National Ecological Centre of Ukraine. URL: <http://climategroup.org.ua/wp-content/uploads/2007/07/problemy-ugleproma.pdf> [consulted on 13th May 2014].

Omelyanovsky, P.I., Korchevoi, Y.P., Prahovnik, A.V., Popov, V.A., Akimov, A.A., et al. 2010. *Teplovaya energetika: novie vizovy vremeni* [Thermal power engineering: new challenges of the time], ed. P.Omelyanovsky, I.Misak. Lvov: NTF “Ukrajinski tehnologiyi”.

Paltsev, S. 2014. Scenarios for Russia’s natural gas exports to 2050. *Energy Economics* 42: 262 – 270.

Petersen.A.H. 2012. *The integration of Ukraine and Moldova into the Energy Community - a liberal intergovernmental analysis*. Master thesis submitted to the Roskilde University, supervised by Kristensen, S.B. Roskilde: Roskilde University.

Petrenko, O. 2012. *Zaporizhia stane centrum vitroenergetyky krajiny* [Zaporizhia will become a centre of wind power generation of Ukraine]. URL: <http://sich.zp.ua/index.php/ru/ekologiya-i-zdorove/1948-zaporizhzhya-stane-tsentrom-vitroenergetiki-krajini> [consulted on 15th May 2014].

Plachkova, S.G., Plachkov, I.V., Dunayevska, N.I., Podgurenko, V.S., Shylyajev, B.A., Landau Y.O., Sigal, I.Y., Danylko G.D., et al. 2012. *Energetika: istoriya, nastoyashcheje i*

budushcheje [Energy: history, present and future]. URL:
<http://energetika.in.ua/ru/books> [consulted on 27th October 2013].

Pidgorny, A.Z. 2008. *Demografichna statystyka* [Demographic statistics]. Odesa. URL:
<http://library.oscu.edu.ua/docs/PodgornyNew.pdf> [consulted on 10th February 2014].

Pramod, P., Mahapatra, S., Verma, S.P., and Sarma J.K. 2012. *Energy systems*. URL:
http://www.astec.gov.in/ncsc/4_th_2_energy_systems.pdf [consulted on 3rd April 2014].

PVResources. 2013. *Large-scale photovoltaic power plants: ranking 1 – 50*. URL:
<http://www.pvresources.com/pvpowerplants/top50.aspx> [consulted on 15th May 2014].

Q Club Energy (QCE). 2012. *Oil refining industry development*. Kyiv International Energy Club. URL: <http://www.qclub.org.ua/en/energy-issues/oil-energy-issues/development/> [consulted on 10th May 2014].

Rashin, A.G. 1956. *Naselenie Rossii za 100 let (1813-1913): statisticheskie ocherki* [Population of Russia within 100 years (1813-1913): statistical outline]. Moscow: Gosudarstvennoe Statisticheskoe Izdatelstvo.

Razumkov Centre (RC). 2003. *Vugilna promyslovisť Ukraïny: stan i tendentsiji na foni restrukturyzatsiji* [Coal industry of Ukraine: state and trends during restructuring]. URL: http://www.uceps.org/ukr/files/category_journal/NSD44_ukr.pdf [consulted on 5th May 2014].

_____. 2014. *Ukraine's gas sector development in the context of European integration*. URL: http://www.razumkov.org.ua/upload/1392734130_file.pdf [consulted on 26th April 2014].

Reshetilova, T.B., Rajhel, B.L., and Polyakov, S.V. 1997. *Ugolnaya promishlennost v razvitii proizvodstvennih sil Ukraini* [Coal industry in development of industrial capacities of Ukraine]. Moscow: Izdatelstvo Moskovskogo Gornogo Universiteta.

REUTERS. 2014. *Ukraine court seizes Odessa refinery*. URL: <http://www.reuters.com/article/2014/04/22/ukraine-refinery-impound-idUSL6N0NE3KG20140422> [consulted on 13th May 2014].

Roelfsema, M., den Elzen, M., Höhne, N., Hof, A.F., Braun, N., Fekete, H., Böttcher, H., Brandsma, R., and Larkin, J. 2014. Are major economies on track to achieve their pledges for 2020? An assessment of domestic climate and energy policies. *Energy Policy* 67: 781 – 796.

Russian Nuclear Association (RNA). 2012. *Zavod po stroitelstvu yadernogo topliva (Smolino)* [Smolino nuclear fuel fabrication plant]. URL: <http://www.atomic-energy.ru/organizations/zavod-po-proizvodstvu-yadernogo-topлива-smolino/4513> [consulted on 14th May 2014].

Saranchuk, V.I., Ilyashov, M.O., Oshovskyi, V.V., Biletskyi, V.S. 2008. *Himiya i fizyka goryuchykh kopalyn* [Chemistry and physics of fuels]. Donetsk: Shidnyi Vydavnychiy Dim.

System Capital Management (SCM). 2014. *Our business: sectors*. URL: <http://www.scmholding.com/en/business/sectors/> [consulted on 15th May 2014].

Shevtsov, A., Zemlyanyi, M., and Doroshkevych, A. 2013. *Restructuryzatsiya atomnoyi galuzi Ukrainy: mozhlyvi prydbannya ta vtraty* [Restructuring of the nuclear sector of Ukraine: possible gains and losses]. The National Institute for Strategic Studies. URL: <http://old.niss.gov.ua/Monitor/april08/13.htm> [consulted on 18th April 2014].

Stock Market Infrastructure Development Agency of Ukraine (SMIDA). 2013. *Bazy danyh* [Database]. URL: <http://smida.gov.ua/db> [consulted on 17th April 2014].

Smil, V. 2010. *Energy transitions: history, requirements, prospects*. California: Praeger.

Tkach, D.V. 1997. Ekologichni umovy rozvytku malych miskykh poselen [Ecological conditions for development of small towns]. In *Regionalni aspekty rozmishchennya produktyvnykh syl Ukrainy: zbirnyk naukovykh prats vykladachiv i aspirantiv kafedry upravlinnya trudovymi resursamy i rozmishchennya produktyvnykh syl Ternopilskoji Akademiji*

Narodnogo Gospodarstva [Regional aspects of distribution of the productive forces of Ukraine: collected scientific works of academics and postgraduate students of the Department of Management of Production Resources and Distribution of Productive Forces of the Ternopil Academy of National Economy], 108 – 114. Ternopil: TANG.

Trypolska, G. 2012. Feed-in tariff in Ukraine: the only driver of renewables' industry growth? *Energy Policy* 45: 645 – 653.

Tytko, R. and Kalinichenko, V. 2010. *Vidnovlyuvalni dzherela energiji: dosvid Polshchi dlya Ukraini* [Renewable energy sources: experience of Poland for Ukraine]. Varshava: OWG.

UATOM. 2011. *Uranodobuvna ta uranopererobna promyslovist* [Uranium production and processing industry]. Website on nuclear safety, protection from radiation and non-proliferation of nuclear weapons issues. URL: <http://uatom.org/posts/29> [consulted on 11th March 2014].

Ukraina Komunalna (UK). 2013. *Prychynu avariji na Vuglegirs'kiy TES viyavleno* [The cause of the accident at Vuglegirska TPP is revealed]. An article of 5th September 2013. URL: <http://jkg-portal.com.ua/ua/publication/one/prichinu-avarji-na-vuglegorskj-tes-vijavleno-34323> [consulted on 12th May 2014].

Ukrbio. 2013. *Vykorystannya solomy dlya potreb ZhKG* [Application of straw in domestic and communal sectors]. URL: <http://bio.ukrbio.com/ua/articles/3669/> [consulted on 15th May 2014].

UKRENERGO. 2014. *Rezhymy roboty OES Ukraini* [Regimes of operation of UES of Ukraine]. URL: http://www.ukrenergo.energy.gov.ua/ukrenergo/control/uk/publish/category?cat_id=35059 [consulted on 17th May 2014].

Ukrenergoexport. 2010. *Energy market model*. URL: <http://www.ukrenergoexport.com/en/content/energy-market-model> [consulted on 17th May 2014].

Ukrhydroenergo. 2014. *PAT "Ukrhydroenergo"*. Official website of the State Enterprise "Ukrhydroenergo". URL: <http://www.uge.gov.ua/> [consulted on 12th May 2014].

UKRSTAT. 2013a. *Statystychna informaciya: navkolyshnie seredovyshe* [Statistical information: environment]. URL: http://ukrstat.org/uk/operativ/menu/menu_u/ns.htm [consulted on 15th May 2014].

_____. 2013b. *Vyrobnytstvo osnovnyh vydiv promyslovoi produkciji za 1990 – 2002, 2003 – 2012 roky* [Supply and production of the main industrial products in 1990 – 2002, 2003 – 2012]. URL: http://ukrstat.org/uk/operativ/operativ2006/pr/prm_ric/prm_ric_u/vov2005_u.html [consulted on 14th May 2014].

UNIAN. 2013. *Ukrajina platyt 200 mln. dol. za zberigannya yadernyh vidhodiv u Rosiji* [Ukraine pays 200 million US dollars to store its nuclear waste in Russia]. URL: <http://www.unian.ua/society/774806-ukrajina-platit-200-mln-dol-za-zberigannya-yadernih-vidhodiv-u-rosiji.html> [consulted on 12th February 2014].

UNIAN. 2014. *Ukrajina u 2013 roci importovala gazu na 12 miliardiv dolariv* [Ukraine in 2013 imported gas for the sum of 12 billion dollars]. URL: <http://economics.unian.ua/energetics/876988-ukrajina-u-2013-rotsi-importovala-gazu-na-12-mlrd-dol.html> [consulted on 11th May 2014].

Vinnichuk, Y. 2012. Bogdan Balasynovych: V Ukraini – 54 miljony kubometriv smittyia [Bogdan Balasynovych: There is 54 cubic meters of solid waste in Ukraine]. *Ekonomichna Pravda* of 6th June 2012. URL: <http://www.epravda.com.ua/publications/2012/06/6/325588/> [consulted on 19th March 2014].

Volchyn, I., Dunayevska, N., Haponych, L., Chernyavski, M., Topal, A., and Zasyadko, Y. 2013. *Perspektivi vprovadzhennya chistih vugilnyh tehnologij v energetiku Ukrajini* [Prospects for the implementation of clean coal technologies in the energy sector of Ukraine]. Kyiv: Gnozis.

Winkler, I., Tevtul, Y., and Winkler, M. 2013. Traditional and sustainable energy production in Southern Ukraine: current state and prospects. In *Black Sea energy resource development and hydrogen energy problems*, NATO Science for Peace and Security Series C: Environmental Security, ed. A.Veziroğlu and M.Tsitskishvili, 109-116. Springer Science and Business Media Dordrecht.

World Coal Association (WCA). 2012. *Coal matters: Global availability of coal*. URL: [http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_matters_2_-_global_availability_of_coal\(16_05_2012\).pdf](http://www.worldcoal.org/bin/pdf/original_pdf_file/coal_matters_2_-_global_availability_of_coal(16_05_2012).pdf) [consulted on 28th October 2013].

_____. 2014. Coal and steel statistics. URL: <http://www.worldcoal.org/resources/coal-statistics/coal-steel-statistics/> [consulted on 7th May 2014].

World Economic Forum (WEF). 2012. *New energy architecture: enabling an effective transition*. URL: <http://reports.weforum.org/new-energy-architecture-enabling-an-effective-transition-2012/> [consulted on 11th December 2013].

World Nuclear Association (WNA). 2014. *Nuclear power in Ukraine*. URL: <http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Ukraine/> [consulted on 11th March 2014].

Wrigley, T. 2011. Opening Pandora's box: a new look at the industrial revolution. URL: <http://www.voxeu.org/article/industrial-revolution-energy-revolution> [consulted on 6th February 2014].

Yang, M. and Yang, F. 2012. *Negotiation in decentralization*. Green Energy and Technology. London: Springer-Verlag.

Zabutyi, K. 2013. Strategiya obmanu [A strategy of fraud]. *Ekonomichna Pravda* of 26th September 2013. URL: <http://www.epravda.com.ua/publications/2013/09/26/396298/> [consulted on 4th May 2014].

ZNUA. 2013. *Ukrajina pochala budivnitstvo zavodu z vyrobnytstva yadernogo palyva* [Ukraine commenced construction of a factory for nuclear fuel extraction]. URL: <http://www.energy-community.org/pls/portal/docs/1676177.PDF> [consulted on 12th February 2014].

Appendix

Figures

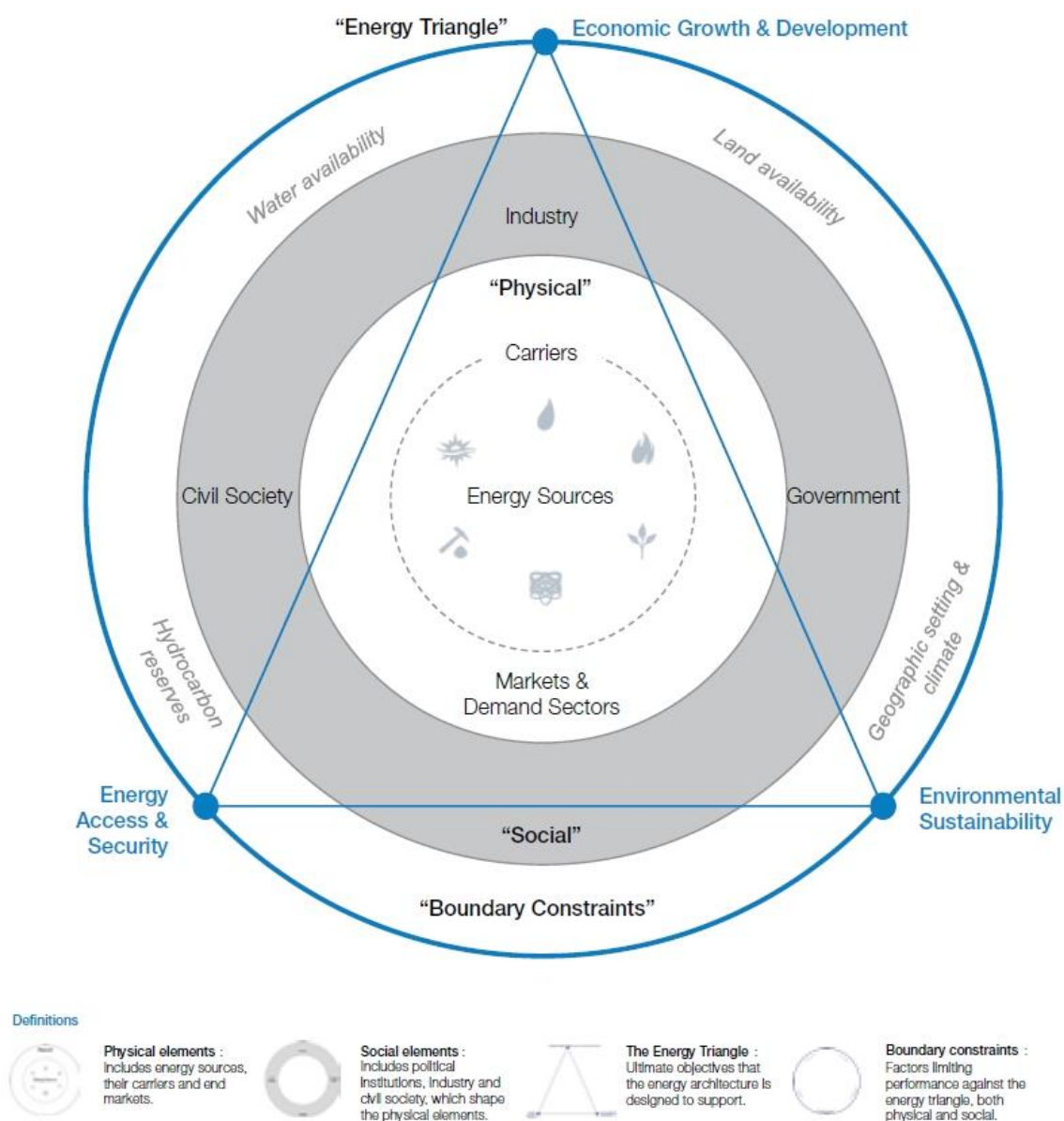


Figure A.1. Energy architecture conceptual framework

Source: WEF 2012



Figure A.2. Distribution of mineral and energy resources in Ukraine

Source: Omelyanovsky *et al.* 2010

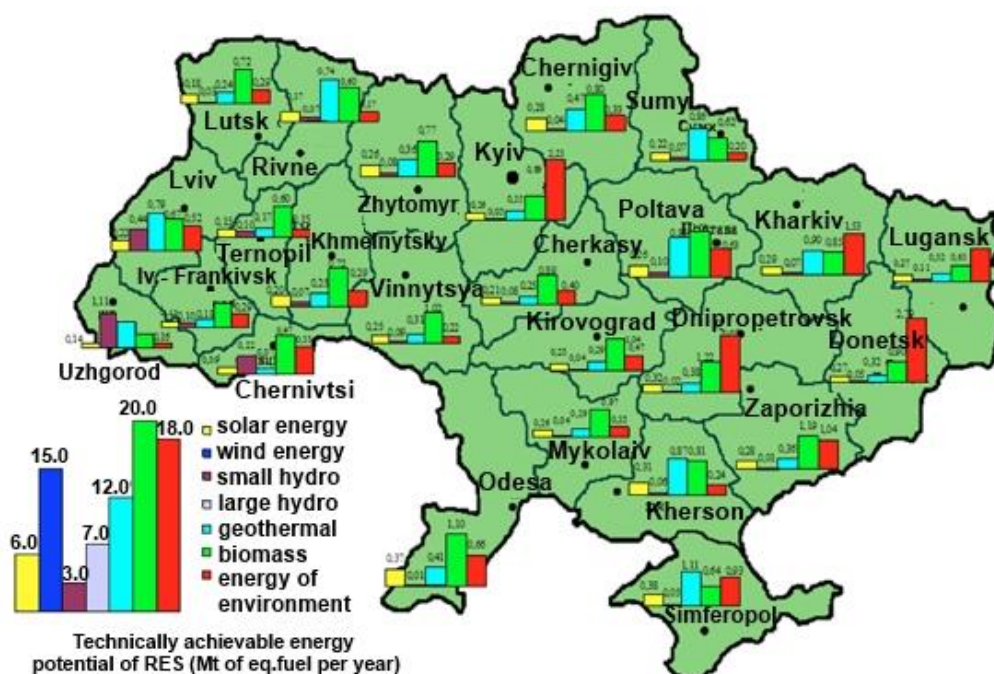


Figure A.3. Potentials for application of different types of renewable energy resources in Ukraine

Source: Ukrbio 2013

Global irradiation and solar electricity potential
Optimally-inclined photovoltaic modules

UKRAINE / УКРАЇНА

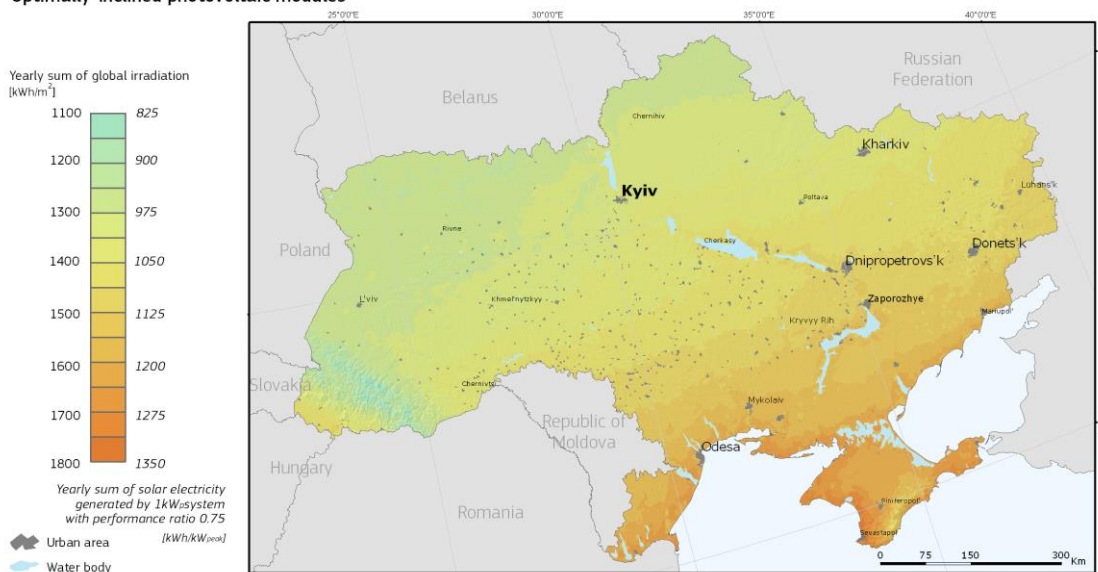


Figure A.4. Solar energy potential map of Ukraine

Source: IET 2012



Figure A.5. Environmental map of Ukraine

(Source: Cherp *et al.* 2007)

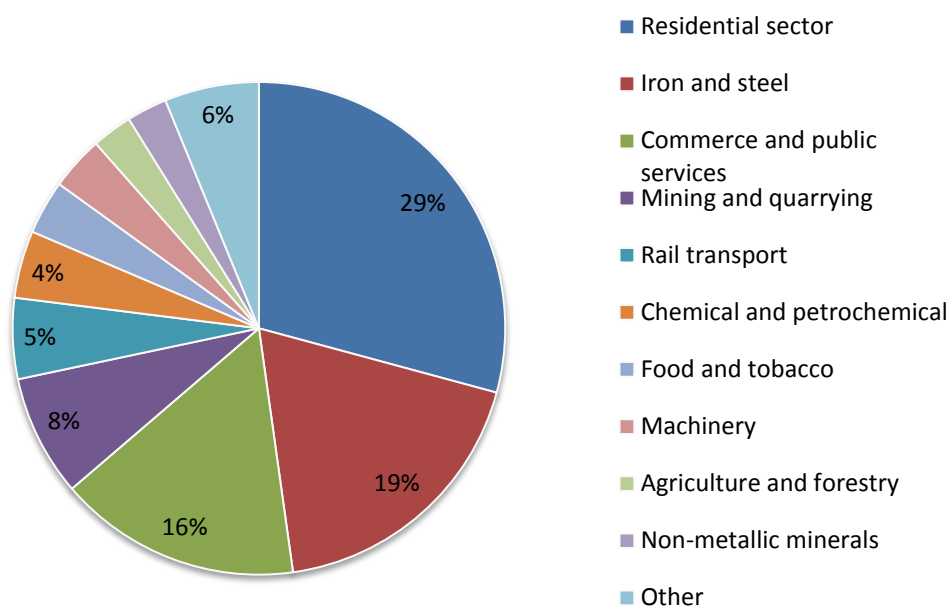


Figure A.6. Electricity consumption by economic sectors of Ukraine, 2011
(Total consumption: 13.4 Mtoe)

Data source: www.iea.org/Sankey/

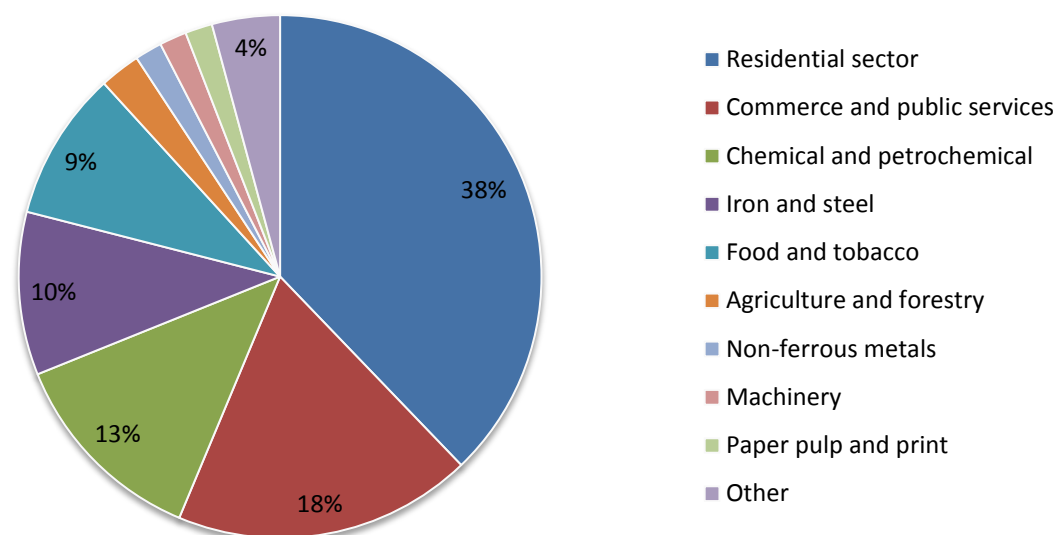
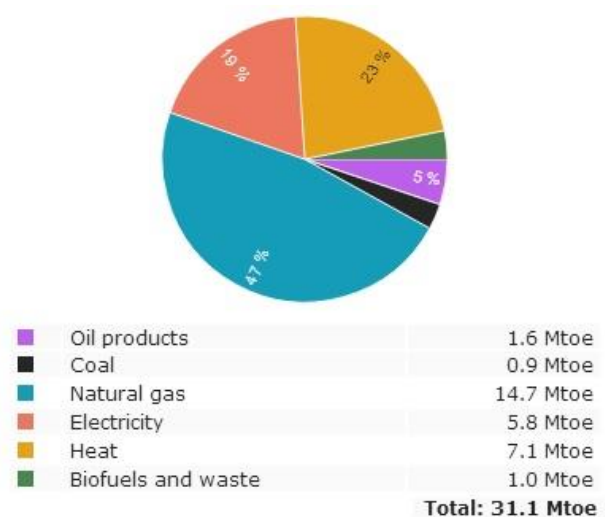
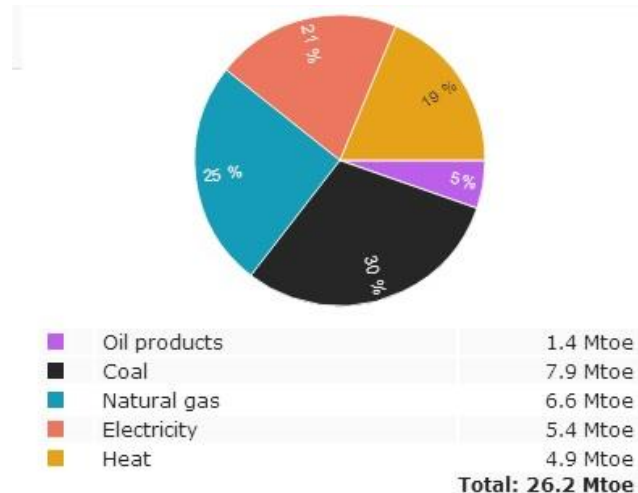


Figure A.7. Heat consumption by economic sectors of Ukraine, 2011
(Total consumption: 10.7 Mtoe)

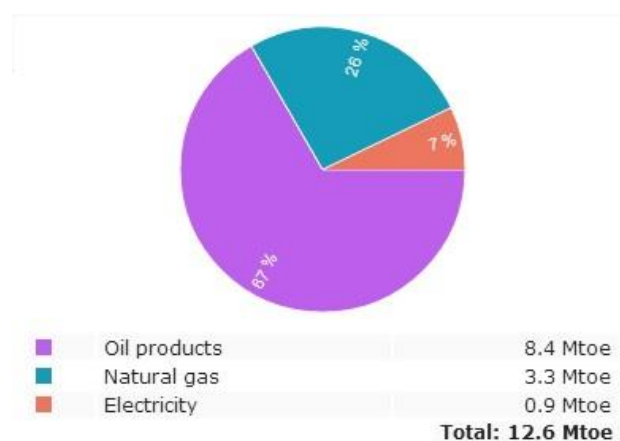
Data source: www.iea.org/Sankey/



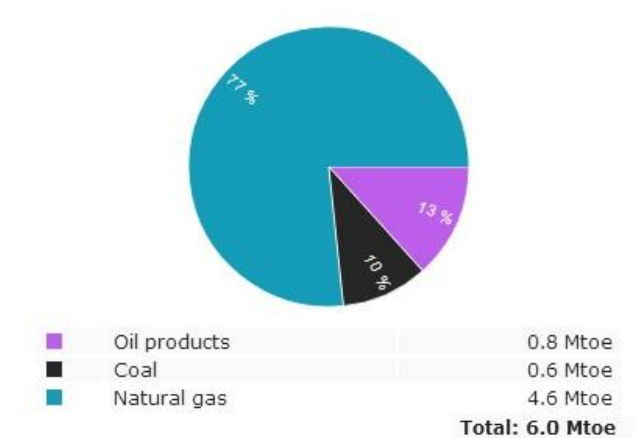
a) residential, public and agriculture sectors



b) industries



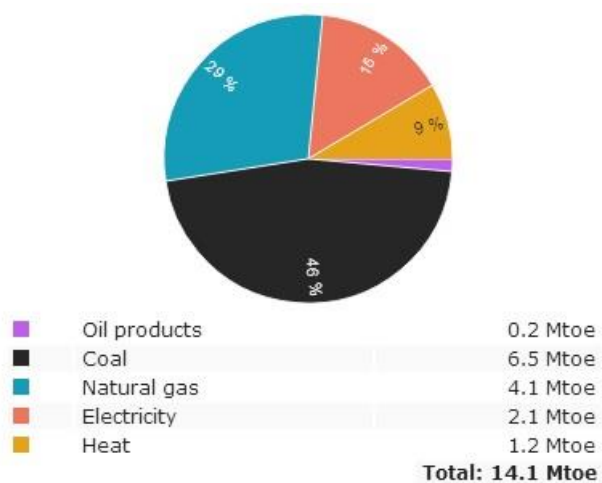
c) transport



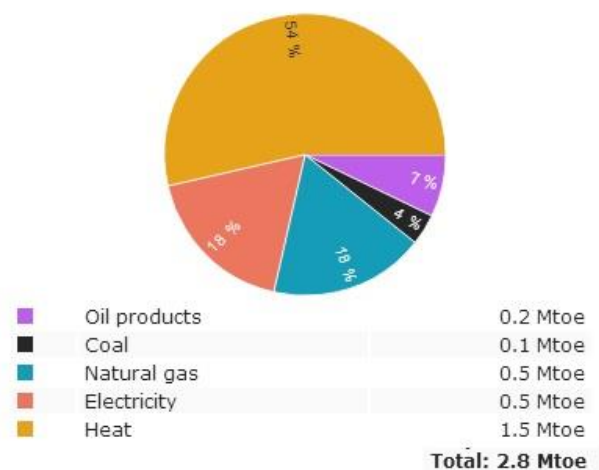
d) non-energy use

FigureA.8 (a-d) Distribution of energy consumption in Ukraine by sectors, 2011

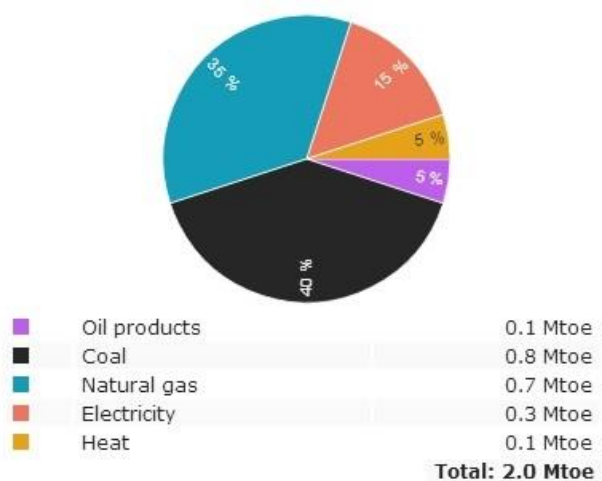
Source: www.iea.org/Sankey



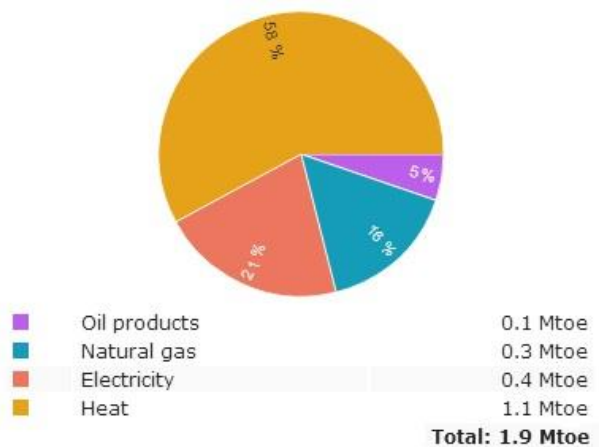
a) Iron and Steel



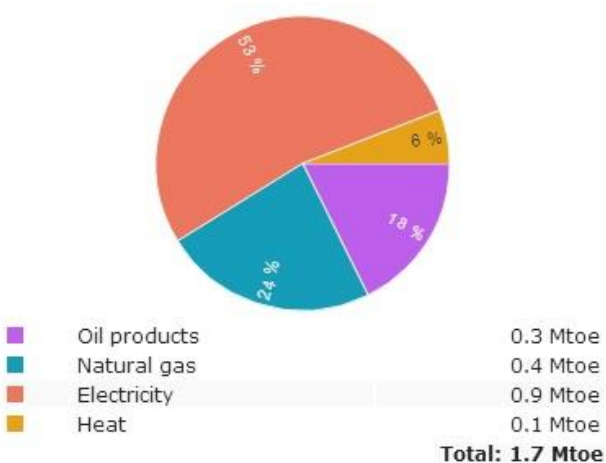
b) Chemical and Petrochemical



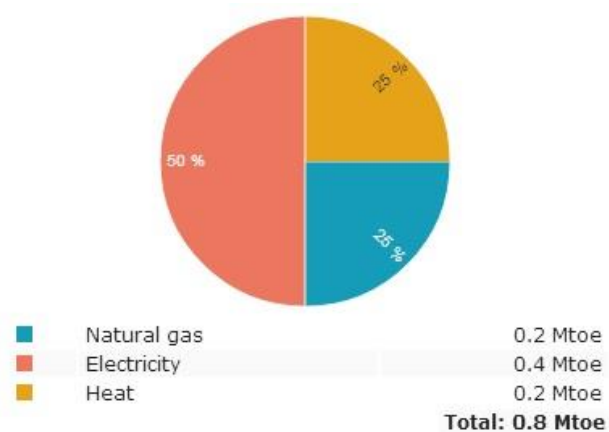
c) Non-Metallic Minerals



d) Food and Tobacco



e) Mining and Quarrying



f) Machinery

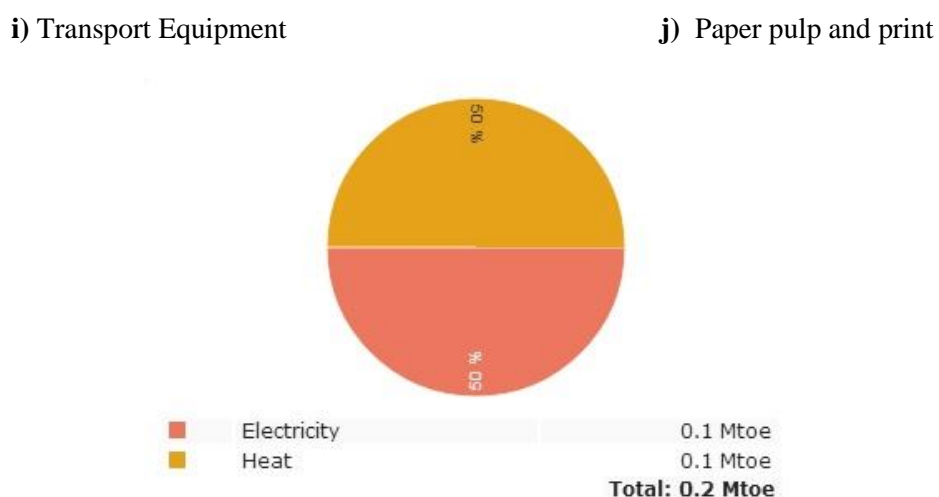
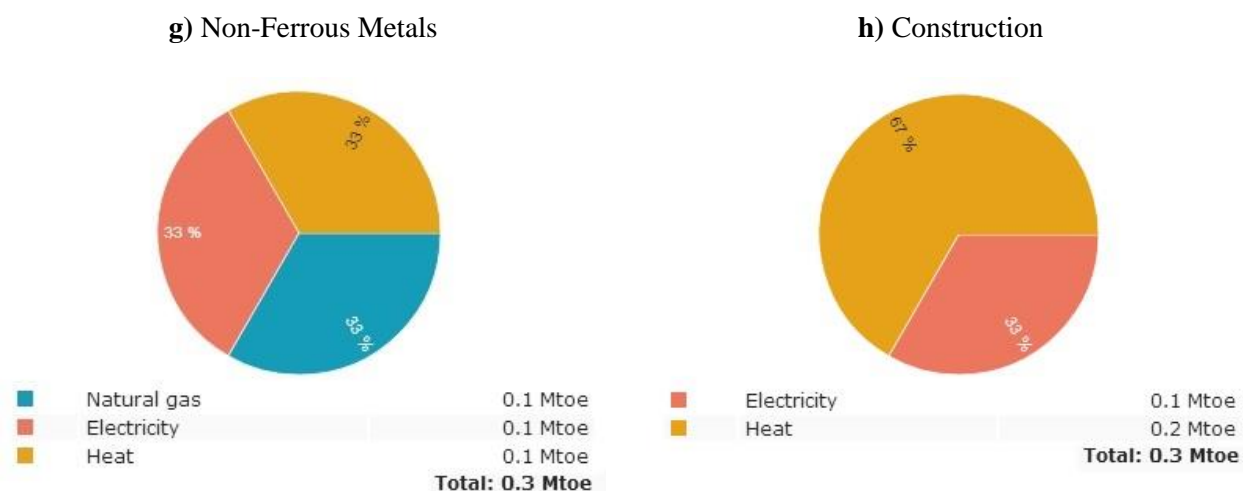
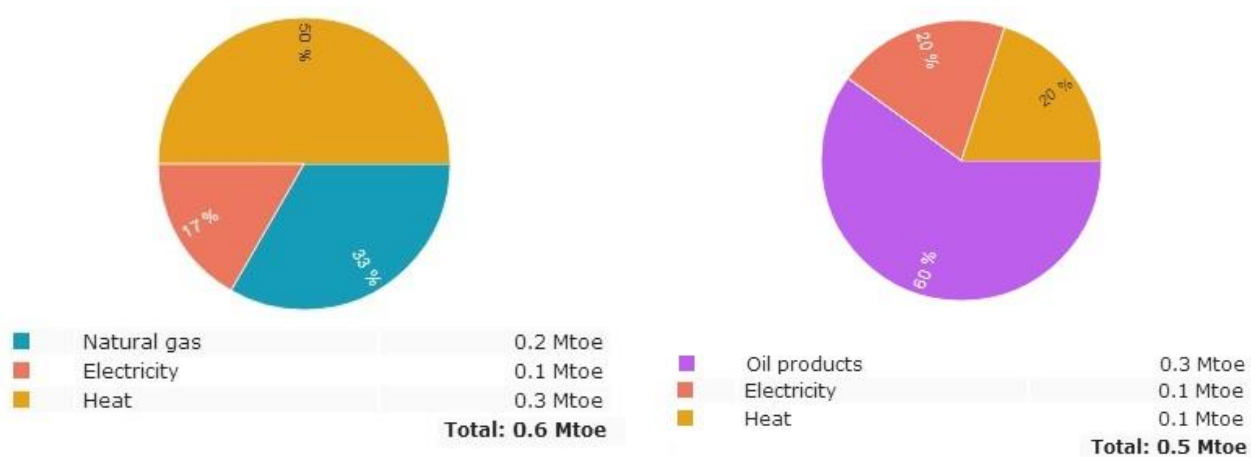
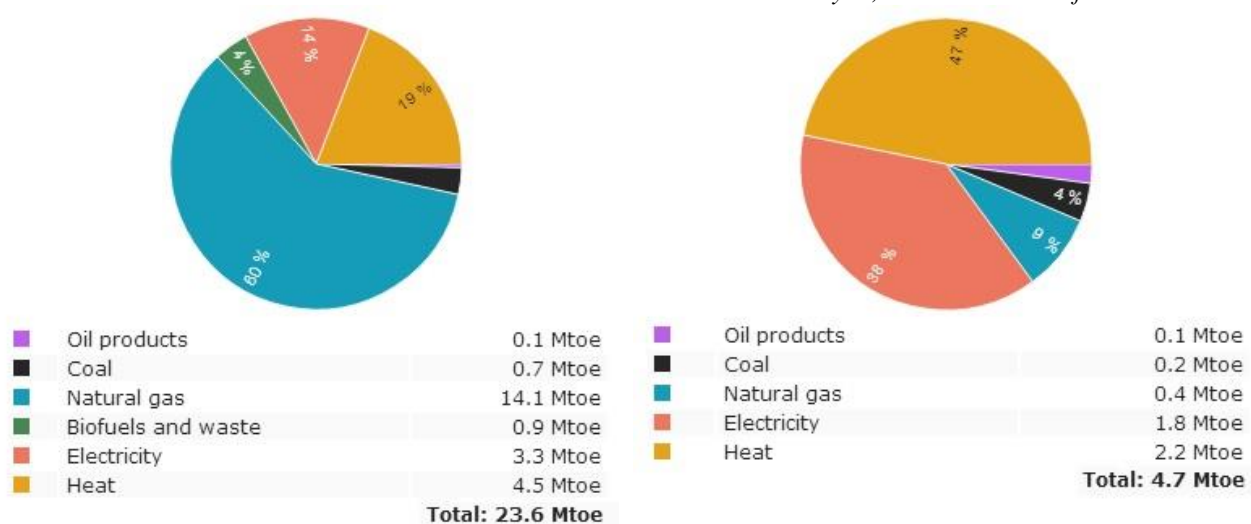


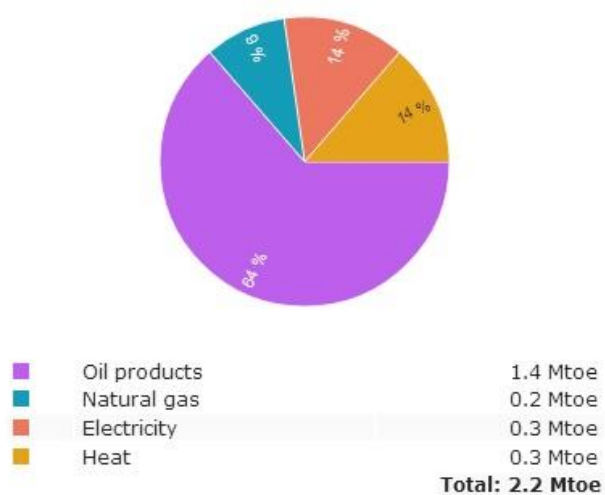
Figure A.9 (a-k) Energy consumption by Ukrainian industries, 2011

Source: www.iea.org/Sankey/



a) Residential

b) Commerce and Public Services



c) Agriculture and Forestry

Figure A.10 (a-c) Energy consumption by residential, public
and agriculture sectors of Ukraine, 2011

Source: www.iea.org/Sankey/

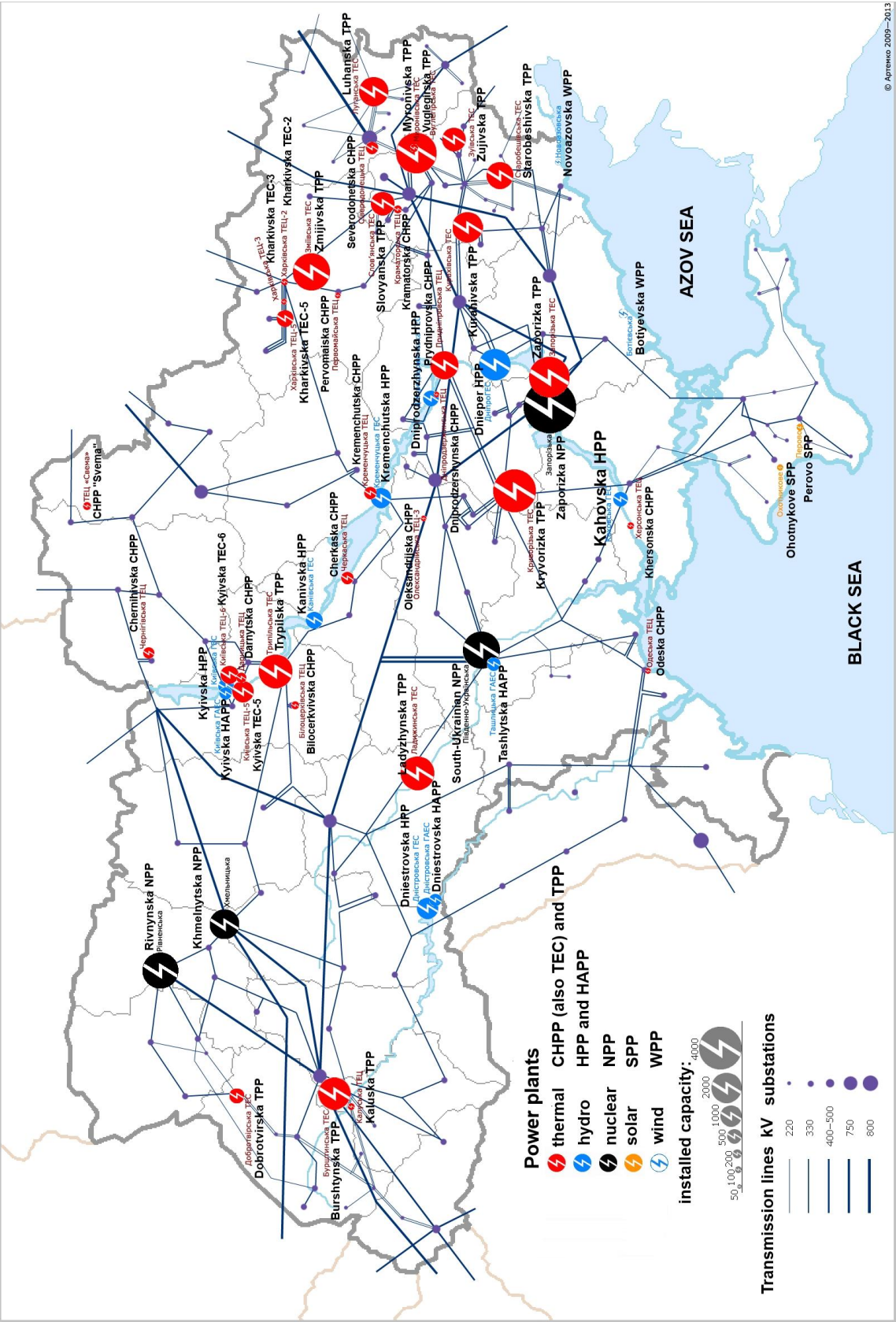


Figure 2.3.2 Power system of Ukraine: power plants and transmission lines

Source: Volchyn *et al.* 2013

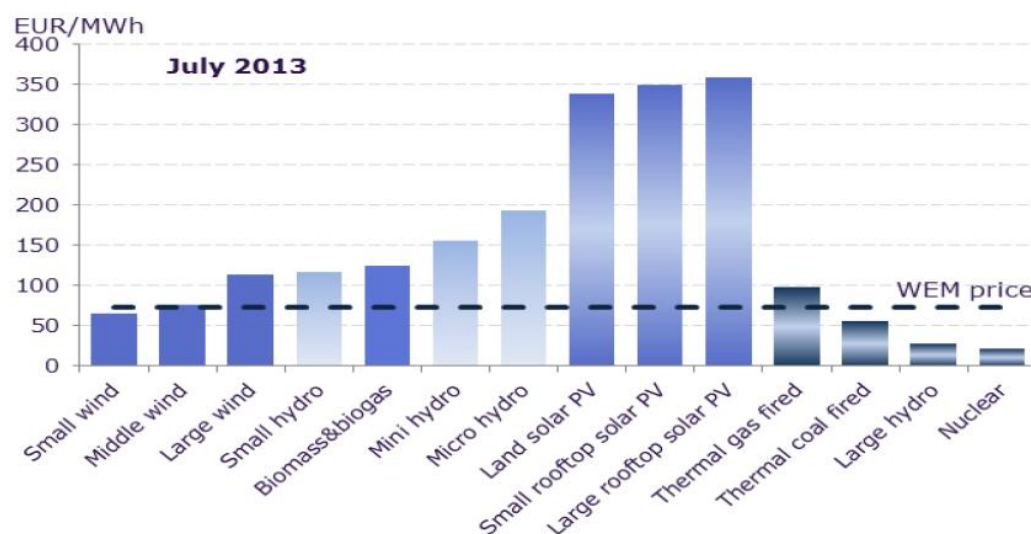


Figure A.12. Tariffs for electricity in Ukraine, July 2013

Source: IMEPOWER 2013

Tables

Table A.1. Distribution of Ukrainian power plants of capacities more than 1,000 kW between various sectors of economy in 1913

| Sector | Number of power plants | Total capacity, thous. kW | Share, % |
|------------------------------|------------------------|------------------------------|-------------|
| Coal mines | 26 | 68.2 | 29.8 |
| Iron & steel works | 19 | 95.4 | 41.6 |
| Other industrial enterprises | 6 | 11.7 | 5.2 |
| Common use (in cities) | 20 | 53.7 | 23.4 |
| Total | 71 | 229.0 | 100 |

Source: Plachkova *et al.* 2012

Table A.2. Information box: Historical transition from firewood and charcoal to coal in Ukraine

Historical transition from firewood and charcoal to coal

From the period of establishment of Kievan Rus in 9-10th centuries, the Slavic people lived in small villages and forests, hunted and trapped animals for their skins and furs, gathered honey and engaged in trade and used firewood as a main source of heat. Notwithstanding the low population densities, the people started felling forests pushing it back for agricultural and beekeeping activities, while simultaneously establishing lumbering operations to use and sell wood.

Lumber became a crucial energy source as the cities, such as Kyiv, were rising (Josephson *et al.* 2013). As wood served multiple purposes (including not only heating, but also illumination, cooking, metal production), and the Little Ice Age took place in ca. 1350 – 1850, wood consumption is estimated to have risen to 4 – 5 m³ per person per year.

The forests were officially controlled by the state from the 13th century, when the first tsars strengthened their property rights to permit inheritance through appropriate deeds. Serving largely immediate or local purposes, lumber was sold abroad (by 16th century), used in metallurgy and mining (17th century) and in shipbuilding (18th century).

In the end of 16th century more cannons and guns had to be produced for military purposes, which led to the rapid expansion of demand for lumber. Due to its low calorific value, it was soon replaced by charcoal, which could provide high enough temperatures in smelters and kilns to efficiently melt metals. The latter were then used for production of weapons, agricultural instruments and other tools. Thus, during the Moscovite and Petrine periods (1613-1725), the process of smelting within the empire was largely applying charcoal fuel produced from lumber.

Metallurgical industry within the Russian empire, up until 18th century, was ultimately concentrated near ore deposits in the Ural Mountain regions. However, as the forests of Ural as a main charcoal source were being denuded, metallurgical industry saw a shift to coal fuel. This increased importance of the Donets River basin (Donbas) coal deposits in Ukraine.

Source: Josephson *et al.* 2013

Table A.3. Change of the structure of energy resources in generation of electric energy at TPPs and CHPPs in Ukraine in 1991-2012

| Energy resources | Year | | | | | | | | | | |
|--|------|------|------|------|------|------|------|------|------|------|------|
| | 1991 | 1994 | 1997 | 2002 | 2005 | 2006 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Coal | | | | | | | | | | | |
| mln tonnes of eq.fuel | 22.7 | 21.6 | 18.1 | 19.8 | 19.8 | 23.7 | 26.3 | 22.7 | 24.8 | 26.5 | 28.5 |
| % | 31.3 | 45.1 | 52.5 | 66.4 | 66.4 | 75.7 | 79.2 | 79.9 | 79.7 | 80.1 | 82.1 |
| Oil | | | | | | | | | | | |
| mln tonnes of eq.fuel | 15.1 | 4.1 | 1.8 | 0.4 | 0.1 | 0.1 | 0.1 | 1.1 | 0.1 | 0.06 | 0.06 |
| % | 20.8 | 8.6 | 5.2 | 0.4 | 0.3 | 0.3 | 0.3 | 3.9 | 0.3 | 0.2 | 0.1 |
| Gas | | | | | | | | | | | |
| mln tonnes of eq.fuel | 34.7 | 22.2 | 14.6 | 9.9 | 9.9 | 7.5 | 5.3 | 4.6 | 6.2 | 6.5 | 6.2 |
| % | 47.9 | 46.3 | 42.3 | 33.2 | 33.2 | 24.0 | 20.5 | 16.2 | 20.0 | 19.7 | 17.7 |
| Total, mln tonnes of equiv.fuel | 72.5 | 47.9 | 34.5 | 30.1 | 29.8 | 31.3 | 31.7 | 28.0 | 31.1 | 33.1 | 34.8 |

Data source: Volchyn *et al.*, 2013

Table A.4. General information on energy generating companies related to thermal power production, 2012

| Energy generating company | Location and % of the country's installed capacity | Owners | Electricity output, mln kWh | Fuel mix (range between company's power plants) | Number of technical failures |
|---------------------------|--|---|-----------------------------|--|------------------------------|
| PJSC "DTEK Zahidenergo" | Western Ukraine, 8.6% | DTEK Holdings Ltd. (60%), PJSC "DTEK" (12%), NJSC "ECU" * (25%) | 15,030 | coal: 97.1 – 99.2% gas: 0.8 – 2.8% oil: : 0 - 0.1% | 133 |
| PJSC "Centrenergo" | Central and Eastern Ukraine, 14.1% | NJSC "ECU" (78%), legal entities (21%), individuals (1%) | 16,660 | coal: 96.2 – 99.2% gas: 0.8 – 3.7% oil: 0 – 0.1% | 73 |

| Energy generating company | Location and % of the country's installed capacity | Owners | Electricity output, mln kWh | Fuel mix (range between company's power plants) | Number of technical failures |
|---------------------------|--|--|-----------------------------|--|------------------------------|
| PJSC "DTEK Dniproenergo" | Central Ukraine (east), 15.2% | DTEK Holdings Ltd. (68%), NJSC"ECU" (25%) | 16,170 | coal: 93.3 – 98.8% gas: 1.1 – 6.6% oil: 0 – 0.1% | 174 |
| PJSC "Donbasenergo" | Eastern Ukraine, Donbas, 5.0% | PJSC "Energoinvest-holding" (61%), NJSC"ECU" (25%) | 8,179 | coal: 97.4 – 98.9% gas: 1.1 – 2.5% oil: 0 – 0.1% | 75 |
| "DTEK Shidenergo" Co.Ltd. | Eastern Ukraine, 7.6% | PJSC "DTEK" (100%) | 15, 656 | coal: 97.7 – 98.7% gas: 0.6 – 1.8% oil: 0 – 1.7% | 95 |
| PJSC "Kyivenergo" | Kyiv region, 2.2% | DTEK Holdings Ltd. (54%), PJSC "DTEK" (18%), NJSC"ECU" (25%), | 1,200 | gas: primary source oil: secondary source | no information available |
| PJSC "Kharkiv TEC-5" | Kharkiv region, 1.0% | "Ukreastgas" Ltd. (100%) | 2,000 (+2,000 Gkal of heat) | gas: primary source oil: secondary source | no information available |
| PJSC "DTEK Krymenergo" | Crimea | DTEK Holdings Ltd. (50%), NJSC"ECU" (25%), Garensia Enterprises Ltd. (12%) | - | - | - |

* NJSC "ECU" – National Joint-Stock Company "Energy Company of Ukraine"

Data sources: SMIDA 2013; Volchyn *et al.* 2013

Table A.5. Top Ukrainian companies according to their revenue in 2012

| Company | Revenue in 2012 , billion EUR (revenue change 2012/2011) | Ranking in Central Europe 2013 | Sector | Description | Owner/ Business group |
|--|---|---|--------------------------------------|--|---|
| Metinvest | 9.7 (-4.1%) | 4 | Manufacturing | Ukraine's largest steel and mining group | Ukraine's oligarch and businessman Rinat Akhmetov / Part of SCM Holdings Group |
| Naftogaz | 9.5 (0.2%) | 5 | Energy & resources | The state oil and gas company | State-owned |
| DTEK | 8.0 (125.3%) | 7 | Energy & resources | Ukraine's largest privately-owned electricity producer, distributor, also involved in hydrocarbons exploration | R.Akhmetov / Part of SCM Holdings Group |
| Energorynok | 8.0 (21.6%) | 8 | Energy & resources | Energy market of Ukraine | State-owned |
| Ukr-zaliznytsia | 5.1 (10.4%) | 21 | Consumer business and transportation | State-owned railway company | State-owned |
| Arcelor Mittal Kryvyi Rih | 2.8 (8.0%) | 47 | Manufacturing | Ukraine's single largest metallurgical factory in terms of annual production capacity | Subsidiary of ArcelorMittal, world's largest steel-producing company |
| Ostchem | 2.0 (28.5%) | 76 | Manufacturing | Fertilizer business of Group DF, which includes mineral fertilizer production, distribution and shipment | A Ukrainian investor and businessman Dmitry Firtash |
| Ukrtatnafta | 1.9 (-8.1%) | 81 | Energy & resources | Ukraine's largest and most modern refinery | Controlled by domestic businessmen, Russia's Tatneft energy company and affiliated groups |
| Energoatom | 1.8 (22.5%) | 93 | Energy & resources | Ukraine's state-owned nuclear generating company | State-owned |

| Company | Revenue in 2012 , billion EUR (revenue change 2012/2011) | Ranking in Central Europe 2013 | Sector | Description | Owner/ Business group |
|-----------------------|---|---|--------------------------------------|--|---|
| Donetskstal | 1.8 (-12.8%) | 94 | Manufacturing | One of Ukraine's largest steel and mining groups | Businessman V.Nusenkis along with partners |
| Kernel | 1.7 (23.1%) | 102 | Consumer business and transportation | One of Ukraine's largest producers of sunflower seeds, oil and related products | Majority owned by a lawmaker A.Verevsky |
| Interpipe | 1.4 (14.9%) | 131 | Manufacturing | A leading manufacturer of steel pipes | Controlled by a Ukrainian businessman V.Pinchuk |
| Galnaftogaz | 1.4 (22.4%) | 137 | Energy & resources | A major supplier and retailer of gasoline | Ukrainian businessman V.Antonov |
| Nibulon | 1.3 (28.4%) | 138 | Consumer business and transportation | Leading domestic producer and exporter of grain and agricultural products | Ukrainian businessman O.Vadatursky |
| Ferrexpo Group | 1.1 (-13.7%) | 174 | Energy & resources | Ukrainian ore mining company, one of the best known domestic companies amongst investors | Mostly owned by a Ukrainian billionaire and lawmaker K. Zhevago |
| MHP | 1.1 (24.1%) | 175 | Consumer business and transportation | Leading Ukrainian poultry producer | Majority owned by a businessman Y.Kosiuk |
| Azovmash Group | 1.1 (10%) | 185 | Manufacturing | One of the largest machine-building enterprises of Ukraine known in the world for production of railway transport, metallurgical, mining and other heavy equipment | 50% state-owned |
| BNK-Ukraine | 0.9 (41.8%) | 231 | Energy & resources | Oil company | A subsidiary of a Belarus company Belarusneft Ltd. |

| Company | Revenue in 2012 , billion EUR (revenue change 2012/2011) | Ranking in Central Europe 2013 | Sector | Description | Owner/ Business group |
|--|---|---|--|--|---|
| Centrenergo | 0.9 (36.4%) | 241 | Energy & resources | One of Ukraine's largest thermal electricity generating companies | 78% state-owned, 22% private |
| Southern GOK | 0.8 (-17.3%) | 275 | Energy & resources | Iron ore mine, located in Kryvyi Rih, part of AME Group | Owned by Evraz Group S.A. and Smart Group LLC (Russia) |
| Lemtrans | 0.8 (44.6%) | 279 | Consumer business and transportation | Largest private freight forwarding company in Ukraine | R.Akhmetov / Part of SCM Holdings Group |
| Cargill A.T. Ukraine | 0.8 (-2.2%) | 290 | Consumer business and transportation | A major player in Ukraine's agriculture market, exporter of grain and sunflower oil | Subsidiary of US-based agriculture giant Cargill |
| Motor Sich | 0.8 (47.9%) | 299 | Manufacturing | A leading producer of aircraft and helicopter engines on post-Soviet surf | Majority owned by domestic businessmen |
| Gazprom Sbut Ukraine | 0.75 (-17.6%) | 303 | Energy & resources | A major domestic supplier of natural gas | Subsidiary of the Russian natural gas giant Gazprom |
| Kriukov car building works | 0.7 (24.7%) | 321 | Manufacturing | Machine building enterprise producing railway cars, one of the largest transport equipment manufacturers in Ukraine | Two Estonian companies (40%), a British company (25%), the rest owned by Russian car building company and Ukrainian businessman S.Tygytko |
| Japan Tobacco International (JTI) | 0.7 (4.0%) | 349 | Consumer business and transportation | Tobacco manufacturing and trade | |
| Serna | 0.6 (40.8%) | 399 | Consumer business and transportation | Grain exports, production of wheat, sunflower, soybean, rapeseed, oils and fats | Subsidiary of the largest global commodity traders – Swiss Glencore |

| Company | Revenue in 2012 , billion EUR (revenue change 2012/2011) | Ranking in Central Europe 2013 | Sector | Description | Owner/ Business group |
|---------------------------------|---|--------------------------------|----------------------|---|--|
| Alliance Oil Ukraine | 0.6 (23.9%) | 413 | Energy and resources | Independent oil and gas company with vertically integrated operations in Russia and Kazakhstan | Russian and Kazakhstan businessmen and partners |
| Odessa Port Plant (OPZ) | 0.5 (5.9%) | 462 | Manufacturing | One of the largest chemical enterprises of Ukraine producing fertilizers sold to domestic market, but mostly exported | State-owned |
| Coal of Ukraine | 0.5 (-24.9%) | 476 | Energy & resources | Coal mining and processing company | State-owned |
| Nikopol Ferroalloy Plant | 0.5 (-16.8%) | 485 | Manufacturing | A major supplier of ferroalloys worldwide | Jointly controlled by a billionaire I.Kolomoisky along with partners and a businessman V.Pinchuk |

Data sources: Deloitte 2013; KyivPost 2011; Podolyanets 2014; SCM 2014

Table A.6. Ownership of the Ukrainian oil refineries

| Refinery | Rated capacity | Short description |
|--|----------------|--|
| Kremenchuk Refinery (OJSC "Ukratnafta") | 18.6 Mt | Created in 1994, owned by a closed Ukrainian corporation Ukratnafta. Main shareholders are Naftogaz of Ukraine and Russian "Tatneft". |
| Lysychansk refinery (LLC "Linos") | 16.0 Mt | Fully owned by a closed corporation LINIK, which is a part of Russian-British holding TNK-BP in Ukraine. |
| Kherson refinery (OJSC "Khersonnafto-pererobka") | 7.1 Mt | The oldest in Ukraine (built in 1938). Since 1999 reconstruction and upgrading project has been implementing on the basis of intergovernmental agreements between Ukraine and Kazakhstan. The main foreign participants are OJSC "Alliance Group" (Russia) and state company "Kazmunaigaz" (Kazakhstan). The refinery was stopped in 2005 because of the need for estimated USD 0.5 billion of investments to increase quality of refining products. |

| Refinery | Rated capacity | Short description |
|---|----------------|---|
| Odessa refinery (OJSC “Lukoil-Odesky Refinery”) | 3.6 Mt | The refinery used to be fully owned by Russian LUKOIL corporation. Stopped its operation for modernization in 2005 – 2008. Since April 2014 the refinery’s seized by Ukrainian court: Russia’s ownership is questioned, investigation of fuel duty fraud takes place. |
| Drogobych refinery (OJSC “NPK Galychyna”) | 3.2 Mt | 25% shares of which belong to the state and around 72% of shares controlled by Pryvat group companies. |
| Nadvirna refinery (OJSC “Naftohimik Prykarpattya”) | 3.6 Mt | 26% of shares belong to the State property fund, 17.5% - “Lider Estate” Ltd, 16.8% - PryvatBank and 14.3% - Copland Industries S.A. (Virgin Islands). |

Sources: Herasimovich 2008; QCE 2012; REUTERS 2014

Table A.7. Structure of installed electricity generating capacities of power plants of Ukraine in 2003 – 2013

| Year | Total installed capacity, mln kW | NPPs | | Large TPPs | | CHPPs and small TPPs | | All HPPs and HAPPs | | Renewables (SPPs, WPPs) | |
|-------------|----------------------------------|--------|------------|------------|------------|----------------------|------------|--------------------|------------|-------------------------|------------|
| | | mln kW | % of total | mln kW | % of total | mln kW | % of total | mln kW | % of total | mln kW | % of total |
| 2003 | 50.9 | 11.8 | 23.1 | 28.1 | 55.1 | 6.2 | 12.1 | 4.8 | 9.4 | 0.059 | 0.12 |
| 2005 | 52.0 | 13.8 | 26.6 | 27.1 | 52.1 | 6.3 | 12.1 | 4.7 | 9.1 | 0.075 | 0.14 |
| 2006 | 52.2 | 13.8 | 26.5 | 27.1 | 52.0 | 6.3 | 12.0 | 4.9 | 9.4 | 0.081 | 0.16 |
| 2007 | 52.2 | 13.8 | 26.4 | 27.2 | 51.8 | 6.3 | 12.0 | 5.1 | 9.6 | 0.083 | 0.16 |
| 2008 | 52.6 | 13.8 | 26.3 | 27.2 | 51.8 | 6.4 | 12.1 | 5.1 | 9.7 | 0.084 | 0.16 |
| 2009 | 53.0 | 13.8 | 26.1 | 27.3 | 51.5 | 6.4 | 12.0 | 5.4 | 10.2 | 0.084 | 0.16 |
| 2010 | 53.2 | 13.8 | 26.0 | 27.4 | 51.4 | 6.4 | 12.0 | 5.5 | 10.3 | 0.094 | 0.18 |
| 2011 | 53.3 | 13.8 | 26.0 | 27.3 | 51.1 | 6.4 | 12.0 | 5.5 | 10.3 | 0.309 | 0.58 |
| 2012 | 53.8 | 13.8 | 25.7 | 27.4 | 51.0 | 6.5 | 12.1 | 5.5 | 10.2 | 0.581 | 1.08 |
| 2013 | 54.5 | 13.8 | 25.4 | 27.6 | 50.7 | 6.7 | 12.2 | 5.5 | 10.0 | 0.935 | 1.71 |

Data sources: UKRENERGO 2014; Volchyn *et al.* 2013

Table A.8. State institutions governing the renewable energy in Ukraine

| State institutions | Responsibilities |
|---|--|
| Parliament of Ukraine | <ul style="list-style-type: none"> – Defines main directions of the state policy in the sector of renewable energy – establishes main rights and obligations of market participants, guaranteed minimum feed-in tariff, etc. |
| Government of Ukraine | <ul style="list-style-type: none"> – Realizes the state policy in the sphere of renewable energy; – develops procedures for the changes of share of raw materials, building materials, scope of work and service of Ukrainian origin in the value of energy plants building; – approves the scope of production which is imported to the territory of Ukraine in the privilege way, etc. |
| National Electricity Regulatory Commission of Ukraine | <ul style="list-style-type: none"> – Confirms the feed-in tariffs for electricity generated from renewable energy sources; – forms and provides a registry of the plants of renewable energy; – licenses the electrical energy production from the renewable energy plants and its supply as a whole; – establishes rules of connection of generating equipment to electrical networks, etc. |
| State Agency on Energy Efficiency & Energy Saving of Ukraine | <ul style="list-style-type: none"> – Provides realization of effective state policy in the sector of renewable energy |

Source: Kurbatova *et al.* 2014

Table A.9. Ranking of energy systems (ES) according to state imperatives

| State imperative | Ranking | | | | |
|-----------------------|---|---|---|---|---|
| | + | ++ | +++ | ++++ | +++++ |
| Domestic order | ES plays a minor role in support of domestic order and its absence will not cause major interruptions in functioning of the national ES | ES plays a minor/secondary role in support of domestic order, although its functioning is critical for small local businesses | ES plays a substantial role in support of domestic order and its functioning is critical for local businesses and enterprises | ES plays an important role in support of domestic order and its functioning is critical for regional to national large businesses and enterprises | ES plays a crucial role in support of domestic order, its functioning is critical for various economic sectors and the whole nation. No substitution for the ES exists in short-term. |

| State imperative | Ranking | | | | |
|------------------------|--|---|--|--|---|
| | + | ++ | +++ | ++++ | +++++ |
| Survival | ES plays a minor role in economic and social terms, no interruptions in the ES have a significant effect on the national/regional economy, but a minor short-term effect on local businesses | ES plays a secondary role in economic and social terms, major interruptions have no effect on national economy, but may cause a short-term destabilization of local to regional economy | ES plays a substantial role in economic and social terms, major interruptions have short-term devastating effect on the national economy | ES is important in economic and social terms, major interruptions may cause short- to medium-term destabilization of national economy | ES is crucially important in economic and social terms, any major interruptions have immediate effect, may cause chaos and long-term destabilization of the country's economy |
| Revenue | ES does not provide revenue or provides it rarely and only in small amounts | ES and economic sectors it is linked to, provide the country with a small irregular revenue | ES and economic sectors it is linked to, provide the country with a relatively small constant revenue | ES and economic sectors it is linked to, provide the country with substantial revenue on annual basis | ES and economic sectors it is linked to, provide the country with large revenue on annual basis for decades |
| Economic growth | ES plays a minor role in the country's economic growth and is not expected to increase in importance in the nearest future | ES currently plays a minor role in the country's economic growth, but is expected to increase in importance in the future | ES and economic sectors it is linked to, play a substantial role in the country's economic growth, and are expected to continue playing it in the nearest future | ES and economic sectors it is linked to, play an important role in the country's economic growth, and are expected to increase in importance in the nearest future | ES and economic sectors it is linked to, play a crucial role in the country's economic growth and are expected to play it in a long-term future |
| Legitimation | Functioning of ES is not or is barely legitimized, society is unaware of the ES operation | Functioning of ES is on the first stages of legitimation, only certain circles of society are familiar with the | Functioning of ES is under the process of legitimation, society is being familiarized with the ES operation | Functioning of ES is well-legitimized, well-accepted within the nation | Functioning of ES is fully legitimized at all levels and widely accepted within the nation |

| State imperative | Ranking | | | | |
|---------------------|---|--|---|---|--|
| | + | ++ | +++ | ++++ | +++++ |
| ES operation | | | | | |
| Conservation | Conservation measures re not taken or taken rarely and are not perceived as important | Conservation measures within ES are taken on an irregular basis, mostly due to pressure coming from the state or in order to receive a revenue | Conservation measures are taken on a regular basis, efficiency of ES operation increases annually | ES operates at a high efficiency with minor environmental impacts | ES operates at a highest possible efficiency with minimal environmental impacts, constant maintenance and improvements |