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Indicators for Assessing the Quality of an Energy Policy

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

Einari Kisel..

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Energiapoliitika kvaliteedi hindamise indikaatorid

EINARI KISEL

TTÜ KIRJASTUS

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ABBREVIATIONS AND UNITS

CAGR	Compound Aggregate Growth Rate
CO2	Carbon Dioxide
GHG	Greenhouse Gases
GWh	Gigawatt hour
EC	European Commission
EEC	Energy Embodied in Consumption
EIA	Energy Information Agency
EU	European Union
FDI	Foreign Direct Investments
GDP	Gross Domestic Product
IEA	International Energy Agency
IT	Information Technology
kWh	kilowatt hour
km	kilometer
m^3	Cubic meter
NO_x	Nitrogen Oxides
PM10	Particultate Matter with diameter less than 10 μm
PPP	Power Purchasing Parity
PV	Photovoltaic solar panels
RD&D	Research, Development and Deployment
TPEC	Total Primary Energy Consumption
TJ	Terajoules
T&D	Transmission and Distribution
USD	United States Dollar
WB	World Bank
WEC	World Energy Council
WEF	World Economic Forum

Unit prefixes

μ	micro, 10^{-3}
k	kilo, 10^{3}
M	Mega, 10^{6}
G	Giga, 10^{9}
T	Tera, 10^{12}

LIST OF ORIGINAL PAPERS

The present doctoral thesis is based on the following publications which are referred to in the text by their Roman numerals I-III:

I. **Kisel, E.,** Ots, M., Hamburg, A., Leppiman, A., Härm, M. Concept for Energy Security Matrix. *Energy Policy*, Vol 95, 2016, 1−9 pp.
II. Ots, M., Hamburg, A., Mere, T., Hõbejõgi, T., **Kisel, E**. Impact of price regulation methodology on the managerial decisions of the electricity distribution network company. In: *IEEE ENERGYCON 2016,* 4-8 April, 2016, Leuven, Belgium, 1-6 pp. IEEE Conference Publications, DOI: dx.doi.org/10.1109/ENERGYCON.2016.7513963.

   This publication was awarded by the Energy Regulators Regional Association (ERRA) as Acknowledged Paper of 2016.

III. **Kisel, E**., Ots, M., Hamburg, A., Mere, T. Estonian Experience by Implementation of Incentive Type of Price Regulation. In: *57th International Scientific Conference of Riga Technical University (RTUCON)*, 13-14 October, 2016, Riga, Latvia, 5 pp (in print).

In the Appendix A, copies of these publications are included.

Author's own contribution

The contribution by the author to the papers included is as follows:

I Einari Kisel is the main author of the paper. He is responsible for literature overview, data collection, and calculations. He had major role in writing.

II Einari Kisel participated in writing of the paper. He contributed to the development and application of applied methodology of the paper, provided expert assessment on implications of regulatory methodologies and is partly responsible for literature overview. He had major role in writing and editing, and presented the paper in the Conference.

III Einari Kisel participated in writing of the paper and prepared the poster presentation. During his earlier engagement in the Ministry of Economic Affairs and Communications of Estonia he developed the legislation for described price regulations and compiled their impact analyses. He had relevant role in writing and editing of the paper.

INTRODUCTION

Energy policy appears to be one of the most challenging and controversial policy for majority of states. Solid energy policy is considered to be a cornerstone of a modern economy and society. Successful energy policy of a state delivers welfare and security to its citizens, promotes investments in economic development, and has limited impact to the nature. In the same time energy policy of a state can oftentimes affect also geopolitical affairs and order of state management, it can be abused and manipulated in order to influence nations. Modern society largely relies on energy supplies, and can be thereby largely influenced.

Common understanding is that energy policy has to deliver secure, affordable and environmentally sustainable energy supply for all citizens. However, methods for measurement of performance of a country in each of these objectives are widely disputed.

Different international institutions (WEC, WEF, IEA, EC, EIA, WB) have created their own methodologies and sets of indicators to provide national energy policymakers and investors with benchmarks about national energy policies. These organisations have used different approaches and address energy policy objectives in their own ways. In addition, national policymakers have sometimes created their own sets of indicators for their energy strategy documents or have used references from scientific literature as a benchmark. All in all, there is no common approach to assess the quality of energy policy.

The most challenging issue for such methodologies is associated with data. Usually these methodologies rely on a set of indicators that are available in public databases. However, these datasets often provide just easily collectable data that do not represent full information about the sector. Even worse, sometimes misinterpretations of data or indicators can guide to misleading conclusions by policymakers and investors. For example, this is often the case when economic monetary indicators like GDP are combined with energy data, and are then interpreted as energy efficiency indicators without considering implications of economic structure of a country, climate, energy trade with other countries etc.

For finance sector the quality of energy policy is one of the basic parameters for investments decisions in the economy of a country. During last decade lenders have started to take countries' energy policy stability and longevity as a vital element of financing decisions. Furthermore, the energy policy assessments by international institutions have been used more and more in evaluating energy sector investments.

Digitalisation of energy sector has provided new opportunities for data selection and collection. Smart energy systems can offer a potential to collect relevant data within very short timeframe also from consumers, and can so substantially improve the ability to manage energy policy. However, policymakers have not made full use of these opportunities for energy sector statistics yet. If treated accurately, additional information gathered by smart energy systems can substantially improve the quality of national and regional energy policies.

Ongoing technological and market-wise transition of energy sector is also likely to change the concepts of national energy policies. Several new technologies have reached their economic maturity and are entering now energy and transport markets in a competitive basis. These new technologies challenge also current business models and policy frameworks. Furthermore, integration of national energy markets into regional ones creates a need for stronger regional energy policies. These transitions put another strain to the energy policymakers' ability to adequately assess the quality of energy policy: right incentives to investors and consumers can significantly improve general long term operations of energy systems, but misinterpretations can lead to stagnation of energy sector.

The aim of this thesis is to analyse current shortcomings of energy policy assessment methodologies and of some specific indicators, and to provide an advanced indicators that would improve the quality of such assessments. The biggest issue of the existing energy policy assessment methodologies is their reliance on existing data. This thesis takes another approach: it explores what would be an ideal set of indicators that the policymakers should follow and use for planning purposes. Thesis ignores the lack of international energy data but re-visits the core objectives of energy policymaking and would provide fruit for thought for policy makers and statistical offices for future items of energy statistics.

First Chapter of the thesis provides an overview about the energy policy assessment methodologies used by different institutions. Second Chapter discusses the challenges and shortcomings of these methodologies and describes principles and components for advanced approach to the analyses in different dimensions. Third Chapter presents a new set of indicators in terms of Energy Security, Competiveness/Affordability, and Sustainability. Fourth Chapter addresses additional challenges that are likely to influence future energy policies. Finally, the Fifth Chapter brings together the conclusions and proposes future work to be taken on the topic.

Thesis relies on the work that the author has carried out as an energy policymaker in Estonia and as a Senior Fellow in the World Energy Council dealing *inter alia* with development of Energy Trilemma Index. Current thesis presents authors' own vision about the set of indicators that energy policymakers should use in their activities.

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This thesis would not have materialised without unprecedented challenges that Estonia had to face in energy sector during last 15 years. Gunnar Okk and Marika Priske have been these persons who have challenged, supported and believed in me in the endeavour to reshape the Estonian energy policy. Special gratitude in this respect goes also to my former colleagues in Eesti Energia AS, in the Energy Department of the Ministry of Economic Affairs and Communications, along with eight former Ministers responsible for energy affairs I had a possibility to work with: they all have made this transition happen.

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1. OVERVIEW OF EXISTING ENERGY POLICY ASSESSMENT METHODOLOGIES

Policymakers have through decades set ambitious objectives through national energy strategies. General objective of a national energy policy is usually aimed to guarantee secure (meaning with least interruptions), affordable (meaning with competitive price to industries and reasonable price for households) and sustainable (meaning with least impact to the environment) energy supplies. Each country has during distinct time periods prioritised differently these dimensions, but in general these three objectives are part of each proper energy policy.

For each of these dimensions one can find in the scientific literature an overwhelming number of publications, addressing whether sustainability, affordability or security aspects of an energy policy. However, as overall energy policy includes also political and subjective aspects, then scientific approach to the issue is fairly complicated. It requires involvement of fair number of scientists that can provide expert assessment on such methodologies.

First attempts to create comparable quantification of these dimensions were made around 10 years ago. Table 1 presents the comparison of the most referred energy policy assessment methodologies that have been developed by now by the World Energy Council [1] and the World Economic Forum [2] that have based their methodologies on the judgement of scientific advisory boards and on available data.

Table 1. Comparison of energy policy assessment methodologies from the World Economic Forum (WEF) and the World Energy Council (WEC)

	WEF Energy Architecture Performance Index 2016	**WEC Energy Trilemma Index 2015**
General Methodology	3 dimensions (16 indicators)	3 dimensions (20 indicators) 90% + Contextual Performance (14 indicators) 10%
Calculation of the score of a country	Final score is an average of three dimensions	Final score is calculated based on weighted average score of a country in sub-dimension
Names of the Dimensions	1. Energy Access and Security 2. Economic Growth and Development 3. Environmental Sustainability	1. Energy Security 2. Social Equity 3. Environmental Sustainability
Reference Values for scores	Target values used as references for best performance	Highest and lowest values among the observed countries are basis for normalised scores

Weighting of Indicators	Each indicator weighs 10-25% within the dimension	Each indicator has equal share within the sub-dimension
Indicators of 1st dimension	1. Electrification Rate (%) 2. Quality of Electricity Supply 3. Percentage of population using solid fuels for cooking 4. Diversity of Total Primary Energy Supply – higher weight for energy exporters 5. Diversity of import counterparts (only for importers) 6. Import Dependence	1. Diversity of Primary Energy Supply 2. Energy Consumption growth compared to GDP growth 3. Import Dependence 4. Diversity of Electricity Generation 5. Energy Storage 6. Preparedness (human factor)
Indicators of 2nd dimension	1. Energy Intensity (GDP in PPP USD per unit of energy used) 2. Degree of Artificial Distortion to Gasoline Pricing (index) 3. Degree of Artificial Distortion to Diesel Pricing (index) 4. Electricity Prices for Industry 5. Cost of Energy Imports (% of GDP) 6. Value of Energy Exports (% of GDP)	1. Access to electricity 2. Access to clean cooking 3. Quality of electricity supply 4. Quality of electricity supply urban vs rural areas 5. Electricity Prices 6. Gasoline and diesel prices 7. Natural gas prices
Indicators of 3rd dimension	1. CO2 emissions from electricity production 2. PM10 particulate emissions in the country level (microgram per m3) 3. NOx emissions of energy sector per capita 4. Methane emissions in energy sector 5. Average fuel economy for passenger cars 6. Alternative and Nuclear energy as share of total consumption	1. Final Energy Intensity 2. Efficiency of Power Generation and T&D 3. GHG emission trend 4. Change in forest area 5. CO2 intensity 6. CO2 per capita 7. CO2 from electricity generation
Additional Indicators		Contextual performance indicators: 1. Political Strength - Macroeconomic environment - Political Stability - Perception of Corruption 2. Regulatory Environment - Transparency of policymaking - Rule of Law - Regulatory Quality 3. RD&D and Innovation - Intellectual Property protection

		- FDI and technology transfer - Capacity for innovation - Number of patents by residents 4. Investability - FDI direct inflows - Ease of doing business 5. Air pollution, water and land impact - Wastewater treatment - Air pollution

Both these methodologies have been in use now for several years and are under constant development. Presented methodology from WEC is the latest update from October 2016 that addresses some of the earlier shortcomings - for example access to energy that was not addressed in the former set of indicators. Evidently, the transition of energy sector has constantly changed also the focus of policymakers and triggers necessity to review the indicators and methodologies.

One of the important features of these methodologies is the recognition that three dimensions of energy policy have to be developed in balance. If countries focus in short term on just one or two dimensions, then they are likely to have technical, political or social drawbacks later with these dimensions that are lagging behind. Classical negative example in this context is the development of Chinese energy policy, where emphasis has been put on the energy security and competitiveness of energy prices by investing in coal based power production, while environmental footprint has been neglected for years. Now the living conditions in several areas have reached so low levels that the government has started to replace coal power plants with cleaner sources. It means that there were made magnitude of unreasonable investments for number of years. As a positive example one could follow the path of Slovenia that has constantly been improving their position in all three dimensions of energy trilemma through the years and has raised its position strongly among long-term investors. Therefore it is important to guarantee during the development of energy sector that all three dimensions receive appropriate level of attention, and more focus is put on these areas that are less developed.

Other international organisations have mainly concentrated on data collection and have developed some indicators in setting general strategic objectives. International Energy Agency (IEA) has developed extensive energy database and has provided number of indicators that in their view energy policymakers should follow [3]. They have also published number of country reports where they address in more detail energy policy details of respective states. However, IEA reports mainly describe the specific issues of energy policies and provide comparable performance assessment only on selected indicators. It should also be recognised that governmental organisation like IEA may have difficulties to present such assessments that may cause unease for their members.

European Commission (EC) has recently also developed a set of Member States energy profiles, where they have used number of indicators [4] to measure the progress of Member States towards political targets. However, comparison of these profiles appears to be difficult, as used indicators do not form an integral methodology – some countries perform better with some indicators, other with others. Nevertheless, as the EU countries have extensive technical and statistical background, there is a clear potential to develop in the future stronger assessment methodology to support policy decisions of Member States for transitioning common marketplace.

The World Bank in turn has gathered extensive database on energy statistics and indicators from all over the world [5]. However, they do not present any further analyses on these figures, but leave the examination to the users of data.

All these institutions influence to large degree energy policy decisions and investments in different parts of the world, therefore it is vital that the methodologies deliver right signals to decision makers. However, if one goes into details of these methodologies and indicators, questions start to rise.

2. CHALLENGES OF EXISTING ASSESSMENT METHODOLOGIES AND INDICATORS

2.1. General Observations on Existing Methodologies

As stated in the introduction, different institutions have developed their own sets of indicators for analysing an energy policy. In general, WEC has well described their selection criteria for indicators in [1], which to large extent applies also to other models used so far:

a. Robustness: Indicators are to be taken from reputable sources with the most current information available;

b. Contextual sensitivity: Indicators should capture different country situations;

c. Relevance: Indicators are chosen or developed to provide insight into country situations in the context of the Index goals;

d. Distinctiveness: Each indicator focuses on a different aspect of the issue being explored, unless reinforcement is required;

e. Coverage: Individual indicators are required to provide data for 50% of countries included in the Index. Only countries with data available for at least 75% of all indicators and 50% per indicator group are included in the Index calculation;

f. Comparability: Data to calculate an indicator is derived from as single and common a unique source as possible, to ensure comparability between countries;

g. Balance: Indicators within each dimension (and dimensions across the Index) exhibit coverage of different issues.

However, this approach largely relies on availability of relevant data and indicators, which often do not provide enough details about the specifics of energy sector of a country. Even worse, in some instances such inaccurate or too general data may deliver wrong signals to the policy makers. To illustrate this statement lets imagine two neighbouring countries: country A produces electricity from natural gas and exports 20% of its production to country B that relies on these imports in its electricity supplies. Energy Intensity of country A is usually higher due to larger volume of primary energy in the energy balance compared to country B (as electricity is usually quite low-value product, it does not provide same level input to GDP). In international comparisons country B would look less energy intensive, and usually also more clean, as the emissions have been emitted only in country A. So the policymakers usually would have a view that the energy and economic policy of country B is more acute. However, if instead of these electricity imports country B would have produced its required electricity itself from coal, the picture would have been completely different. Therefore it has to be stated that the selection of indicators for energy policy assessment must be taken very carefully in order to signal right incentives.

Current thesis takes an alternative approach: it is explored what should be the most relevant data in order to assess the quality of an energy policy. Therefore main emphasis on indicator selection is put on relevance, distinctiveness and contextual sensitivity, while the other selection criteria are ignored. The outcome should signal to the energy policy makers what data they should gather in order to make more justified decisions about their energy strategies.

2.2. Challenges of Existing Methodologies

This section highlights the main shortcomings of existing assessment methodologies. While in general the results of methodologies provide good benchmarks for policymakers, the practical application of the methodologies for further steps is often not easy for following reasons:

a. **Difficult to use for planning**. One of the specific challenges for all of these methodologies is that gathered data and indicators are difficult to be used for future policymaking. They provide good historical overview of the performance of the energy sector in specific market circumstances, subject to weather conditions, infrastructure restrictions, market prices, etc. However, to plan and forecast such circumstances is nearly impossible. Policymakers can influence infrastructure developments and market operations, but current indicators used in assessment methodologies are difficult to forecast. From this perspective methodologies and indicators should also highlight the abilities and vulnerabilities of infrastructure and markets to deliver best solutions to the marketplace in any circumstances.

b. **Reliance on general data**. Existing methodologies largely rely on general primary energy indicators that do not go into nature of a specific country. Oftentimes it is referred that countries have very different circumstances to develop their energy policy, and therefore it is nearly impossible to compare the outcome. While this is largely true, it can be argued that the general objectives of each energy policy is tied to triple objective of secure, affordable and sustainable supply for all citizens. However, different is the nature of energy required by citizens: in cold climate people need more energy for heating and have a higher needs for insulation of buildings, in hot climate for cooling; in industrialised countries more energy is required for manufacturing processes, while service-oriented economies consume usually less energy per capita (although in the latter people may consume even more energy intensive products produced somewhere else), etc. Energy intensity indicators are usually the ones that ignore the differences in consumption patterns.

c. **Weighting of indicators**. The weight of an indicator in the final result should reflect the importance of the indicator in the overall result. WEC and WEF have used different approaches for weighting indicators: while WEF has used expert opinions for setting the weight for each indicator, then WEC has given equal share to each indicator within the dimension. Both approaches are subjective and may lead to over- or underweighting of some indicators. Therefore this thesis has also not tried to weight the indicators, as it would always be subjective and can only be based on the assessment of relevant experts.

However, one way to overcome described methodological issues of indicators is to make a deeper distinction between different energy uses: electricity, heating and cooling, transport and industrial purposes. Here the availability of data becomes crucial: this would require much more detailed statistics from each of these sectors. Even more: considering the increasing coupling of energy sectors, the final use of energy has to be followed more closely. Smart metering can provide the possibilities to do so, and the statistical databases have to use this opportunity.

Division of energy sector into subsectors creates intriguing questions about the scope of a national energy policy. For example, whether non-energy uses of energy (for example for producing chemicals) should constitute a part of energy supply policy or is it a part on economic policy? Should exported energy volumes (in the form of coal, oil and its products, gas, electricity) be part of energy policy or economic policy? These two aspects are usually the ones that create main difficulties in comparability of national energy statistics: countries that use primary energy also for industrial purposes or export energy products have usually higher share of fossil resources in their energy mix, although it is often not tied with their national energy demand (only via energy required for manufacturing). Therefore these countries are usually seen as more energy intensive and often also emission intensive compared to countries that just use their products.

Another difference between the methodologies of WEC and WEF is about reference values. While WEC uses the best and worst results among the countries as references for normalisation of the rankings, then WEF sets reference values that would serve as benchmarks to reach some score. While both approaches can be well justified, the WEF approach provides clearer targets to countries and would therefore serve better for the purpose of improving energy infrastructure and its operations. Similar approach is applied by financial rating companies that set reference values for countries or companies to reach defined benchmark.

In addition to above WEC has added to the assessment also Contextual Performance indicators to emphasise the value of stability of political, societal and economic frameworks to the energy sector. While this context is relevant, then each of these indicators could also be analysed under some dimension. For example political stability and control of corruption can be considered as indicators in Energy Security dimension, economic strength indicators can be associated with affordability dimension. However, these divisions should be made with extreme care, as these indicators may influence also other dimensions.

All in all, current methodologies have number of shortcomings due to general nature of data. In order to make more sensible analyses, countries and institutions should dig deeper into different energy sectors in order to capture specifics of each country and to make results more comparable. Current thesis will provide an attempt to guide such analyses with more detailed set of indicators that would better capture peculiarities of national energy systems.

2.3. Novel approach to assessment methodologies

Hereby this thesis takes an alternative approach: national energy policy should focus only on the energy required by citizens and national economy, and leave aside other uses of energy (for manufacturing of other products and for exports). Then it is possible to concentrate only on these energy supplies that are required in a country, and would be possible to improve the comparability of data: it allows comparing the ways how countries approach their energy needs.

To further illustrate the issue, an example from Estonian statistics is provided in Figure 1, based on data from [6] and authors' calculations. First column provides amounts of primary energy that are used for energy production. From these volumes are deducted already volumes that are used for non-energy purposes (for chemicals production). However, this column includes primary energy that is used for production of electricity for exports – in Estonian case it amounts in some years up to 30% of total electricity production. Furthermore, this column does not provide information about transport fuels: the fuels that are purchased for use are not presented in this statistics.

Second column describes final energy consumption volumes: here again one can find in official statistics a column on fuels, which purpose is unclear. In practice, these fuels in Estonia are used for heat production and should be reflected in heat statistics.

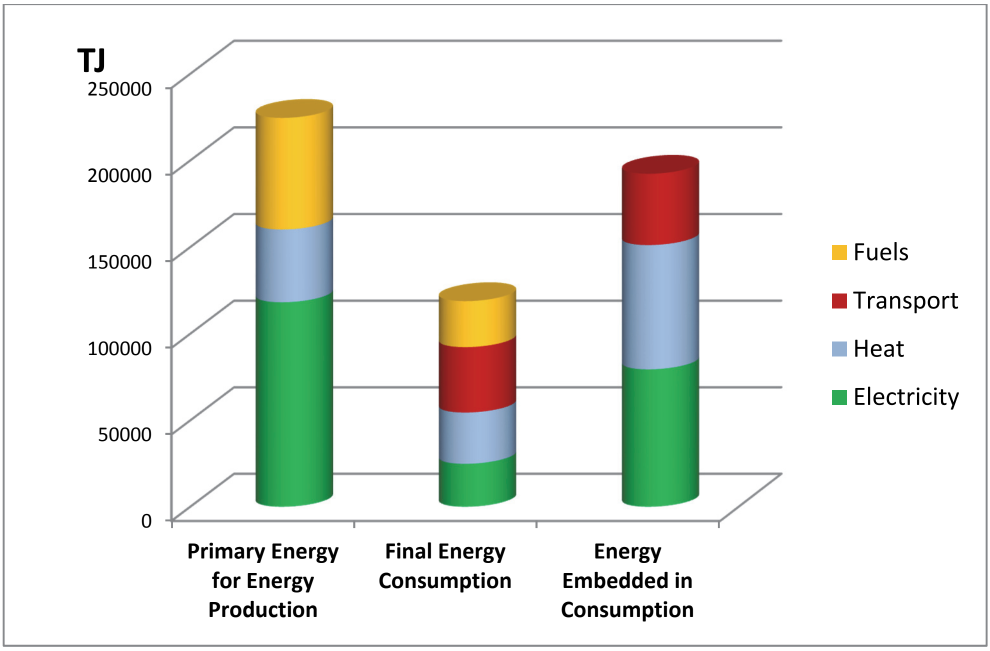

Figure 1. Alternative ways to present energy balance (example: Estonia 2014)

In order to understand the full energy footprint of a country, third column presents calculated primary energy that is required to provide final energy consumption in the country, oftentimes referred in literature as Energy Embodied in Consumption (EEC) [7, 8, 9]. Here are taken into account energy efficiency of power production, electricity losses, heat losses in production and distribution, and additional energy required in refining of crude oil. This approach provides much better overview about the impact of energy sector and more realistic primary energy volumes that are directly required for energy supply in a country.

EEC approach eliminates several issues that are hidden in current energy data and indicators: usually the data of countries with industries that use energy sources for non-energy purposes have difficulties to explain their high environmental impact, although the products they produce are usually consumed all over the world. Same counts for energy exporting countries like Saudi Arabia or Russia: their environmental data is often distorted because of high exploration or production volumes, but the countries that use these energy supplies look very neat. Politically it would incentivise that the countries should abandon production of these resources but should concentrate on import, but in terms of global emissions this approach would often mean even higher emissions. If to include this required energy to consuming countries energy balance, their political focus is also likely to shift towards globally cleaner solutions.

Furthermore, the statistics from electricity, heat and transport sectors should not look only on the consumed volumes, but should also look at the characteristics of the infrastructure, stocks and storages. These features describe largely the state of energy security aspects in electricity and heat sectors, and should be compared with indicators that describe the ability to cover peak demand (like Reserve Margin or N-1 criteria).

Finally, the distinction between energy uses provides also a possibility to new approach on weighting of indicators: higher weight in final score should be put on these sectors that have higher share in a given country. This would provide final score with balance of energy uses specific to this country. For example in case of countries with high heat demand would this approach allow to put more emphasis to indicators that describe heat sector, while in case countries in hot climate the share of heat sector in final score would be weighted to be negligible.

3. NEW SET OF INDICATORS FOR ENERGY POLICY

Current chapter provides an alternative approach to indicators that energy policymakers should consider. It is clearly recognised that currently energy statistics in majority of countries does not gather such detailed data. The aim of the thesis is to provide guidance what kind of data would be relevant to be gathered and structured by the policy makers in order to improve justification of energy policies.

In general the logic of Energy Trilemma is followed when structuring the indicators. Following chapter is structured into three sections:

a. Energy Security Indicators
b. Affordability and Competiveness Indicators
c. Sustainability Indicators

Energy Trilemma approach delivers majority of controversies of energy policy, in the same time addressing more in detail the peculiarities of electricity, heating/cooling and transport sectors. Each following section will present a set of indicators relevant for this dimension of energy policy.

3.1. Energy Security Indicators

Energy Security is one of the most difficult dimensions of energy sector to evaluate [15, 16, 17, 18, 19, 20, 21, 22, 23, 23, 25, 26, 27]. As there is no common approach to measure performance of states on energy security, countries have often developed their own approach to the objectives they want to pursue. This dimension has been thoroughly analysed and presented by the author in [I]. The publication introduced by the author a novel concept for Energy Security Matrix that is hereby presented in Table 2.

Energy Security Matrix structures relevant energy security indicators from the aspects of Technical Resilience and Vulnerability, Economic Dependence and Political Affectability for electricity, heat and transport fuel sectors. From the logical sequence of the Matrix one can observe that Operational and Technical Resilience indicators refer to short- to medium term energy security (from seconds up to one year planning), while Technical Vulnerability, Economic Dependence and Political Affectability indicators are addressing more longer term issues of energy security. However, the longevity of long-term energy issues can lead to unwanted developments that can also in short term influence operations of energy system. In practice, operational and technical resilience indicators address potential threats from existing system, while long-term indicators incentivise the needs for energy security investments and/or required regulatory changes in order to encourage improvements in future energy-mix.

Table 2. Energy Security Matrix (provided by the author)

	Energy Security Indicators for		
	Electricity Sector	Heating/Cooling Sector	Transport Sector
Operational Resilience to internal disturbances (flexibility)	- Share of unreliable capacity compared to minimum load (with and without interconnections) - Share of reliable capacity (incl. capacity available during peak via interconnections) compared to Peak Load		
Operational Resilience to external disturbances (flexibility)	- Resilience to Acts of Terror - Resilience to Cyber Attacks - Resilience to natural disasters - Resilience to climate change		
Technical Resilience (capacity)	- Reserve Margin (also in N-1 cases) - Weighted Average age of Reliable Power Capacities and networks - Average Return on Reliable Power Production and network Investments	- Stocks of Fuels for Heating compared to Monthly Peak Consumption - Weighted average age of district heating capacities and networks - Average return on district heat production and network investments	

Technical Vulnerability (energy)	- Diversity of Potential Electricity Supplies (Herfindahl Index) - Potential Supply compared in annual consumption (subject to Electrification Rate)	- Diversity of Potential Heat Supplies (Herfindahl Index) - Share of Potential Heat/cooling Supply compared to Annual Consumption	- Diversity of Energy for Transport Supplies (Herfindahl Index) - Potential of Supply in case of supply disruptions compared to Annual Consumption
Economic Dependence	- Merchandise value of power exports or imports compared to GDP	- Merchandise value of fuels imported for heating/cooling supplies compared to GDP	- Merchandise value of fuels imported for Energy for Transport compared to GDP - Merchandise Value of exported Energy for Transport compared to GDP
Political Affectability	- Level of Political Stability in given country - Level of Political Stability in supplying countries - Interest level from other countries to influence the sectors' policy - Openness of the country to the external influence - Level of Corruption		

Operational resilience indicators for internal disturbances are relevant only for electricity sector: heat and transport fuel sectors are not so time-critical, their consumption/production balance is more flexible and does not have so much intermittent producers that would pose threat to stable supplies. Listed electricity sector indicators describe the most difficult situations for power system operations and characterise the flexibility of the power system to cope with these situations.

Operational resilience to external disturbances is relevant for all energy sectors, as it may have a medium term impact to the whole energy system and a country as a whole. Therefore the analysis of the country's energy systems to avoid external disturbances should be part of energy security assessment in all sectors.

Technical resilience indicators incentivise the readiness of the system to cope with extreme demand. This is relevant for electricity and heat sectors, where the energy cannot be stored but has to be produced as much as it is required at the moment. This makes the readiness of the energy system for peak consumption extremely important. However, it has to be noted that with technical advancements in electricity and heat storage systems this set of indicators might need to be revised in coming years. Also new concepts on hard and soft resilience [28] may provide in the future new possibilities for such assessments.

The key to Technical Vulnerability of energy system lies largely on potential and diversity of different energy supplies and suppliers, both in terms of supply sources and routes. This analysis has to be taken very carefully considering the potential of manipulation of the markets that may influence the economic outcome of energy system operations. Therefore here the analysis has to be country specific in order to find the potential risks of supplies in a more detailed manner.

Economic dependence of energy sector may have a strong impact to the countries overall economic performance and influence its welfare and stability. However, it could be noted that the lower is the share of costs and revenues of energy sector in the GDP, the lower is the influence that energy can have to the welfare of the country. It can also be noted that high energy costs can be offset with energy exports (that are usually also higher in same cycles) or with energy efficiency measures. So the overall aim of the country should be to have a neutral balance between the energy export revenues and import costs, in order to minimise the impact of the energy sector to political stability.

Lastly, Political Affectability is subject to geopolitical interests, and for majority of the countries does not pose any issue. However, the countries that are under political interest sphere of aggressive countries, this layer of energy security becomes critical in the evaluation. There are number of non-measurable indications that may be found there, but common denominators for those aspects are political stability and corruption. These are the main ways how countries energy policy decisions can be influenced.

Energy Security Matrix lists the indicators that should ideally be measured or assessed in order to provide detailed judgement about the energy security policy of a country. It uses the approach to assess, how well are national energy needs guaranteed from technical, economic and political perspectives. This provides the magnitude of analysis that ideally should be made for the purpose.

One of the main differences of Energy Security Matrix compared to the Energy Security dimensions of WEC and WEF methodologies is the approach that describes more the qualities of infrastructure and whole energy system, and does not rely so much on operational indicators. This approach concentrates on ability of infrastructure to cover the load and demand, and when compared with other countries it allows also for policymakers to see the shortcomings of infrastructure and operations of a system. These indicators are also much easier to forecast for planning purposes, so they can be easily used for strategic planning.

As one of the components of energy security, Energy Security Matrix highlights under Technical Resilience indicators also the importance of average return of network investments. Considering the importance of regulatory environment to guarantee reasonable returns for energy investments this specific issue has been explored more in detail in [II]. Furthermore, Estonian experiences with application of different price regulation methods were discussed in [III]. This paper provides input also for the market design aspects of an energy policy, that are further discussed in Chapter 4.

The set of indicators in Energy Security Matrix was proposed by the author and was analysed with co-authors of the publication. All in all, the indicators provided in the Energy Security Matrix should be considered by policymakers in the development of national and regional energy security strategies.

3.2. Affordability and Competiveness Indicators

Determination of the second pillar of energy policy is again approached differently by WEC and WEF. While WEC indicators address the affordability of energy to households (called as 'Social Equity') by looking the share of energy costs compared to average income in a country, then WEF defines it as 'Economic Growth and Development' and analyses some economic indicators of energy system.

Both approaches appear to be appropriate for different consumer groups. The aim of the energy policy should be to guarantee affordable energy supplies to the citizens [13], but also competitive energy prices to industries for economic growth. These two consumer groups are the most sensitive ones to energy prices. Other consumer groups like service companies and institutions or transport appear not be so sensitive to energy prices.

However, the use of indicators that are tied to Gross Domestic Product for these analyses appear not to be appropriate. It can be argued that with new digital economies the concept of GDP does not work anymore. For energy policy purposes it is important to follow prices for two consumer groups: households energy costs are important social factor that reflects the welfare of the citizens, and industrial energy prices describe the attractiveness of energy sector to potential industrial investors.

When analysing the energy prices, then it is important to include all taxes (except VAT for non-households), network charges, levies, subsidies and other components that are included to the final price of energy to customers. However, the costs covered to consumers by the state (for example electricity costs to vulnerable customers) should be deducted from total cost.

In addition to prices and costs the attention should be given here to the access level to energy services. In number of Asian, Latin American and African countries people cannot afford modern energy supplies. However, there is an important flaw in the current official statistics about access to electricity: it counts only these households that are connected to networks, but not those who have been supplied through local modern off-grid solutions like solar PV panels. Therefore it is essential that this technological development should be also captured in the statistics.

From these principles the author has composed the set of indicators in Table 3 to measure affordability and competiveness of national energy sector.

Table 3. Relevant Affordability and Competiveness Indicators (provided by the author).

	Affordability Indicators for		
	Electricity Sector	Heating/Cooling Sector	Transport Sector
Affordability to Households	- Electricity Cost as a share of Average Income (%)	- Heating/Cooling Cost as a share of Average Income (%)	- Energy for Transport cost as a share of Average Income (%)
Competiti-veness of prices to Industry	- Percentage difference with lowest electricity price for industries in reference countries with annual consumption over 40 GWh	- Percentage difference with lowest heat price for industries in reference countries with annual consumption over 10 GWh	
Access to electricity supplies	- Electrification Rate, including off-grid solutions		

As clarified earlier, in all cases the cost must include also all taxes and levies. Affordability of electricity should be calculated based on Formula (1):

$$A_{EL} = \left(\frac{\sum C_{EL} - \sum C_{EL\,HEAT} - \sum C_{EL\,TR}}{I_{AVG}}\right) * 100\% \qquad (1),$$

where

A_{EL} – affordability of electricity supply for households;
$\sum C_{EL}$ – total cost of electricity for households;
$\sum C_{EL\,HEAT}$ – total cost of electric heating and cooling (including heat pumps, cooling appliances, electric heaters) for households;
$\sum C_{EL\,TR}$ – total cost of electric transport for households;
I_{AVG} – average income per capita.

Similarly should be calculated the affordability of heating and cooling, based on Formula (2):

$$A_{HEAT} = \left(\frac{\sum C_{EL\ HEAT} + \sum C_{DIST\ HEAT} + \sum C_{LOCAL\ HEAT}}{I_{AVG}}\right) * 100\% \qquad (2),$$

where

A_{HEAT} – affordability of heating and cooling supply for households;
$\sum C_{DIST\ HEAT}$ – total cost of district heating and cooling for households;
$\sum C_{LOCAL\ HEAT}$ – total cost of local heating (including firewood, gas and oil cost for boilers) for households.

Affordability of transport sector should include only the transport fuel cost in accordance with Formula (3):

$$A_{TR} = \left(\frac{\sum C_{OWN} + \sum C_{PUBLIC}}{I_{AVG}}\right) * 100\% \qquad (3),$$

where

A_{TR} – affordability of transport for households;
$\sum C_{OWN}$ – total own transport energy cost (including $\sum C_{EL\ TR}$) for households;
$\sum C_{PUBLIC}$ – total energy cost of public transport.

Competitiveness level of electricity and heat sector energy prices should be calculated in accordance with Formula (4):

$$C = \left(\frac{P_{AVG}^{N}}{P_{AVG}^{BEST}}\right) * 100\% \qquad (4),$$

where

C – Competitiveness factor;
P_{AVG}^{N}- Average price of electricity (heat) in relevant country for consumers with annual consumption over 40 GWh (above 10 GWh for heat consumers);
P_{AVG}^{BEST} –Average price of electricity (heat) in country with cheapest energy prices for same consumer category.

Electrification Rate is usually measured as the share of people whose households are connected to power grid. However, considering more and more wide application of off-grid solutions (especially in less developed countries in Africa) these households shall also be considered to counted as electrified ones. Therefore Formula (5) presents an improved calculation for Electrification Rate:

$$E = \left(\frac{P_{NET}+P_{OFFGRID}}{P_{TOTAL}}\right) * 100\% \qquad (5),$$

where

E – Electrification Rate;
P_{NET} – Number of people in households that are connected to power grid;
$P_{OFFGRID}$ - Number of people in households that are supplied with off-grid appliances;
P_{TOTAL} – Number of population in a given country.

In case of industrial energy prices is important to follow the difference with countries with lowest energy prices – the attractiveness of a country for industries is not only dependent on energy prices, but on several other factors like the size of the country, availability of relevant workforce, average income level etc. However, if energy prices are substantially higher than in best countries it is unlikely that energy intensive industries would settle in such a country. Transport costs do not appear to have so much implication on the competitiveness and therefore can be ignored.

In case of households' heating costs it is vital to take into account the costs of district heating and also local heating. This data often not covered by official statistics, but it would be important for policymakers to understand the implications of the sector to households, especially in countries with cold climate. This problem is rising as an issue also in electricity sector, where off-grid solutions are getting stronger presence in some countries, but statistics about their energy consumption is not in reach to governments. The challenge will be addressed also in Chapter 4.

The set of Affordability and Competiveness indicators presents again the vision of the author.

3.3. Sustainability Indicators

General approach of the thesis is based on the principle that we analyse the way how the national energy requirements of a country are supplied. Considering this focus, one might find that most of the environmental indicators provided in public databases do not follow the same path. Usually indicators gathered in databases reflect the emissions emitted in a country.

However, such widespread indicators create an important misconception: policymakers that are keen to reduce national emissions will rely more on imports of energy from other countries. As imported energy products (gasoline, diesel, or electricity) carry no emissions that are emitted in the exploration, refining and production of a product, it incentivises to environmentally concerned policymakers that energy import is the cleanest solution for their respective country. Nevertheless, they ignore emissions that have emerged in other 'not-so-concerned' countries in the production processes, and open the door for Carbon Leakage. Therefore "Energy Embodied in Consumption" concept (EEC) provides much better overview about the real emissions associated with energy sector ecological footprint [7, 8, 9] and should be used by policymakers to deliver stronger incentives to reduction of emissions and also energy efficiency.

From this perspective the approach of energy sector footprint appears more sensible, but it is more difficult to trace. While the emissions from exploration of crude oil and natural gas, and refining of crude oil products can be assessed with reasonable precision, then electricity import emissions are very difficult to trace. Ideally it would require hour-by-hour settlement of power balance with associated emissions to each country. With all available IT solutions it can be manageable, but it would require substantial changes in settlement systems and should be triggered by governments in energy statistics requirements.

Another aspect that is often overlooked in sustainability assessments is the variety and nature of emissions. WEF has introduced in their approach number of indicators that assess along with traditional CO_2 emissions also indicators on particulate matter, NO_X and methane emissions; WEC in turn has used Yale University [14] data on different air emissions and water use. Combining these data together and adding to these also nuclear emissions would provide more comprehensive overview about the implications of the energy sector to environment. However, the weighting of these emissions against each other should be topic for further studies.

In addition, sustainability dimension should also evaluate energy efficiency level in each sector. Despite the variety of indicators that are used to measure energy efficiency, there appears to be two consumer groups that matter most for this policy: households and manufacturing sectors [10]. Although the energy efficiency of manufacturing industry is not easily comparable among countries, then comparisons of same industries in different countries would provide solid reference for policy makers. For example, comparison of cement industries [11] or some other widespread industries [12] would provide an effective benchmark to national energy sustainability policies of manufacturing industries.

Table 4 presents the set of sustainability indicators that is proposed by the author for the advanced policy assessment. It should be underlined that all emissions should be calculated based on Energy Embodied in Consumption (EEC) concept in the given country.

Table 4. Relevant Sustainability Indicators (provided by the author).

	Sustainability Indicators for		
	Electricity Sector	Heating/Cooling Sector	Transport Sector
Air emissions	- CO_2, NOx, methane, PM, emissions per kWh of EEC	- CO_2, NOx, methane, PM, emissions per kWh of EEC	- CO_2, NOx, methane, PM, emissions per passenger km
Nuclear waste	- Nuclear waste per kWh of EEC	- Nuclear waste per kWh of EEC	
Water use	- m^3 per kWh of EEC	- m^3 per kWh of EEC	
Energy efficiency of households	- consumption of households per capita	- consumption of households per capita per degree days	- passenger km of households per capita
Energy Efficiency of Cement sector	- kWh per tonne	- kWh per tonne	

For the calculation of emissions from electricity sector a general approach should be used as presented with Formula (6):

$$CF_x = \frac{E_{NAT} + E_{IMP} - E_{EXP}}{EC_{TOTAL}} \quad (6),$$

where

CF_x – Emission x Concentration Factor;
E_{NAT} – Emissions from power plants in a given country;
E_{IMP} – Emissions associated with imported electricity;
E_{EXP} – Emissions associated with exported electricity;
EC_{TOTAL} – Total electricity consumption in a given country (includes final consumption and grid losses).

Formula (6) shall be applied to all forms of emissions and for water use. Ideally it should include also the emissions that are associated with flaring of gases and oil products, and also with refining of oil products (if oil products are imported in the form of gasoline or diesel).

Energy Efficiency Factor of heating and cooling sector should be calculated as presented in Formula (7):

$$EE_{HC} = \frac{C_{HEAT} + C_{COOL}}{P_{TOTAL} * (DD_{HEAT} + DD_{COOL})} \quad (7),$$

where

EE_{HC} – Energy Efficiency Factor for heating and cooling;
C_{HEAT} – Households' total consumption of heat (both district heat and locally produced heat in all forms, including grid losses);
C_{COOL} – Households' total consumption of cooling (district cooling plus electricity for cooling);
DD_{HEAT} – Heating Degree Days;
DD_{COOL} – Cooling Degree Days.

As stated earlier, presented sustainability indicators provide policymakers with much better understanding about the state of play and about the potential of sustainability of respective energy systems. Furthermore, they would remove some misconceptions that are hindered into current energy statistics. However, it would require much more detailed data and analysis of energy supplies.

All presented sets of indicators in Tables 1, 2 and 3 have described the vision of the author about the structure of ideal energy policy assessment. The grounds for such proposals have emerged from the 15 years of experience as energy policymaker in Estonia and energy policy assessor in the World Energy Council. It is clearly recognised that these are idealistic sets of indicators and there is currently not enough data available, but this thesis provides directions what data should be relevant to consider for proper energy policy analysis.

4. SUGGESTIONS FOR ADDRESSING EMERGING IMPLICATIONS TO ENERGY POLICIES

In parallel, energy sector has entered into a transition of technologies and markets. This is strongly driven by innovations in technologies that some years ago appeared to be too costly. There are number of implications from this transition that are likely to influence also current principles of energy policymaking. Current chapter highlights some trends and changes that are likely to add additional complexity to energy policy assessments in coming years, and suggestions by the author how to address these issues. Because of these new challenges the author has given up the original idea of the thesis to provide a novel methodology for energy policy assessment: these new trends may change the overall logic of energy sector.

Emergence of new technologies is a key to face climate change challenges in a cost-effective way. However, it can already be observed that new technologies have created significant changes in the economics of the energy system and have pushed aside some existing assets that are necessary for safe operations of the system. With development of electric cars electricity storage technologies have received strong push forward and are likely to influence soon also electricity sector. Small-scale electric storage technologies along with solar PVs are likely to become economically feasible solutions to millions of households in coming years, especially in rural areas. This may trigger increase in investments to **decentralised off-grid electricity production** facilities, mostly in remote or less populated areas. If this will happen, then by time current grids in some regions may become obsolete and financing of new grids and big power plants (even big wind turbines) becomes more difficult. Similar trend has already happened in IT sector and is going on in heating sector: small personal devices are often preferred by consumers even if they are a bit more expensive.

Another trend that the introduction of renewable solution is bringing along is **zero-marginal-cost of electricity production**. As renewable energy sources have no significant short-term marginal cost (mainly investment cost) then the focus of energy decisions is moving from energy supply to energy investment. It may appear that electricity markets may not be the most attractive solution for consumers and they are keener to rely on their own energy supplies – this would put pressure also to current power and gas market designs that have to deliver against new low-cost technologies. From one hand, it relieves governments from responsibility to guarantee energy supplies to all citizens, from other hand it may create additional difficulties to energy suppliers and vulnerable customers that are not able to invest themselves in new technologies.

However, countries and national networks are looking for new synergies also from **regional integration**. National power and gas markets are turning more and more into regional markets. This brings along also a need to create **regional energy policies** instead of national energy policies. Integration of the EU electricity and gas markets has already brought along **disputes on electricity market designs** – the regulations of countries are too different and may provide unfair competitive advantages to some market players. The arguments about the appropriate ways to structure the markets in the way that would deliver all objectives of Energy Trilemma are increasing largely due to the inappropriateness of some policy measures in some countries that do not aim for balanced energy policy in long run. Such measures put pressure also to well-designed markets that have to find ways how to avoid negative impacts from neighbouring markets. These disputes put further strain to the attractiveness of power markets as a sector to invest.

Such developments will also have significant impact to energy policy designs:

a. One of the main concepts of power sector implies that system has to have always required capacities available. This concept will be altered once electricity storage technologies will become widespread. Already introduction of electric cars may in smaller countries reduce the requirements for peaking capacities and may have in long term an influence to balancing of power system. Therefore there will be new possibilities to address in energy security dimension.
b. From one hand, new technologies may improve the affordability and competitiveness of energy sector. However, current energy taxation policies might not necessarily work in new circumstances. In the EU countries the taxation of transport fuels provides important revenues to state budgets, electricity, emissions and fuel taxes provide additional revenues in some states. All of these are likely to decrease. Governments may need to find completely new ways of taxation to cover decreases in tax revenues. This will possibly have an influence also to the affordability and competitiveness of energy sector.
c. Due to the further integration of national energy markets the number of international disputes about the energy sector operations is likely to increase. Considering the volumes of vested interests in energy sector it can be expected that some companies and countries in stress may create also new tensions in geopolitical arena. These discrepancies between market regulations are expected to raise further concerns for energy policymakers in affected countries.

These trends will influence widely also energy policies, but are often not captured by energy statistics or indicators. Therefore governments should review the ways how data is gathered in order to avoid new misconceptions or false incentives to consumers or investors.

All the above is likely to bring along a need for good transition management on behalf of governments. The focus of energy policy shall therefore move from managing the investments towards management of energy transition. The readiness and ability of government to manage positive transition is becoming more and more an issue for energy policy as well. Whether this leadership of transition management shall be led in details by the governments, or should the governments set the general frameworks and would leave the market to deliver best solutions [29], must be clearly decided b policymakers. If managed properly then both options can deliver expected results, but the pathway has to be clearly defined by national and regional policymakers in international cooperation.

Altogether these implications must be analysed separately by the policymakers. The ability of a national energy system to adapt and to transform into new realities is becoming a new dimension of an energy policy that makes it difficult to assess in the future. Some of these regulatory aspects were analysed also in [II] and [III] for the distribution system operations, trying to capture the best practices of price regulation. However, the ability of an energy policy to reflect and react on positive changes is becoming another dimension of an energy policy that should be considered in the future evaluations from different perspectives.

Therefore the contextual performance assessed by the WEC is becoming more and more relevant, but the assessment of this dimension requires deep forward-looking analysis of legal and political frameworks of energy sector in countries. Current thesis cannot cover this aspect, but it suggests exploring these issues in future works.

5. CONCLUSIONS AND FUTURE WORK

The indicators proposed by the author hereinbefore are based on the experiences from written papers and energy strategies that author has compiled and analysed during last 15 years. The thesis provides more deep approach to the energy policy indicators that are usually gathered and analysed by the authorities or international institutions, and provides a set of 58 indicators that energy policy makers should follow in their activities.

New sets of indicators presented in Tables 2, 3 and 4 provide alternative approaches for assessors of the quality of national energy policies. These tables present Energy Trilemma dimensions (Energy Security, Affordability and Competiveness, Sustainability) from different perspective with the aim to help energy policymakers and investors to make more justified decisions. It can be concluded that these new sets of indicators can provide a new quality for energy policies.

The original intention of the thesis was to provide a new methodology for energy policy assessment. However, with recent developments of new technologies, political strains, energy economics and disputes on future energy market designs, the energy policymaking has turned into even more complicated exercise. While the general concept of delivering secure, affordable and sustainable energy supplies has remained in the focus for policymaking, the number of ways of implementation has been increasing substantially and can be even more argued. Therefore the introduction of a new methodology for energy policy assessment will still be aspirational target, although the current thesis provides a set of new indicators and list of challenges to be considered in this respect.

First of all, energy statistics must go deeper into different energy sectors in order to provide more reasonable results. The thesis provides an approach that electricity, heat and transport fuels consumption should be explored on the basis of Energy Embodied in Consumption that would characterise the energy footprint of a country. This approach would send better signals also to policymakers and investors.

In terms of energy security indicators it is crucial to move towards indicators that describe the abilities of energy infrastructures (production facilities and networks) to cope with required supplies. Current indicators used to capture energy security aspects by exploring the operations of the markets cannot catch the essence of energy security. Indicators provided in the thesis like diversity of potential energy supplies would provide a new approach to such analyses.

The main challenge with affordability and competitiveness indicators are hidden in the comparability of the data. Here the policymakers and statistical offices should strive to define standard consumers also in global scale, and to search the price data for such consumers. However, the emerging changes in the energy sector are likely to have a major impact to the analyses and statistics of affordability.

In case of energy sustainability indicators more emphasise should be given to the diverse nature of impacts that energy sector has to the environment. Policymakers should strive also to analyse the impacts of all emissions and wastes, plus the water use of energy sector. Furthermore, the impact of different emissions should be better analysed in order to provide stronger case for more comprehensive assessments on environmental impacts.

When it comes to weighting of different sectors against each other the EEC concept appears to be a good way to do that. EEC concept provides a possibility to eliminate differences of countries that emerge from different energy resource policies and concentrates on the analysis how efficiently national energy policy addresses Energy Trilemma. However, the weighting of indicators against each other will remain a subjective exercise for policymakers and will depend on political priorities.

Future work should also address the state of openness of countries energy policies to changes. This aspect is largely dependent on political, economic and legal aspects of countries energy regulations. Considering the expected energy transition in coming years the readiness of countries to deliver required investments and changes to the markets define the success of the countries in long run. However, such a comprehensive analysis cannot be made within this thesis.

All in all, energy policy making is encountering difficult times, where a strong leadership is required to carry out the transition. It is clear that historic indicators cannot capture all aspects of changes, and therefore the policymakers need to revisit the core data of their policies due to the changes that are happening in the sector. The thesis provides an input to this process, but the decisions about the further progress have to be made by the policymakers.

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ABSTRACT

Indicators for Assessing the Quality of an Energy Policy

The thesis analyses and proposes 58 indicators that would deliver more justified energy policy incentives to decision makers. Indicators are presented for electricity, heating and transport sectors, and are structured in three dimensions of energy trilemma: energy security, sustainability and affordability/competitiveness. In terms of energy security the proposed indicators are headed towards the qualities of an infrastructure, not about the operations of the system. In case of affordability/competitiveness the focus should be more on comparable economic data. Analyses of environmental sustainability should be more comprehensive and should include more different impacts of energy sector from the perspective of energy embodied in national consumption. The data collection should strive more towards detailed data from different energy uses that would be available through the application of smart energy systems.

The thesis takes also look into emerging aspects of that will influence energy policy in coming years, and makes suggestions for further studies to be taken in the topic.

KOKKUVÕTE

Energiapoliitika kvaliteedi hindamise indikaatorid

Käesolev doktoritöö analüüsib ja pakub välja 58 indikaatorit, mida energeetika otsustajad peaksid jälgima põhjendatuma energiapoliitika kujundamiseks. Indikaatorid esitatakse elektri, soojuse ja transpordisektori kohta, ning nad on struktureeritud energeetika trilemma kolme dimensiooni (energiajulgeolek, säästlikkus, taskukohasus/konkurentsivõime) kohaselt. Energiajulgeoleku osas pakutud indikaatorid keskenduvad taristu omadustele, mitte sedavõrd süsteemi toimimise karakteristikutele. Taskukohasuse/konkurentsivõime dimensiooni hindamisel on fookus võrreldavate andmete kogumisel. Keskkonnasäästlikkust on hinnatud senisest laiapõhjalisemalt lähtudes riigi energiatarbest lähtuva energiavarustusega seotud aspektidest. Pakutud indikaatorite jaoks andmete kogumine peaks olema tulevikus suunatud nutivõrkude poolt pakutavate võimaluste paremale ärakasutamisele.

Doktoritöö toob välja ka uued aspektid, mis lähiaastatel hakkavad mõjutama energiapoliitikat, ja teeb ettepanekuid edasiste uuringute osas mida peaks antud teemal ette võtma.

ELULOOKIRJELDUS

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3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	1998	Ärikorraldus/Sotsiaalteaduste magister
Tallinna Tehnikaülikool	1995	Soojusenergeetika/magister
Tallinna 54. Keskkool	1990	

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti keel	emakeel
Inglise keel	kõrgtase
Vene keel	kõrgtase
Soome keel	kesktase
Saksa keel	algtase

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
1994 (3 kuud)	MSI Residential Course, Taani
1995-1997 (kokku 1 kuu)	Systematic Solutions, USA
1996 (3 nädalat)	LCG Consulting, USA
1997 (nädal)	Bradford University
2002 (3 päeva)	EBS Juhtimiskoolituse keskus
2011 (2 päeva)	Dutch Institute for Public Administration

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2012 –	Maailma Energeetikanõukogu	Euroopa regiooni juht, volinik, vanempartner
2002 – 2012	Majandus- ja kommunikatsiooniministeerium	Asekantsler, osakonna juhataja
1995 – 2002	Eesti Energia AS	Energiakaubanduse direktor, keskkonnajuht, strateegia analüütik, jne

7. Teadustegevus

- Maailma Energeetikanõukogu 2013-2016 aasta "Energy Trilemma Index" aruanded, sisu arendaja
- Maailma Energeetikanõukogu 2014-2016 aasta "Issue Monitor" aruanded, sisu arendaja
- Maailma Energeetikanõukogu 2016. aasta aruanne "The road to resilience – Managing cyber risks", vanemprojektijuht

8. Kaitstud lõputööd

- Magistritöö: "Elektritootmise strateegiline planeerimine Eestis", 1998, juhendaja prof. Heino Levald
- Diplomitöö (magistritöö): "Soojuselektrijaama kontseptsioon", 1995, juhendajad dots. Tõnu Suurkuusk, PhD Jörg von Smuda

9. Teadustöö põhisuunad

Energiapoliitika hindamine, indikaatorite ratsionaalsus, mudelanalüüs, energiaturu mudelid, energiajulgeolek, energiaturu globaalsed trendid

CURRICULUM VITAE

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3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	1998	Business Administration/ Master of Social Sciences
Tallinn University of Technology	1995	Thermal Engineering/ Engineer (equal to Master of Technology Sciences)
Tallinn Secondary School no 54	1990	

4. Language competence/skills (fluent; average, basic skills)

Language	Level
Estonian	Native
English	Fluent
Russian	Fluent
Finnish	Average
German	Basic

5. Special Courses

Period	Educational or other organisation
1994 (3 months)	MSI Residential Course, Denmark
1995-1997 (altogether 1 month)	Systematic Solutions, USA
1996 (3 weeks)	LCG Consulting, USA

1997 (1 week)	Bradford University
2002 (3 days)	EBS Management Training Centre
2011 (2 days)	Dutch Institute for Public Administration

6. Professional Employment

Period	Organisation	Position
2012 –	World Energy Council	Regional Manager for Europe, Senior Fellow
2002 – 2012	Ministry of Economic Affairs and Communications of Estonia	Undersecretary of State for Energy, Director of Energy Department
1995 – 2002	Eesti Energia AS	Director of Energy Trade, Environmental Manager, Strategy Analyst, etc

7. Scientific work

- World Energy Council "Energy Trilemma Index" reports 2012-2016, principal contributor
- World Energy Council "Issue Monitor" report 2014-2016, principal contributor
- World Energy Council 2016 report "The road to resilience – Managing cyber risks", Senior Project Manager

8. Defended theses

- Master Thesis: "Strategic Planning of Power Production in Estonia", 1998, supervisor prof. Heino Levald
- Diploma Thesis (equal to Master Thesis): "Concept for a Power Station", 1995, supervisors Associate Professor Tõnu Suurkuusk, PhD Jörg von Smuda

9. Main areas of scientific work/Current research topics

Assessment of Energy Policy, Rationale of Indicators, modelling, energy market designs, energy security, trends of global energy markets.

APPENDIX A

I. **Kisel, E.,** Ots, M., Hamburg, A., Leppiman, A., Härm, M. Concept for Energy Security Matrix. *Energy Policy*, Vol 95, 2016, 1−9 pp.

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Concept for Energy Security Matrix

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HIGHLIGHTS

- Energy security should be analysed in technical, economic and political terms;
- Energy Security Matrix provides a framework for energy security analyses;
- Applicability of Matrix is limited due to the lack of statistical data and sensitivity of output.

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ABSTRACT

The following paper presents a discussion of short- and long-term energy security assessment methods and indicators. The aim of the current paper is to describe diversity of approaches to energy security, to structure energy security indicators used by different institutions and papers, and to discuss several indicators that also play important role in the design of energy policy of a state. Based on this analysis the paper presents a novel Energy Security Matrix that structures relevant energy security indicators from the aspects of Technical Resilience and Vulnerability, Economic Dependence and Political Affectability for electricity, heat and transport fuel sectors. Earlier publications by different authors have presented energy security assessment methodologies that use publicly available indicators from different databases. Current paper challenges viability of some of these indicators and introduces new indicators that would deliver stronger energy security policy assessments. Energy Security Matrix and its indicators are based on experiences that the authors have gathered as high-level energy policymakers in Estonia, where all different aspects of energy security can be observed.

1. Introduction

Assessment of the quality of energy policy has been the topic for a number of recent studies. The most prominent general assessment of energy policies has been issued by the World Energy Council (WEC) in association with Oliver Wyman [1], another recent energy policy assessment has been issued by the World Economic Forum (WEF) in association with Accenture [2]. Both of these assessments regard energy security as one of the main dimensions of energy policy. Table 1 provides the dimensions and indicators used in these two reports to assess energy security.

Also International Energy Agency has described the approach to assess the short-term energy security of the country [3] with its MOSES model. IEA has also analysed in detail oil and gas supply security in its member states [4] and has described a general framework to assess governance and electricity market arrangements, power system security and adequacy by looking at external and domestic risks and resilience of the power system. However, as IEA admits, their frameworks “cannot be used to compare the overall energy security of different countries, although specific sources and fuels can be compared”. European Commission has used Energy Import Dependence as the main numerical indicator for energy security in its communication on energy security [5].

However, if energy policymakers would try to use these sets of indicators in their national strategic planning activities in order to improve their country's situation, they would find that these indicators would depend on several unpredictable factors. Even worse: some of these indicators may even incentivise policy makers to take national decisions, which would have negative

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Table 1
Main characteristics of the energy security policy assessment methodologies by WEC and WEF.

WEC energy sustainability index	WEF energy triangle
1. Diversity of electricity generation (Shannon index) 2. Ratio of total energy production to consumption 3. Distribution losses as percentage of Generation 4. 5-year compound aggregated growth rate of the ratio of TPEC (Total primary energy consumption) to GDP 5. Days of oil and oil product stocks 5a. Exporters: fuel exports merchandise value as a percentage of GDP 5b. Importers: net fuel imports as a percentage of GDP	1. Diversity of total primary energy supply (Herfindahl index) 2. Electrification ratio (%) 3. Quality of electricity supply (Survey) 4. Percentage of population using solid fuels for cooking (%) 5. Import dependence (%) 6. Diversification of Import counterparts

regional or global impact. For example, in order to calculate Energy Import Dependence, official statistics uses for some energy resources primary or secondary energy (coal, crude oil and oil products, biomass), but for some resources tertiary energy (as electricity from nuclear, wind and solar). This misleading statistics delivers that final energy produced from primary energies always has a bigger weight in these calculations: for example electricity originating from biomass (counted in statistics as used primary energy of biomass) has much higher weight than electricity produced from wind (counted as tertiary energy of electricity produced) due to the technological losses of transformation. Therefore Energy Import Dependence delivers very misleading signals to the policy makers that try to decrease the dependence of a country.

The aim of the current paper is to discuss the approach to energy security indicators and to provide some additional viable indicators that should be considered by the policymakers for higher quality of energy strategies. Following observations are based on long-term experience of the authors as energy policymakers in Estonia. Nevertheless, current paper does not intend yet to provide an exhaustive methodology for full assessment of energy security of a country, but discusses the components for such methodology.

However, it is understood that the main problem is associated with the availability of data: indicators which are currently collected and available in world-wide energy-related databases are not providing adequate background for energy policymakers. This is another issue for the policymakers to address: in the absence of data, which would provide right incentives, it is extremely difficult to make adequate energy policy decisions.

2. Materials on energy security

In addition to the studies by World Energy Council and World Economic Forum, several national approaches have been also applied to energy security assessments. Most interesting ones have been applied by the USA [6] and Lithuania [7]. There is also a number of scientific assessment methods used to approach the energy security from different angles. Christie [8] has approached energy security from the perspective of the vulnerability of the energy infrastructure, Chester [9] and Ciuta [11] have described the multiplicity of the definitions and indices of the energy security, Rogner [10] and Makovich [12] have approached energy security from the perspective of costs to the society. Hughes [13] has described a generic framework for IEA conceptual approach to short term energy security [3] and Winzer [14] has defined energy security as the continuity of energy supplies relative to demand. All of these references have in turn used a number of earlier studies in this regard.

Nevertheless, if energy policymakers would try to use these different assessment methods for the development of their national energy policies, they would soon find that the application of energy security indicators from these investigations is quite difficult. These reports provide variety of retrospective indicators and overviews about the energy security levels and its changes over the years in history, but it is nearly impossible to provide plausible forecasts of these energy security indicators. And as far as energy security is one of the main pillars of the Energy Trilemma [1], it is a constant struggle for policymakers to find proper indicators, which would help them to prepare stronger energy policies in this respect.

For example, it would be rather difficult to forecast the energy mix of power production in the liberalised energy markets, especially in case when there is a high share of variable hydro power in the power system or strong interconnections to neighbouring countries, which can be used to import or export substantial volumes of power. And it is even more cumbersome to predict the geopolitical or national political changes, which may also influence national energy security.

The definition of energy security is another widely disputed matter in the literature. One of the most comprehensive set of energy security definitions is provided by Winzer [14]. From the variety of definitions one could come to the conclusion that we should distinguish between short- and long-term energy securities. Short-term energy security can be largely assessed by the potential of an energy system to deal with disturbances (in other words by describing the Operational Resilience of the energy sector). In case of long-term energy security (which should aim to describe the investment climate to tackle energy security issues), one could distinguish three layers, which should be part of every energy security policy: Technical Resilience and Vulnerability, Economic Dependency and Political Affectability. So all in all there are four layers to energy security:

1. Short Term Operational Resilience should describe the ability of the current infrastructure of the national energy system to cope with different disturbances of energy supply and demand from seconds to days. The question one should ask here would be "how flexible is the current infrastructure to cope with potential disturbances? " This layer is usually described by the characteristics of technical infrastructure and its operations (power capacity margin, diversity of power and heat production, oil stocks, SAIDI, etc.). To capture the level of technical resilience the WEC [1] measures in its methodology Ratio of Total Energy Production to Consumption, and Days of Oil and Oil Product Stocks for transport sector. The WEF [2] uses for similar purposes in its assessment indicator on the Quality of Electricity Supply for electricity sector (based on their Survey). IEA [4] looks in terms of electricity in general to the power system operating practices, situational awareness, coordination, communication and other such aspects, which subjectively can describe the power system resilience to shocks.
   However, majority of these indicators show only the result of the operations (subject to market situation, weather impacts, unexpected outages etc.), but they do not describe the capabilities of the infrastructure (capabilities of different production

facilities, network configuration, impact of intermittent producers, interconnections, stocks etc.) and do not take into account implications from other potential threats to energy infrastructure (as cyber threats, water restrictions, terrorism etc.), which would ideally provide much better overview about the responsiveness of the infrastructure to potential threats. Only WEC's oil and oil product stocks indicator (see Table 1) indicate the level of vulnerability of a country to oil supply disruptions, other indicators are a result of the operations of an energy system. IEA analyses the operational practices, but other such international frameworks do not address such kind of short term resilience.

In case of power supplies one could also analyse an additional layer of Operational Resilience (as an example by ENTSO-E [16,17]), which looks separately at the immediate flexibility of power system to deal with potential disturbances. European Commission has recently also used this approach in their special stress-tests on the short term resilience of the EU gas sector [18]. For the energy policy planning purposes it could be taken into account in the analysis of Technical Resilience.

2. Technical Vulnerability should describe the ability of the energy system to cope with operations in long term (up to 10 years). This layer should describe the diversity of energy systems and the ability to cope with expected long-term loads. The question one should try to answer here is "how capable is the system to cope with long term trends? " Diversity of supplies (both by source and by market players) should enable energy systems to address the issues of the demand changes, potential abuse of market situations and potential impact of the failures of important infrastructures. In parallel one should look at the age of infrastructures and the ability to renew them, potential share of indigenous resources, and also the ability of the infrastructures to incentivise demand side energy efficiency.

   WEC [1] measures in its methodology Diversity of Electricity Generation (based on Shannon Index), Distribution Losses as percentage of Generation, 5-year compound aggregated growth rate of the ratio of TPEC to GDP. For similar purposes WEF [2] uses in its assessment indicators of Diversity of Total Primary Energy Supply (based on Herfindahl Index). MOSES model form the IEA [3,4] looks at the resource adequacy, diversity, flexibility, asset performance and sustained emergency events. European Commission has used also the market share of 3 largest power suppliers [15] as an indicator of the market power, ENTSO-E has also looked from the perspective of long term system adequacy for power sector [16,17]. As one can see, these indicators can provide quite vague retrospective assessment of the levels of energy security of the countries, and are usually more suitable to be used in case of energy importing countries.

3. Economic Dependency describes the magnitude of influence, which energy sector has to the economy of a country. The question one should ask here is "how much is the country's economy dependent from energy sector? " This layer is usually described with macro-economic indicators (Energy Import Dependence, share of energy exports/imports merchandise volumes in the GDP, share of production from indigenous energies etc.). Depending on countries energy balance, the nature of risks associated with Economic Dependency influences largely also the next layer: energy importing countries are striving to reduce their economic and political dependence, while energy exporting countries are more interested about their income and geopolitical influence. WEC [1] addresses this layer with indicators on the share of fuel exports/imports merchandise value as a percentage of GDP, WEF [2] tries to capture it by measuring Energy Import Dependency.

   Though, it would again be rather difficult to make any energy policy decisions based on these indicators: the merchandise value is dependent on the price of energies, the import volumes are dependent on the market conditions and availability of local resources. However, they provide quite good incentive about the level of current Economic Dependence and can be used also to forecast potential future dependence.

4. The layer of Political Affectability should characterise the openness of the energy policy to the (geo)political influence. This layer should respond to the question "how much can other countries influence the energy policy of the country? " This layer is usually not measured, though it has a vast impact to the energy sector developments. The openness to political corruption, instability of governments and potential geopolitical interests may have very clear influence to the energy policies and to the investments in the energy sector. This layer can be assessed by the different political stability and corruption indexes, though the forecasting of this layer is always unpredictable. WEC [1] tries to take this layer into account with its contextual performance indicators on Political Stability and Control of Corruption; WEF [2] indicators do not address this layer at all. IEA [4] analyses in electricity market the regulatory and institutional frameworks, applied legislation, rules and standards. In terms of oil and gas markets IEA has also analysed the legislation and preparedness measures in cases of emergencies.

But again, for the forecasting purposes it would be nearly impossible to make any predictions of these indicators in majority of the countries. To assess that, one could look for the trends in political stability of a country and of a geopolitical region, and the openness of a country to a political interference.

Another aspect that could be discussed in terms of energy security is the division of energy sectors. Very often energy sector is divided into electricity, oil and gas sectors, sometimes coal sector is added there. However, one may argue that from the state citizens' basic needs perspective it should be essential to guarantee the supplies of electricity, heat and transport fuels. In this context gas can be one source of these supplies, which can to some extent be replaced. Indeed, gas is often also used for industrial purposes to produce other products, but this may not be considered as the basic need for the citizens' energy supplies.

When considering heat supplies, both local and district heat production shall be considered. In this context another mislead comes out from statistics: usually heat supplies are only measured in terms of district heating (as secondary energy), and local heat supplies are measured as fuel supplies to consumers (in terms of primary energy). For the sake of comparability and the general purpose, the governments should measure more heat energy and not the primary energy put into the process. Current article considers heat consumption both in terms of district and local heat output.

In case of cooling as one form of energy supplies to customers, ideally one should measure the volume of delivered cooling volume. However, it is understood that the measurement of this volume is nearly impossible, so cooling in terms of the current article is considered to be a part of electricity consumption, as it is also appearing in the statistics. It is clear that the countries with hotter climate have therefore higher need for electricity per capita.

Therefore current paper takes an approach that for the basic energy needs of a state we should look for electricity, heat and transport fuels sectors, and to assess them in aforementioned four layers of energy security.

3. Indicators for Technical Energy Security

Technical Energy Security in terms of this article covers the layers of Technical Vulnerability, Technical Resilience and Operational

Resilience of electricity, heat and transport sectors. In practice it means in terms of energy policy the requirement to guarantee accordingly needed energy, capacity and flexibility of an energy system. However, it is clear that not all of these layers have the same importance for different energy sectors. The latter layer (flexibility/Operational Resilience) makes actually electricity sector very different form the other energy sectors. Even more, in practice one can observe that power supply markets have designed separate markets for all these objectives: balancing markets for flexibility, power markets for energy supplies, and capacity remuneration mechanisms or national power security reserves for capacity delivery.

In following sub-chapters are discussed the most important indicators for Operational Resilience, Technical Resilience and Technical Vulnerability.

3.1. Indicators for Operational Resilience

In terms of Operational Resilience one should look for disturbances that may have an immediate widespread impact to the operations of an energy system. Here we can distinguish between internal and external disturbances – the ones that are originating from energy system operations and the others that are affecting system from outside. The most important internal disturbances are usually changing load and intermittent power production, while the most important external disturbances may occur from acts of terror or cyber-attacks. Power sector may have by far the largest impact due to internal disturbances; therefore it is worthwhile to look for indicators of Operational Resilience only for this sector. In order to assess the Operational Resilience of the power system to internal disturbances one can ask, how manageable power system in difficult situations is.

In this respect, managing minimum and maximum loads are the most difficult situations for system operator. If intermittent producers produce too much energy during minimum load it may lead to overload of the system and to system failures that bring along brown-outs or black-outs. Similarly, if intermittent producers produce too little during peak load, then it may lead to brown-outs or black-outs. In order to measure this flexibility of the power system, we should analyse the operations of the systems in these two extreme cases. These basic aspects of security of supply must form a part of energy security policy.

In order to assess the magnitude of these impacts, we should assess the potential influence of intermittent capacities to the system operations in these two cases. To assess the magnitude of the potential issue during minimum load, the ratio between intermittent capacities to minimum load can be presented as follows:

$$K_{IM,MIN}=\frac{P_{wind}+P_{solar}+P_{IM}-P_{STOR}}{P_{min}}*100\%, \tag{1}$$

where:

$K_{IM,MIN}$ – Ratio of Intermittent Capacity to Minimum Load
P_{wind}- Installed Net Wind Capacity (MW);
P_{solar} – Installed Net Solar Capacity (MW);
P_{IM} – Other Installed Intermittent Capacities (MW);
P_{STOR} – Capacity of Storage Facilities (as for example Pumped Storage) (MW);
P_{min} – Annual Minimum Load (MW).

$K_{IM,MIN}$ would indicate how difficult it would be to maintain the operational balance between the load and production of a power system in case of low load periods, when intermittent capacities can also peak with their production. Often there is also a potential for countries to export excess power or switch off intermittent facilities, but the indicator would indicate the level of difficulty to manage the balance. It goes without saying that if the share of intermittent capacity is high compared to minimum load, the power system is more difficult to manage.

In other extreme case of internal Operational Resilience one can assess the potential to cover maximum load with reliable capacities (i.e. without intermittent capacities) taking into consideration their average availability (usually around 90% of the time), and including also potential capacity available via interconnections during peak. This would indicate the most difficult potential situation to dispatch in high-load periods:

$$K_{REL,PEAK}=\frac{P_{REL}\cdot 0,9+P_{HYDRO}+P_{IMP}}{P_{PEAK}}*100\%, \tag{2}$$

where

$K_{REL,PEAK}$ – Ratio to cover Peak with Reliable Capacities;
P_{REL} – Capacity of Reliable Power Suppliers, i.e. from fossil fuels, nuclear and biomass (MW);
P_{HYDRO} – Available Capacity of Hydro Plants during Peak (MW);
P_{IMP} – Capacity that can be imported (based on TSO assessment);
P_{PEAK} – Forecasted Peak Gross Consumption (Net Consumption and Losses).

Although this indicator provides good assessment of the potential operations, the flows via interconnectors are not always controlled by the national system operator. Therefore the capacity available via interconnectors during peak hours has to be assessed very carefully. However, if the countries work in the same market designs and rules with no bottlenecks (like Nordic and Baltic countries), it is worthwhile to analyse these indicators not only within national borders, but for the whole region.

By combining these two Ratios into one graph (Fig. 1) we can compare different countries power systems Technical Resilience in the most difficult situations for Transmission System Operators (TSOs). Fig. 1 provides such a comparison among the EU states, based on 2012 data from ENTSO-E [16,19].

These indicators represent how flexible is the power system to deal with intermittent supplies. Lower levels of the Ratio of Intermittent capacity to Minimum Load represent higher flexibility of the power system. However, ratio levels over 100% indicate that countries' power system cannot absorb during minimum loads the whole load and the excess volumes have to be absorbed by neighbouring countries, or some intermittent capacities have to be shut down.

The Ratio of potential supplied load compared to Maximum Load represents the ability of the country to cover its maximum load (including the import capabilities). Level below 100% represents severe difficulties in this regard; level over 150% speaks about the strong ability to cover peak loads (but may fall behind in terms of affordability of the power price in terms of Trilemma).

The countries that are represented in the upper left quadrant of Fig. 1 can be considered to have stronger level of Technical Resilience of the power system, as their power system can take care of the most difficult situations of the system operations. These countries that are in the right side quadrants of Fig. 1 rely on their power supply flexibility largely on their neighbours, and that cannot be always highly assessed.

If internal Operational Resilience indicators would be fairly easy to assess, then external ones are much more complex. These assessments for electricity, heat and transport fuels sectors have to be based on thorough analysis of the vulnerability of the system infrastructure to acts of terror and increasingly also to cyber-attacks. Increasing threats to energy systems in this respect can also be associated with climate change or natural disasters. For

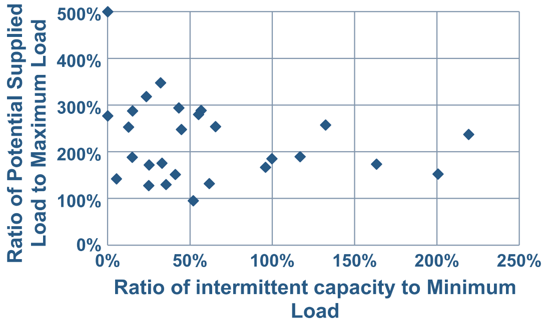

Fig. 1. Share of intermittent capacities to minimum load versus level of reliable capacities compared to maximum load in the EU 28 states in 2012.

example Fukushima nuclear accident was mainly driven from the underestimation of impact of natural disasters that may occur in the relevant region, and had an enormous impact to the energy security situation of Japan.

It is also obvious that the results of such analyses are quite sensitive and would not be usually made public. However, it would be worthwhile if governments would coordinate their methodologies in this respect and use same kind of principles in their national assessments.

3.2. Indicators for Technical Resilience

The most widely used indicator for Technical Energy Security in power sector is Power Capacity Reserve Margin that aims to describe the ability of the power system to cover peak load. This margin is often also referred as the main indicator of Power Generation Adequacy. Transmission System Operators often use in their analyses Power Capacity Reserve Margin as the main indicator to assess the security of power supplies:

$$P_{CRM}=\left(\frac{P_{INST}+P_{IMP}-P_{RESTR}-P_{REC}-P_{OUT}-P_{SR}-P_{EXP}}{P_{PEAK}}\right)*100\% \quad (3)$$

where:

P_{CRM} – Power Capacity Reserve Margin;
P_{INST} – Installed Net Capacity of the system;
P_{IMP} – Capacity that can be imported (based on TSO assessment);
P_{RESTR} – Capacity with Restricted Availability, i.e.:

1) Capacity of Intermittent Power Producers, mainly wind, solar and CHP-s that depend on heat load;
2) Capacities that cannot be used due to environmental restrictions;
3) Preserved capacities (with start-up time more than 168 h);
4) Other net capacities that are permanently not available;

P_{REC} – Capacities under reconstruction or planned maintenance;
P_{OUT} – Capacities in unplanned outage or maintenance;
P_{SR} – System Reserve of TSO (for example Outage Reserve);
P_{EXP} –Capacity booked with binding export agreements;
P_{PEAK} – Forecasted Peak Gross Consumption (Net Consumption and Losses).

This indicator can also be analysed from the N-1 (without largest production capacity) and from the N-1–1 (without largest production capacity and without largest interconnection capacity) perspective, which provides an assessment of the vulnerability of the system to unplanned outages.

P_{CRM} is a good indicator for assessing Technical Resilience of the power sector in a given country or region. Although, it does not take into account potential impact of the network configuration (for example internal bottlenecks) and ignores the potential of intermittent capacities like wind and solar to supply energy also during peaks. One can also observe that different regions in the world apply very different principles for calculating P_{CRM}: often P_{IMP} is not counted, or P_{RESTR} is calculated with very different principles, etc. Therefore often these results are not comparable between countries. In addition, it is often difficult to forecast the availability of capacity via interconnectors during peaks, as it much depends on the market situation in the neighbouring state during these hours.

Similarly can be assessed the Technical Resilience of heat sector for district heating areas, but it is much more complicated to make an overall assessment for heat sector capacities of a whole country: in some district heating areas capacity can be more than enough to cover peak loads, in another it may be scarce. An alternative way for heating sector can be to assess the potential to supply heat from fuel stocks available at production facilities during maximum consumption times: this would provide an assessment how vulnerable are the production facilities to potential disturbances in fuel supplies.

Another aspect of long-term Technical Resilience is the economic viability and the age of power and heat production facilities and networks. If the returns on investments of production facilities or network companies are not high enough to justify investments in these infrastructures, then the long-term security of supplies, especially peak capacity supplies is threatened. In order to assess the economic health of the infrastructures, the average age and returns on investments of infrastructure would incentivise how well are settled the investment requirements for system renewal in a country and would be additional indicators that the policy makers should follow for long term energy security policy.

Often countries look also for the share of potential to supply power and heat from indigenous resources, as it would incentivise the level of the worst case in electricity and heat supplies, when there are no external energy supplies to the country. It may be worthwhile to be analysed, although these indicators largely depend on the reliability of the suppliers of imported fuels and would not deliver comparable results with other countries that may have higher or lower political risks associated with supplies.

3.3. Indicators for Technical Vulnerability

If Technical Resilience indicators incentivised how a country is delivering needed electricity and heat capacities for its citizens, then Technical Vulnerability indicators incentivise how the required energy volumes would be guaranteed in long term. Here one should look at the diversity of supplies and how capable are the infrastructures to deliver required energy.

Often here governments look at the diversity of their energy supplies. However, this provides only a result of the market operations and does not provide information of the system capabilities. For example some countries may be reliant mainly on one energy source in everyday operations, but may have also reserve capacities available for the case of supply disruptions. So the diversity of the system is hidden from official statistics. Another example may be the case, when electricity or heat facilities have dual fuel capabilities that allow them to switch from one fuel to another, subject to price or availability. This flexibility provides very valuable diversity for supplies, but cannot be found in official statistics.

Another drawback of this indicator is sometimes high volatility of the outcome: the result of production mix may be largely influenced by the availability of hydro, solar and wind resources and from supplies via interconnections subject to market prices. In principle the potential to supply energy should be based on infrastructure, not on market operations.

An alternative way to assess this potential is to analyse the diversity of potential electricity and heat supplies with Herfindahl Index, subject to average availability of the facilities:

$$HHI_E = {W^{\%}_{Nuclear}}^2 + {W^{\%}_{Coal}}^2 + {W^{\%}_{Gas}}^2 + {W^{\%}_{Oil}}^2 + {W^{\%}_{Mix}}^2 + {W^{\%}_{Biomass}}^2 + {W^{\%}_{Wind}}^2 + {W^{\%}_{Solar}}^2 + {W^{\%}_{hydro}}^2 + {W^{\%}_{Import}}^2, \quad (4)$$

where

$W^{\%} = \frac{P*A*t}{W_\Sigma}$ – share of potential production from given energy source;
P – Total Net Capacity of given energy source (MW);
A – Average annual availability of maximum capacity of given facilities (usually 80–90% for nuclear, coal, gas, oil, biomass and mix energies; 15–30% for wind; 15–25% for solar, 20–80% for hydro);
t – annual 8760 h
W_Σ-Total potential annual production from all energy production facilities (GWh)

Another indicator to analyse with the same logic would be the ratio of potential energy supplies to the annual consumption that would provide information about the total capabilities of the supply infrastructures:

$$K_{POT} = \frac{W_{Nuclear} + W_{Coal} + W_{Gas} + W_{Oil} + W_{Mix} + W_{Biomass} + W_{Wind} + W_{Solar} + W_{hydro} + W_{Import}}{W_T}, \quad (5)$$

where

$W_{(x)} = P*A*t$ - Potential supply from given energy source (GWh);
$W_T = \frac{W_A}{E}$ - Total required energy supply (GWh);
W_A - Annual consumption (GWh);
E – Electrification Rate of the country (%)

Higher values of ratio K_{POT}, indicate also better level of Technical Vulnerability. Formulas 4 and 5 can also be applied to Heat and Transport Fuels sectors with relevant energy sources. In case of transport fuels it would be worthwhile to analyse separately potential supplies from indigenous crude oil production and oil products facilities, and to add there also separately oil stocks.

4. Indicators for Economic Energy Dependence

National security can often be affected by the energy cost or revenue streams of a country. If a country relies too much on the imports of transport fuels, then too high cost of imports influences substantially also economic state of a country. High share of the cost of imported energy in GDP oftentimes reflects also the influence of economic interests to the national energy policy decision making. It can be observed that countries with high dependence on imported energy sources (for example several countries in Eastern and Southern Europe) tend to make more political decisions that take into account the interests of their supplier countries. It also means that they are more open to external influence to their energy policy.

Oppositely one can also observe that countries with very high dependence on energy revenues in their GDP (for example some oil and gas production countries) are largely influenced by the market prices. If a country relies too much on oil export revenues, it would pose a threat to the stability of its economy (GDP might be too much influenced by the changes in global crude oil prices). The higher is the share of revenues of exported energy in the GDP, the more the security policy and political decisions may be reliant on the energy price levels in global or regional markets.

Ideally countries should look for a balance between import and export of energy supplies in monetary terms in order to avoid any external influence to their economic and energy policy. The larger the Economic Dependence of a country on energy import costs or export revenues, the more they may be affected by the economic interests and market fluctuations.

Looking by energy sectors, then Economic Dependence of a national power sector could be assessed by the difference between merchandise value of imports for power supplies (including power imports and imports of fuels for power production) and of exports of power, to be compared with the GDP of a country:

$$EED_{power} = \frac{M_{Import} - M_{Export}}{GDP}, \quad (6)$$

where

EED_{power} – Economic Energy Dependence of power sector (%);
M_{Import} – Merchandise value of imports of power sector (Monetary Unit);
M_{Export} – Merchandise value of exports of power sector (Monetary Unit);
GDP – Gross Domestic Product of a country (Monetary Unit)

This indicator would provide the incentive about the monetary value of the dependence of a country on these revenue streams. In addition one could also look at the diversity of potential revenue streams (to identify the potential of different suppliers to supply the market). Similarly can Economic Dependence be measured for transport fuels.

In the case of heat sector one cannot talk about exports, as usually the sector has a local nature. For the purposes of Economic Dependence level it would be reasonable to measure the merchandise value of imported fuels for heat supplies as a share of GDP, which incentivise the reliance of a country on these costs.

However, these indicators largely depend on the market prices so it may happen that there are quite wide annual variations in results. Even more, for the purposes of policy making, it is difficult to make reliable price forecasts for these indicators. Nevertheless, if the target is to strive towards balance between total merchandise value of energy exports and imports, it would be a self-balancing exercise for policy makers: higher energy import costs oftentimes balance off higher expected export revenues streams.

5. Indicators for Political Affectability of energy sector

As recent decades have proved, energy sector can be used as a tool to influence economic and political decisions of a country. Reliance of a modern society on energy supplies make states more and more vulnerable to energy supply disturbances, and this fact is often abused in acts of war or oftentimes in cases to influence political decisions.

In order to assess the affectability of a country to such interventions, we have to understand the reasons why countries might be in the political turmoil in energy sector: usually it is whether for the reasons of political power (like former Soviet Union states are still under special attention from Russia) or because of their valuable energy resources (like Kuwait in 1990ies, or Central Asian countries through the years).

For majority of the countries this layer has low relevance, as there is low interest of other countries to intervene in their society, economy or political frameworks. In Western European countries such interventions are merely felt, as their political establishment is fairly transparent, markets diversely integrated, and not dependent on only one external supplier country. However, in case of Eastern European countries one can oftentimes note a reliance of energy supplies from Russia and difficulties of processes that try to lessen such dependence. Examples of such cases could be most clearly observed in electricity and gas markets of Ukraine, Bulgaria or Lithuania, where development of alternative supply sources have faced strong and unjustified political opposition.

Nevertheless, this layer is the most difficult one to assess in numerical terms, apart from the openness of a country to external influence which is related to both the Economic Dependence and Technical Vulnerability. In first instance the policymakers should make a subjective assessment of energy sectors in this respect. As regards the Political Affectability one should firstly assess the external political interests to influence country's politics and energy policy or the interest on energy resources from other countries (or vice versa). If some interest can be observed, then we should have a closer look to the potential ways on energy policy manipulations.

In practice one can observe two types of manipulations: manipulation of energy policy decision makers (a number of cases in countries of former Soviet bloc) and manipulation of energy system operations (like with Ukrainian gas supplies by Russia). From these examples it could be observed that there are mainly two aspects that allow such kind of interventions:

a. the precondition for manipulation of political decisions is the openness of decision makers to corruption;
b. The precondition for manipulation of the development of energy system (apart from technical dependence) is the instability of the political settings that make it easier to manipulate the decisions to be made for energy sector development.

From this perspective it can be concluded that corruption and political stability indexes can provide information about potential risks associated with political influence in a country in question. Transparency International measures annually the perceptions towards corruption and the stability of political system that should also be used by countries to assess their energy policy [20]. In the context of corruption it is also worthwhile to assess the level of openness of manipulation of the public opinion, as this may sometimes trigger unwanted developments of energy policy developments in more democratic countries.

Electricity, heat and transport fuels sectors should be assessed separately in these terms in order to better identify the risks associated with abovementioned aspects. In terms of Political Affectability of the Heat Sector one should use the same indicators as for Power Sector (political stability, corruption), but to be assessed separately for the heating fuels supply situation. For policy making purposes countries cannot usually predict these indicators, but can tackle the identified issues with other measures.

6. Energy Security Matrix

To summarise all the above, an Energy Security Matrix could be sketched as follows in Table 2:

This set of indicators could be considered by the energy policymakers in case of each national energy strategy. However, this list is not exhaustive, and should be considered case by case: there are some countries, where some of these indicators have higher relevance than in others.

From the logical sequence of the Matrix one can observe that Operational and Technical Resilience indicators refer to short- to medium term energy security (from seconds up to one year planning), while Technical Vulnerability, Economic Dependence and Political Affectability indicators are addressing more longer term issues of energy security. However, the longevity of long-term energy issues can lead to unwanted developments that can also in short term influence operations of energy system. In practice, operational and technical resilience indicators address potential threats from existing system, while long-term indicators incentivise the needs for energy security investments and/or required regulatory changes in order to encourage improvements in future energy-mix.

Operational Resilience indicators for internal disturbances are relevant only for electricity sector: heat and transport fuel sectors are not so time-critical, their consumption/production balance is more flexible and does not have so much intermittent producers that would pose threat to stable supplies. Listed electricity sector indicators describe the most difficult situations for power system operations and characterise the flexibility of the power system to cope with these situations.

Operational Resilience to external disturbances is relevant for all energy sectors, as it may have a medium term impact to the whole energy system and a country as a whole. Therefore the analysis of the country's energy systems to avoid external disturbances should be part of energy security assessment in all sectors.

Technical resilience indicators incentivise the readiness of the system to cope with extreme demand. This is relevant for electricity and heat sectors, where the energy cannot be stored but has to be produced as much as it is required at the moment. This makes the readiness of the energy system for peak consumption extremely important. However, it has to be noted that with technical advancements in electricity and heat storage systems this set of indicators might need to be revised in coming years.

The key to Technical Vulnerability of energy system lies largely on potential and diversity of different energy supplies and suppliers, both in terms of supply sources and routes. This analysis has to be taken very carefully considering the potential of manipulation of the markets that may influence the economic outcome of energy system operations. Therefore here the analysis has to be country specific in order to find the potential risks of supplies in a more detailed manner.

Economic Dependence of energy sector may have a strong impact to the countries overall economic performance and influence its welfare and stability. However, it could be noted that the lower is the share of costs and revenues of energy sector in the GDP, the lower is the influence that energy can have to the welfare of the country. It can also be noted that high energy costs can be offset with energy exports (that are usually also higher in same cycles) or with energy efficiency measures). So the overall aim of the country should be to have a neutral balance between the energy export revenues and import costs, in order to minimise the impact of the energy sector to political stability.

Lastly, Political Affectability is subject to geopolitical interests, and for majority of the countries does not pose any issue. However, the countries that are under political interest sphere of aggressive countries, this layer of energy security becomes critical in the evaluation. There are number of non-measurable indications that may be found there, but common denominators for those aspects are political stability and corruption. These are the main ways how countries energy policy decisions can be influenced.

Nevertheless, if all these indicators could be gathered by the countries to a common database, it would provide a strong basis for energy security policy assessments and developments.

7. Conclusions and Policy Implications

The assessment of the energy security level of a country is a complex issue. Based on the analysis of the indicators used by

Table 2
Energy Security Matrix.

	Indicators for		
	Electricity Sector	Heat Sector	Transport Sector
Operational Resilience to internal disturbances (flexibility)	– Share of unreliable capacity compared to minimum load (with and without interconnections) (See Formula 1) – Share of reliable capacity (with and without interconnections) compared to Peak Load (See Formula 2)		
Operational Resilience to external disturbances (flexibility)	– Resilience to Acts of Terror – Resilience to Cyber Attacks – Resilience to natural disasters – Resilience to climate change		
Technical Resilience (capacity)	– Reserve Margin (also in N-1 and N-1–1 cases) (See Formula 3) – Weighted Average age of Reliable Power Capacities and networks – Average Return on Reliable Power Production and network Investments	– Stocks of Fuels for Heating compared to Monthly Peak Consumption – Weighted average age of district heating capacities and networks – Average return on district heat production and network investments	
Technical Vulnerability (energy)	– Diversity of Potential Electricity Supplies (Herfindahl Index) (see Formula 4) – Potential Supply compared in annual consumption (subject to Electrification Rate) (see Formula 5)	– Diversity of Potential Heat Supplies (Herfindahl Index) (see Formula 4) – Share of Potential Heat Supply compared to Annual Consumption (see Formula 5)	– Diversity of Energy for Transport Supplies (Herfindahl Index) (See Formula 4) – Potential of Supply (incl. Capacity of Oil Production, Capacity of Oil Products supply facilities, Oil Stocks, etc.) in case of supply disruptions compared to Annual Consumption (see Formula 5)
Economic Dependence	– Merchandise value of power exports or imports compared to GDP	– Merchandise value of fuels imported for heat supplies compared to GDP	– Merchandise value of fuels imported for Energy for Transport compared to GDP – Merchandise Value of exported Energy for Transport compared to GDP
Political Affectability	– Level of Political Stability in given country – Level of Political Stability in supplying countries – Interest level from other countries to influence the sectors' policy – Openness of the country to the external influence – Level of Corruption		

international organisations in their assessments on energy security, we have identified several inadequacies that may lead to wrong political or policy decisions. For the purposes of more adequate development of energy policy it is crucial to use more adequate indicators, which incentivise to decision makers more secure and efficient way of development. From this perspective we have crafted Energy Security Matrix that lists relevant indicators to be explored from short-term perspective (Operational and Technical Resilience) and long-term perspective in three layers (Technical Vulnerability, Economic Dependence and Political Affectability), and is applied to all main energy sectors of a country. However, it applies that long term energy security issues can often lead to short term operational issues, and upside down. Therefore both timeframes are relevant to be analysed and addressed by energy policymakers.

Current misleading indicators, often used by international organisations and policymakers, may lead to inadequate assessments on energy policy, to inadequate investment decisions or to short-sighted energy market designs and regulations. Furthermore, energy statistics gathered today are not representative to describe modern threats to energy systems and are sometimes misused by energy policymakers in their activities. All these inadequacies may lead to energy supply disruptions in shorter or longer term. Indicators listed in Energy Security Matrix would help to avoid such inadequacies.

However, it is well understood that currently there is no sufficient data available in order to fill the full Matrix, but countries should strive to gather this data in order to improve the quality of their energy security policy. Partial analysis can result often in biased or misleading results. Therefore numerical assessment of energy security level of the countries in each of the listed layers and sector should be a topic for further studies subject to availability of relevant data. Even more, as energy security is only part of energy policy trilemma, further studies on the balance between contradicting energy policy objectives would provide even higher value for the policy makers and to the quality of relevant policy decisions and measures. Further studies may also address the ways of weighting of different indicators and sectors, as current approaches of international organisations differ largely in these aspects.

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Impact of price regulation methodology on the managerial decisions of the electricity DSO

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Abstract **Electricity distribution network companies' activities and managerial decisions depend substantially on the applied regulatory methodology. The impact of different regulatory methodologies on different results like security of supply, investors' attractiveness and network tariffs level has been evaluated. The rate of return method has been used for the regulation of the electricity network tariffs in Estonia since 2004. The results of 10-year regulation period have been evaluated in comparisons to other methods available.**

Index Terms **Economics, power distribution, power system management, power system reliability**.

I. Introduction

Electricity distribution network companies' activities and managerial decisions depend substantially on the applied regulatory methodology. In this article, the impact of different regulatory methods on the strategic priorities of the companies with the aim of finding the best methodology for the main strategies that a distribution network company may have, are evaluated.

Some of the previous studies have assessed the impact of quality regulation on investment decisions [1] or have looked at the financial risks associated with performance based regulations [2] [3]. Up to now there seems to be a very limited number of studies exploring connections between a regulatory method and the managerial decisions of distribution network companies.

II. Methodology of Price Regulation

Price regulation methods [4] [5] can be divided into four categories: Price cap, Revenue cap; Rate of return and Long Run Average Incremental Cost Bottom Up (LRAIC BU). Pedell [6] has described all these three methods. Several sources as Green and Pardina [7], Netz [8], Armstrong and Sappington [9], Alexander et al. [10], Hertog [11], Joskow [12] [13] have described Price Cap and Rate of Return methods. The impact of regulatory practices have been described in a number of articles and regulators' reports [14] - [18].

If the pure rate of return method is used, then the risks associated with controllable and uncontrollable costs are covered, or in other words, the company has no risk associated with the costs. This method allows the company to apply for a tariff adjustment as soon as the price is not based on the costs of the company any more. Quite the contrary, pure *price cap* method leaves all these risks to be covered by the company and leaves options for the company to decide how to eliminate those in different ways. The only difference of the revenue cap is the elimination of sales volume risk.

The price cap method presumes that if the company can manage more efficiently on its own, it can earn extra profits, and also *vice versa*: if the company does not fulfil the expectations set by the regulator or manages less efficiently, its profit will be lower and it cannot earn profit agreed by the regulator.

The basis of the *price cap* method is fixing of prices for a certain time period. Doing so, the time period must be chosen long enough to guarantee that the company can reach the expected efficiency. On the other hand, the time period should not be too long in order to avoid high risk of forecasts. Each year the prices are adjusted in accordance with inflation and factor x, which reflects the cost efficiency target, or in other words, prices should not increase faster than inflation minus the efficiency goal x.

According to the (LRAIC BU) or hypothetical network model, an ideal network is modelled assuming that the most modern and optimal technological solutions for the network configuration to supply all customers with highest quality standards is used. In case of a distribution network, it should be modelled considering the geographical location of consumers and producers and with inputs from the transmission network. The distribution network is then configured as an ideal system and is assumed to be built in the most economical way to guarantee the supply of existing customers. It is assumed that the most economical solution is applied and the network is built as a Greenfield project.

All in all, the challenge in application of different regulatory methods for DSOs often comes back to the "management of strategic gaming" [19]. Each method triggers different economic actions from companies and regulators. Even in the most advanced British utility regulation one can observe constant urge to find better regimes for the companies concerned [20] [21].

Since detailed sector-specific regulatory rules were introduced in Estonia in 2002 [22], the authors of the present article have more than 10 years of experience in the application of the described regulation methods. For 10 years the rate of return method has been used in Estonia for price regulation of distribution network companies [23] - [25]. In Figure 1 we can explore the actual return on capital[1] for four largest network companies in Estonia (Elering, Elektrilevi, Imatra Elektrivõrk and VKG Elektrivõrk[2]) and it has been compared with the WACC applied by the regulator [26]. As one can see from the results, the network companies have usually not reached the WACC level applied by the regulator. During its 10 years of existence the largest distribution Network Company Elektrilevi has never reached the WACC applied by the regulator, its actual result has always been below the expected level. The RoR implemented in Estonia differs from the classical type of RoR. The costs included to the tariffs are not based on historical cost base and the regulator is actively demanding implementation of cost saving measures: incl. reducing of energy losses, saving on operational costs, etc. The outcome clearly indicates that the RoR implemented in Estonia does not guarantee the required return.

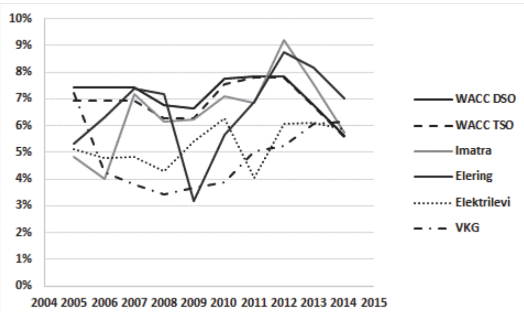

Figure 1. Return on capital of Estonian electricity network companies

III. Method for Assessment of Regulatory Methodology

Each regulatory method triggers a different logic of the managerial decisions taken by network companies. In the following sub-chapters one can find a comparison of the impacts assessed from the company's management perspective - how they would prioritise their activities and strategy having in mind different incentives provided by different methods.

Different methods for assessment of regulatory methodology were analysed. As it became clear to the authors that it would be impossible to provide reasonable impact assessment of regulatory methodology in monetary or technical terms without speculative assumptions, the assessment was carried out as an expert opinion of the authors on 5-point Linkert scale. The authors had to find a consensus in score in order to be approved. For each grade the rationale of the assessment discussed by the authors is also added.

Although this method is based on the authors' subjective judgements, it was considered to be the only appropriate way forward. The subjectivity is decreased by the fact that the authors represent opponent parties of the regulation. The assessments represent their long experience as practitioners in the energy sector in Estonia. As all the previously described regulatory methods have been applied in different sectors in Estonia, the assessments are based on the real practical experience.

The relevant managerial decisions of a network company can be divided into three wider groups as follows:

1) The Quality of Network Service presented in table 1
2) Cost of Network Service to Society presented in table 2
3) Risks of owners and lenders presented in table 3

On the basis of the method and criteria described above one can assess the impact of the different regulatory methods. In tables 4 to 7 the assessments of impact of regulatory methods on the managerial decisions of a power network company are described.

TABLE 1. Criteria for Assessment of the Quality of Network Services Scores

	1	2	3	4	5
Security of Supply level	Level decreases substantially	Level decreases	Current level remains	Level increases	Improvements faster than the level agreed on
Quality of Customer Service	Level decreases substantially	Level decreases	Current level remains	Level increases	Improvements faster than the level agreed on
Readiness to manage disruption crises	Very low, lack of needed financial and human resources	Below average	Average, needed financial and human resources are covered partly	Above average	High, sufficient financial and human resources are available
Long-term investments	Only critical investments are carried out to retain minimum standards	Below average	Sufficient investments in infrastructure, but not in technological development of the network	Above average	Investments are made as agreed, including also investments in innovative solutions
Stability of construction market	Investment volumes stable for 1-2 years	Below average	Investment volumes stable for 5 years	Above average	Investments volumes stable for 10 years

[1] Return on Capital is calculated on the basis of book records. Operating profit is divided by the sum of residual value of capital assets and working capital. The amount of working capital is used in calculations as 5% of the annual revenues.
[2] Elering is the TSO; Elektrilevi, VKG Elektrivõrk and Imatra Elektrivõrk are three largest DSOs in Estonia, with market shares of 87,3%; 3,0% and 2,7%.

TABLE 2. CRITERIA FOR ASSESSING NETWORK SERVICE TO SOCIETY

Score	1	2	3	4	5
Price Level	Highest price level	Slightly higher price	Average price level	Slightly lower price level	Lowest price level
Attractive-ness of the country for investors	Lowest level	Low level	Average level	High level	Highest level of attractive-ness
Admi-nistrative burden	The highest	High	Average	Low	The lowest

TABLE 3. CRITERIA FOR ASSESSING RISKS FOR LENDERS AND OWNERS

	Score				
	1	2	3	4	5
Risk of un-controllable costs and sales volume	Very high	Above average	Average	Below average	Very low
Objective regulatory lag	Very high risk	Above average risk	Average risk	Below average risk	Very low risk
Subjective regulatory lag	Very high risk	Above average risk	Average risk	Below average risk	Very low risk
Underinvestment risk	Very high	Above average	Average	Below average	Very low
Overinvestment risk	Very high	Above average	Average	Below average	Very low

TABLE 4. ASSESSMENT OF IMPACT OF PRICE CAP METHOD

Criteria	Score	Rationale for Score
Level of Security of Supply	2	Realisation of risks of increase of uncontrollable costs brings along a decrease of the operating costs; it may happen most promptly and influence first and foremost the maintenance and repair costs and investments in the network. Therefore the security of supply would be lower.
Quality of Customer service	3	As long as the company has a strong incentive to reduce its costs to raise its profit, the quality of customer service remains the same (if there is some inefficiency in the management) or decreases (by curtailing of existing services: e.g. reducing the number of people in call-centres extends the waiting time there).
Readiness to disruption crises	2	In order to increase efficiency the reserves of appliances are reduced; it makes the crises management more difficult.
Interest of the network company to carry out long-term investments	2	As long as there is some inefficiency in the management of a company, there is no impact on its long-term investments. However, when a company has reached a high level of effectiveness, the RPI-x can be only reached at the expense of long-term investments.
Stability of construction market	3	Realisation of risks of increase of uncontrollable costs brings along some reduction of investments (e.g. by restraining of works, prorogation to the future, etc.); that in turn restrains the construction market and makes the investment climate worse.
Price level to consumers	5	Price Cap should in principle give a lower price increase than RPI (however, if the investments exceed depreciation or the costs are evaluated inadequately, the regulator can also apply RPI+x in some cases,).
Attractiveness of the country to investors	3	As long as the company covers all the costs associated with connecting to the network, the cost for connection is high and attractiveness for investors low. Still, a presumed decrease of the network price can be attractive for some investors.
Administrative burden for the company	4	As the prices are adjusted for a fixed period (3-5 years), the administrative burden is rather low.
Risk of un-controllable costs and sales volume	1	All uncontrollable risks are borne by the company.
Objective regulatory lag	1	The price is fixed for a long period on the basis of the historical data: the Regulator sets the price for the following 5 years on the basis of the data from the previous full year.
Subjective regulatory lag	5	Fixed regularity, the risk is low.
Underinvestment risk	2	Strong pressure to reduce costs may lead to a decrease in the required investments.
Overinvestment risk	5	Constant requirement to reduce the costs limits the capability to invest.

TABLE 5. ASSESSMENT OF IMPACTS OF REVENUE CAP METHOD

Criteria	Score	Rationale for Score
Level of Security of Supply	3	Cost-effective network company can reduce its costs only at the expense of long-term investments, that hinders improvements in security of supply in long-term. Hedged risks help to keep the existing level of security of supply.
Quality of Customer service	4	As long as the company has a strong incentive to reduce its costs to raise its profit, the quality of customer service remains the same (if there is some inefficiency in the management) or decreases (by curtailing of existing services). Lower risk due to hedging of some associated risks.
Readiness to disruption crises	3	To increase efficiency the reserves must be reduced. Still, partly hedged risks provide possibilities to keep larger „hot reserve“ of appliances.
Interest of the network company to carry out long-term	3	As long as there is some inefficiency in the management of a company, there is no impact on its long-term investments.

investments		However, when the company has reached a high level of effectiveness, the RPI-x can be only reached at the expense of long-term investments.
Stability of construction market	4	Stable for 3-5 years, but during the regulatory period some changes in investment volumes may occur and that may impact the network construction and maintenance price and quality. A complicated situation from the partners' point of view (no long-term stability).
Price level to consumers	4	Revenue Cap should in principle give a lower price increase than RPI (however, if the investments exceed depreciation or the costs are evaluated inadequately, the regulator can also apply RPI+x in some cases).
Attractiveness of the country to investors	3	As long as the company covers all the costs associated with connecting to the network, the cost for connection is high and attractiveness for investors low. Still, a presumed decrease of the network price can be attractive for some investors.
Administrative burden for the company	4	As majority of the factors are fixed, the administrative burden is rather low. However, to compensate hedged risks the company has to keep the regulator constantly informed during the regulatory period and therefore the level of administrative burden is higher compared to Price Cap method.
Risk of un-controllable costs and sales volume	3	All uncontrollable risks are borne by the company, sales volume risk is hedged.
Objective regulatory lag	2	The price is fixed for a long period on the basis of the historical data: the regulator sets the price for the following 5 years on the basis of the data from the previous full year.
Subjective regulatory lag	5	Minimal, fixed regularity for adjustments.
Underinvestment risk	3	Strong pressure to lower costs may lead to a decrease in the required investments. Still, the risk is somewhat lower compared to Price cap method as far as some operating cost risks are hedged.
Overinvestment risk	5	Constant requirement to reduce the costs limits the capability to invest, the risk is low.

TABLE 6. ASSESSMENT OF IMPACTS OF RATE OF RETURN METHOD

Criteria	Score	Rationale for Score
Level of Security of Supply	4	Cost based price guarantees the changes of security of supply at the agreed pace.
Quality of Customer service	5	As long as company must reduce its costs, the quality of customer service remains the same (if there is some inefficiency in the management) or decreases (by curtailing of existing services). Lower risk due to hedging of associated risks.
Readiness to disruption crises	4	Reserves are kept as agreed with the regulator.
Interest of the network company to carry out long-term investments	4	Cost based price guarantees the development of the network at the agreed pace. The agreement on the allowed rate of return is the key to succeed.
Stability of construction market	5	Regular fixing of prices keeps the construction market stable.
Price level to consumers	3	In accordance with the agreed level of security of supply and customer service.
Attractiveness of the country to investors	3	As the company covers partly the costs associated with connecting to the network, the cost for connection is average and attractiveness for investors medium.
Administrative burden for the company	3	Regular adjustments (subject to the company's initiative for the price adjustment) make a medium administrative burden.
Risk of un-controllable costs and sales volume	4	Delays in adjustments are possible both by the regulator and the company.
Objective regulatory lag	4	As the price is not fixed for a long period (a potential 2-3 years' time lag still remains, as the price is set on the basis of the previous full year data), the risk is substantially lower compared to the other methods.
Subjective regulatory lag	2	Unlike the other methods there is no agreed time set – a company can apply for price adjustments any time. Possible delays by the regulator due to the bureaucracy or unwillingness to make unpopular decisions.
Underinvestment risk	4	As the regulation is strictly cost based, the risk of underinvestment is fairly low.
Overinvestment risk	3	Depends on the owner: if the owner is the state or a municipality, then the owner is also interested in the quality of the service; that is not always the case with private owners.

TABLE 7. ASSESSMENT OF IMPACTS OF LRAIC BU METHOD

Criteria	Score	Rationale for Score
Level of Security of Supply	1	If the modelled price is too low, then the company retrenches to survive. If the price is higher, then the company can maximise its short term profits by cutting the costs. This has a long-term negative impact to all selected indicators.
Quality of Customer service	1	
Readiness to disruption crises	1	
Interest of the network company to carry out long-term investments	1	
Stability of construction market	1	No stability as due to the cost-cutting only indispensable investments are made.
Price level to consumers	3	Stable as an ideal network does not change much, adjustments are only due to inflation.
Attractiveness of the country to investors	2	As long as the company covers all the costs associated with connecting to the network, the cost for connection is high and attractiveness for investors low.
Administrative burden for the company	1	Very complicated and demanding calculations. Ideal network requires permanent adjustments due to the changes in the network configuration.
Risk of un-controllable costs and sales volume	1	All uncontrollable costs and the sales volume risks are borne by the company.
Objective regulatory lag	1	Computing model calculates the theoretical costs required and the difference with the actual costs can be

		substantial.
Subjective regulatory lag	5	Fixed regularity, the risk is low.
Underinvestment risk	1	High risk of underinvestment as the company lacks a motivation to improve security of supply.
Overinvestment risk	5	Computing model defines the limits for investments, the risk is minimal.

IV. Selection of the Preferred Regulatory Method

Selection of a regulatory method depends on the priorities of the government. Depending on the development stage of the electricity network, the priorities of the state may be either increasing the network quality, aiming for the lowest network tariffs to society, or providing low risks for the owners and lenders. Table 8 below describes overall results of the assessment carried out in Chapter 3; it can be as a basis for the selection of the regulatory method for policymakers.

TABLE 8. AVERAGE SCORES OF THE ASSESSMENT PER METHOD

	Price cap	Revenue cap	Rate of Return	LRAIC bottom up
Quality of Network Service	2.4	3.4	4.4	1
Cost of Network Service to Society	4.3	3.7	3	2
Risk of Owners and Lenders	2.8	3.6	3.4	2.6

The data in Table 8 provide grounds for a number of important conclusions:

- If the priority is to raise the quality of network, then the Rate of Return method appears to be the most suitable approach;
- In order to prioritise the low network tariffs to society, policymakers should select Price Cap method;
- In order to attract new owners and lenders to the network business, Rate of Return and Revenue Cap methods appear to be equally attractive approaches;
- To balance all these aspects, the Rate of Return method seems to be the most appropriate solution for a long term policy selection for the electrical networks regulation;
- LRAIC regulatory method seems not to be an attractive solution for the power distribution businesses.

However, it should also be noted that for the sake of a long term stable investment climate of the network business, it is advisable to avoid frequent changes of the regulatory methods. Frequent changes of regulatory methods may ruin the attractiveness of any investment in the energy sector [27]. Therefore the Rate of Return method has a clear advantage also in terms of the stable investment climate.

In order to double-check the outcome of the analysis we have also audited the impact of the Rate of Return method on Elektrilevi OÜ, the largest electricity network company in Estonia. The company is 100% owned by Eesti Energia AS, which in turn is 100% owned by the Estonian Government. The main objective of the government has been to maintain stability of the price of the network services while increasing the quality of the network. The increase of the value or attractiveness of the company has not been a priority for the government.

Figure 2 presents the changes of the electricity supply security indicator SAIDI[3] in Elektrilevi OÜ from 2007 to 2013. The calculations of SAIDI do not take into account the impact of occasional weather impacts.

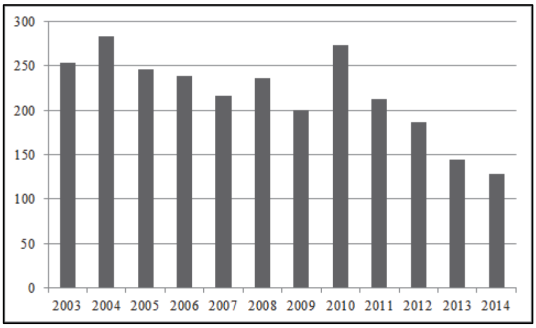

Figure 2. Changes in network quality indicator SAIDI in Elektrilevi OÜ

Graph 3 presents the network tariff and the rate on capital of Elektrilevi OÜ[4] in the timeframe of 2005-2014, adjusted to the changes of Consumer Price Index [28].

As it can be seen from Graph 2 and 3, the Rate of Return method has enabled improvements in the quality of the network services while the network tariff has remained stable for the customers and the company has earned reasonable returns on their investments. So the main objectives of the government as the owner of the utility and developer of the attractive utility services have been achieved.

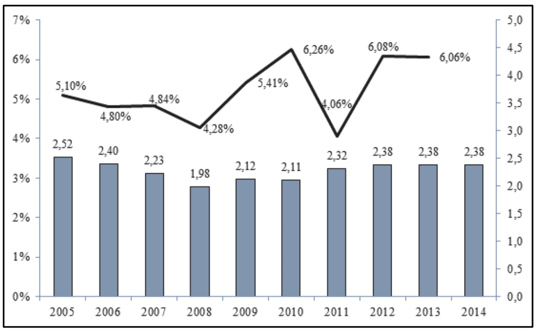

Figure 3. CPI adjusted price and return on capital of Elektrilevi OÜ services during from 2005 to 2014

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[3] System Average Interruption Duration Index - the average outage duration for each customer served

[4] The network tariff of Elektrilevi OÜ is excluding the costs for transmission. The cost of transmission is excluded due to the fact, that this is a non-controllable cost for the company.

V. CONCLUSIONS

The aim of the article was to analyse the impact of different regulatory methods of the electricity network companies on their strategic managerial decisions and to provide some advice for finding the most efficient method to reach the objectives of the network business. The analyses have been made by using the experience of regulation of distribution networks in Estonia. Four regulatory methods were analysed: price cap, revenue cap, rate of return and LRAIC BU. The managerial decisions analysed were divided into the network quality, cost of network service to society and the risk level for the owners and lenders.

As a result of the analysis and based on Estonian experience the Rate of Return method was assessed to be the best method for long term objectives. The impact of Rate of Return method was also controlled against the overall results of the activities of Elektrilevi OÜ, the largest distribution company of Estonia, where one can observe improvements in the quality of the network services while the price of the network service remained stable and its profit of the utilities was in an expected range.

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III. **Kisel, E**., Ots, M., Hamburg, A., Mere, T. Estonian Experience by Implementation of Incentive Type of Price Regulation. In: *57th International Scientific Conference of Riga Technical University (RTUCON)*, 13-14 October, 2016, Riga, Latvia, 5 pp (in print).

Estonian Experience in Implementation of Incentive Type of Price Regulation

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Abstract—**Administrative resources of the regulatory body and the number of regulated utilities is an important criteria in selection of price regulation methodology. Estonian experience is based on a large number of relatively small utilities. The price regulation methodology implemented is incentive type of Rate of Return where the important element is the regulatory deterrence, where the company can select whether to apply for new tariff or to rely on the existing one. The administrative burden is minimized in this case. The results of price regulation indicate significant savings on energy losses and stable service tariffs.**

Keywords—economics, power distribution, power system management, power system reliability.

I. Introduction

The first objective of the price regulation is sustainability - the regulated company must be able to finance its operations and make any required investment, so that the company can continue operating in the future [1]. From customers' perspective, high quality of the service provided and minimum price are the expectations. From shareholders' point of view reasonable rate of return on invested capital shall be guaranteed. Theoretically, it is possible to reach a theoretical maximum of the quality by building double or triple power lines or gas pipes, exceeding the n-1 criteria. However, one must agree that these type of technical solutions are only theoretical. Depending on the legislation of the specific jurisdiction, the task of the regulator is to select or to assist in selection of the regulatory methodology which corresponds to the main objective of price regulation. The summary of different regulatory objectives indicates, that the main criterion for selecting of regulatory methodology is to reach the maximum efficiency where the customers´ and the companies´ interests are in balance.

The regulatory methods can be divided to two main categories: ex-ante and ex-post [2]. By using of ex-ante regulation, the prices are fixed by the regulator. By using of ex-post regulation, the prices or fees are applied by the company without any coordination by the regulator and the regulator may control later whether these prices or fees meet the criteria set by the legislation. At present, the Natural Gas Act in Estonia has applied such a regulation, whereby the market dominant gas company must base its prices on the costs and earn justified return of the investment made [3]. A similar regulation is applied in the district heating sector in Finland and Sweden, where the companies apply prices designed by themselves and the regulator has the right to control their justification [4]. The same type of ex-post price control is implemented by the Competition regulation. According to the article 102 of the Treaty on the Functioning of the European Union the abuse of the dominant position by imposing of unfair selling prices is prohibited [5]. The same type of principles are established in Estonian national Competition Act [6]. In Estonia there are several practices by implementation of the Competition Act in cases of abuse of the market dominating position by unfair pricing [7], [8].

The ex-ante methods can be divided in three main categories:

- Rate of return (RoR);
- Price cap
- Long Run Incremental Costs Bottom UP (LRAIC).

According to different sources the above mentioned regulatory methods have different definitions. The price cap is defined as incentive type of regulation and named as retail price index minus x (RPI-x) in a number of sources [1], [9]-[11].

The RoR and RPI-x are more or less based on existing network installations and to the historical costs associated to the operation of those existing assets. In contrast to RoR or RPI-x the LRAIC model is based on hypothetical system [2], [12]. By using LRAIC the only data corresponding to the existing situation are the demand, capacity and geographical location of the existing customers. It means that the basic approach of those methods is totally different, as provided in Table 1.

TABLE 1. PROFIT ELEMENTS COVERED BY ALTERNATIVE REGULATORY REGIMES

Regulatory System	Covered by Regulation	Ignored by Regulation
Price cap	P	Q, C_x, C_n
Price cap with cost pass-through	P, C_x	Q, C_n
Revenue cap	P, Q	C_x, C_n
Rate of return	P, Q, C_x, C_n	-

Furthermore, each method can have different subdivisions, depending on which economical risks are left to be handled by the company. From companies point of view, the profit is the main result of the regulation [11]. The profit is dependent on different inputs as described in equation (1).

$$R= PQ - C_x (Q) - C_n (Q) \qquad (1)$$

where

- R - company's profit
- P - price
- Q - sales volume
- C_x - exogenic or uncontrollable costs
- C_n - endogenic or controllable costs

The profit covered by classic type of RPI and RoR is described in Table 1 [11]. In a simplified approach, the classic type of RPI-x seems to be the most desirable, due the fact that it is more oriented to the efficiency gains, where the RoR seems to cover all risks related to the regulation. In practice, the regulatory methods are hybrids, containing elements from different alternative methods.

Another issue is the administrative cost of economic regulation. In the case of a small number of large size utilities it is efficient to apply an advanced and costly regulatory system. It pays off due to the fact that the efficiency for the society is higher than the resources spent on regulation. Another issue is the large number of small utilities, as is the situation of regulated sectors in Estonia.

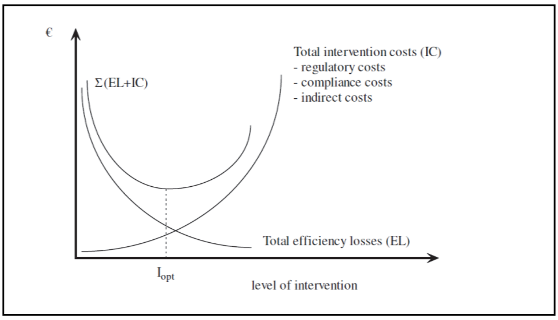

Fig 1. Optimal level of welfare loss control.

The effect of economic regulation on the level of whole society is analysed by Hertog [13], [14]. It is important to find the optimal level of intervention by the regulator. Beyond an optimal point, the additional resources spent on regulation will give no additional effect, but in contrast to desired result will be an additional burden for the society. The core of this basic framework is captured in the diagram on Fig 1.

II. ESTONIAN CASE OF REGULATION OF LARGE NUMBER SMALL SIZE UTILITIES

In the case of large number of small utilities, the cost of regulation shall be especially considered by selecting of regulatory methodology. In Estonia the number of utilities regulated by the regulatory body – Estonian Competition Authority (ECA) - is 260. This includes energy and water utilities [15]-[21]. The annual turnover of the smallest companies may not exceed 50 000 €. It can be assumed that by applying of economic regulation, it is possible to save 5% for the society. From this perspective it is reasonable to apply the regulation which annual costs are not exceeding 2,500 €. The 2016 annual budget of ECA is 1.8 m€, with the proportion of 60% (i.e 1.1 m€) for the regulatory activities [22]. In addition to the energy and water regulation the budget for regulatory activities includes the regulation of postal, railway and airport sectors [23]. If all resources available for regulatory activities would be spent for price regulation of energy and water utilities, the budget per utility would be 4 231 € per annum. In practice this amount is much lower due to the fact that besides the price regulation the regulatory body is responsible for a number of tasks, like EU co-operation, surveillance of electricity and gas markets, solving of customers complaints, etc. However, it is clear that within this budget is impossible to introduce advanced type of RPI-x regulation. From utilities point of view, the administrative burden by selecting of regulatory methodology shall be considered. If a large utility is on higher or at least on equal level with regulator to present data or to have discussions, a small utility suffers lack of resources for that. Beside direct administrative costs, also indirect costs related to the regulation exist, like the cost of capital. The level of regulatory risk is included to the cost of capital [12]. This shall be also considered by selecting of regulatory methodology.

The RoR implemented in Estonia includes a number of elements from RPI-x, where various risks shall be covered by companies. There is a 15 years of experience of using this methodology in economic regulation of energy and water utilities in Estonia [24]. One of the main principles in using this methodology is the companies right to present the application to fix the new tariff on any time. Companies are obliged to monitor the cost base, in case the tariff is not covering all costs, the company can apply for a tariff increase. This moment occurs for example where the sales volume has declined, uncontrollable costs like fuel or electricity have increased or the cost of capital has changed. For implementation of new tariffs the regulator´s approval is needed. This can be a time-consuming process with administrative burden, especially for small-size utilities.

Referring to Table 1, by using of classical type of RoR method, the controllable costs are covered by the regulation

[11]. That is the case where the company carefully monitors costs and the tariffs are actually fixed by the regulator in accordance to the basis of the historical costs of the company. The method used in Estonia differs a lot from the classical type of RoR where the costs included to the tariffs in principle differ from the company´s historical cost base and the regulator is actively demanding implementation of cost saving measures: reducing energy losses, saving on operational costs, etc. By using of so called "incentive type of RoR", controllable costs are not covered by the regulation.

To reach the energy conservation target, the obligation to reduce the power losses has been set to the utilities [25], [26]. The reason of obligation was the extremely high power losses in distribution companies up to 20% by starting the price regulation in the beginning of 2000s. The fulfilment of the obligation is company´s risk, similar to the efficiency target x used by RPI-x regulation. The company can maximise the return on capital by saving more than established by the regulator. In an opposite case, the difference shall be paid from the company´s return.

By using classic type of RoR, the risk of sales volume is covered by the regulation [11]. Based on forecasted sales volume, the weighted average of last three years is used as a rule in Estonian price regulation. If there are significant changes in customer structure, the detailed analyses are prepared [26]. By using the weighted average consistently, it is possible to eliminate this risk. Special situation may emerge in case of constantly declining sales volumes, like in district heating sector in Estonia, where the sales is declining due to the demographic situation and energy efficiency measures implemented by the customers. In this case, the sales volume is a clear risk for companies. In order to address cases like this, an under/over recovery system similar to revenue cap could be used [27]. This type of system was used in energy regulation in Estonia until 2012. In order to decrease the administrative burden, the under/over recovery is not used anymore. This is clear evidence, that the risk on sales volume is not automatically covered by the regulation.

By using the classical type of RoR the risk of uncontrollable costs is covered by the regulation as well [11]. Despite the companies right to turn to the regulator by applying for a new tariff, this type of risk exists. The cost pass-through principle combined with cost under/over recovery should be used for full coverage of the risk of uncontrollable costs. If the company is earning more or less than expected return due to the changes in uncontrollable costs, this will be over- or under-recovered by fixing the tariffs [1], [27]. For example, if the electricity cost for compensation of losses of a power DSO is more than expected, it will be compensated to the company during the next regulatory period. Or *vice versa*, if the electricity price is cheaper than expected, this amount will be paid back to the customers during the next regulatory period. This type of scheme was used in Estonian price regulation but is abolished now in order to simplify the price regulation. Similarly to the sales volume, the risk on uncontrollable cost is not automatically covered by the regulation.

All in all, the general target of Estonian price regulation has been to ignore the risk on controllable cost, but to cover the risk on sales volume and uncontrollable costs. The risks on sales volume and on uncontrollable costs shall be covered by the company, by presenting of tariff application to the regulator.

The regulatory model introduced in Estonia can be characterised as having set up the goal to save on administrative costs of the regulatory body. There is no requirement for systematic data collection, the historical data and prognosis are prepared only by applying of new tariff. This system can be defined as some kind of regulatory deterrence where the company knows that applying of tariffs will rise notably heavy administrative burden. This is motivation system to rely on existing tariffs and not to turn to the regulator for fixing new tariffs.

III. Analysis of results of implementation of incentive type RoR price regulation method

The main results of 15 years price regulation in Estonia are the efficiency gains in energy savings and the fact that the companies' actual return is mostly equal or below the WACC set by the regulator. The prices in real terms have been almost stable or even declining [15]. The outcome clearly indicates that the incentive type of RoR implemented in Estonia does not guarantee the required return which is one of the main characteristics of the classic type of RoR. On Fig 2 the average return on invested capital of the largest Estonian power utilities is presented.

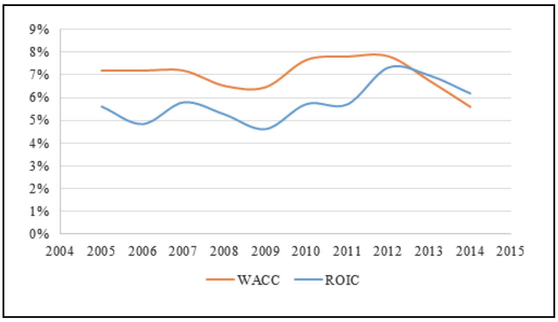

Fig 2. Average Return on invested capital of power networks incl. Elering, Elektrilevi, Imatra, and VKG.

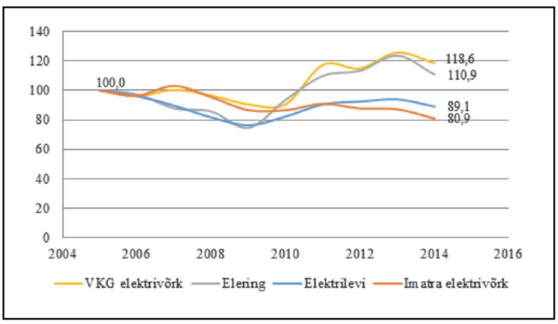

Fig 3. Relative change of tariffs of the largest power networks in real terms. The tariff in 2005 is 100 units.

The main target of RPI-x regulation is the decline of tariffs in real terms, this is included to the price formula as a negative value of the x-factor. By using of RoR, the price development in line with inflation could be expected. The analyses of power networks indicate that the tariffs have been stable or declining in real terms (Fig 3). The tariffs of Elering (TSO) have been increased by 11% (Fig 4). The main reason of tariff increase is the intensive investment program carried out by building international links whereby the regulatory asset base (RAB) of the company has increased 1.55 times. Without building of those international links, the tariffs would have been decreased from 100% to 83% in real terms. [15].

The reduction of electricity losses in power distribution networks is a success story of Estonian price regulation. 15 years ago, before the start of economic regulation, the power losses of 20% were commonly observed. Today the losses are close to the technical minimum where the further reduction is not much possible. The reduction of electricity losses of 3 largest DSO's with summary market share of 93% is presented on Fig 5 [28], [15].

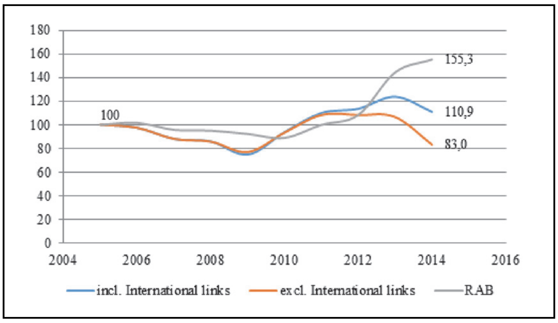

Fig 4. Relative change of tariffs and RAB of Elering in real terms. The tariff in 2005 is 100 units.

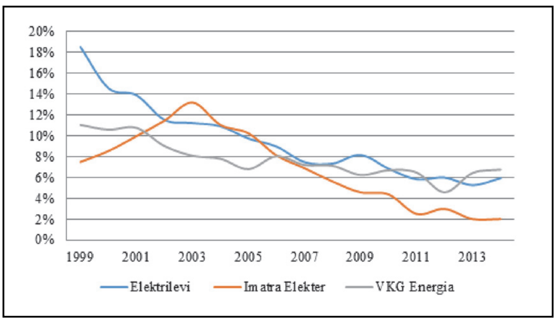

Fig 5. Electricity losses of distribution operators in percentages.

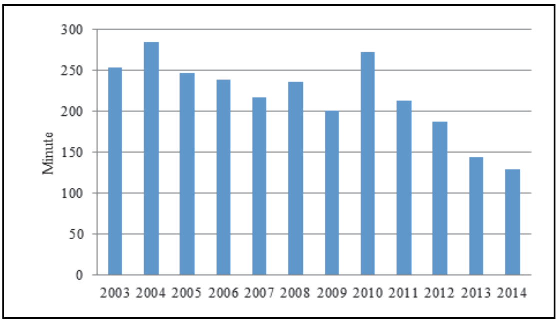

Fig 6. Changes in network reliability indicator SAIDI in Elektrilevi OÜ

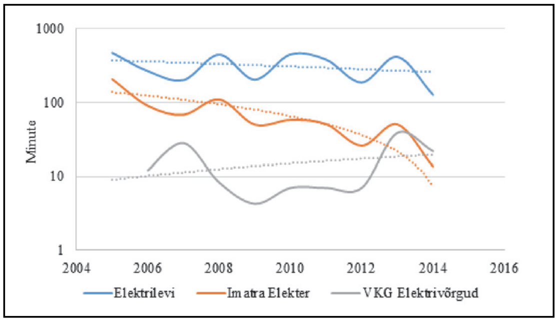

Fig 7. Changes in network quality indicator SAIDI in largest DSO's on the logarithmic scale.

Fig 6 presents the changes of the System Average Interruption Duration Index (SAIDI) of the largest power DSO Elektrilevi OÜ from 2003 to 2014. SAIDI indicates the average outage duration for each customer served. The calculations of SAIDI on Fig 6 do not take into account the impact of occasional weather impacts [2]. The calculations of SAIDI of three largest power DSO's is presented on Fig 7, this includes the impact of weather as well [15]. The conclusion is that the network reliability indicators have been improved during this period.

IV. CONCLUSION

The aim of the paper was to analyse the impact of the price regulation methods in the case of a large number of small size utilities with restricted administrative resources of the regulatory body. The "incentive type of RoR" model has been implemented in Estonia, where the regulator is inventively regulating the company's costs, including the energy efficiency. The results of the price regulation indicate that the tariffs have been declining in real terms and significant energy savings have been reached.

The conclusion is that the incentive type of RoR has the biggest impact on company's operational costs. The clear indicator is the reduction of energy losses, where the regulator is pushing the company toward of efficiency in operating costs. The similar indicator is the actual return on capital that has been mostly below the allowed return by the regulator. This is indicating that a part of the operational costs, not included to the tariff by the regulator is financed from company's return. This fact is also indicating, that the RoR implemented in Estonia is not a classical one, where the allowed return is guaranteed to the company. The fact that the tariffs are declining in real terms is indicating some relation to the RPI-x, which is indicating, that the incentive type of RoR implemented in Estonia has some elements of RPI-x. The "incentive type of RoR" is suitable by regulating a large number of small utilities with limited administrative resources where the effect of regulatory deterrence is motivating the utilities to manage within the budgets set by the regulator.

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