Opportunity and prospect analysis of RES utilization for sustainable development of Ekaterinburg city in Russia

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Abstract. Recently megalopolises have become centres of economy development worldwide. Gradual growth in energy consumption and thereafter – enormous power production and delivery to sustain metropolis' needs entailed, rapid increase in emissions of hazardous substances in quantities, no longer tolerable for secure residence in majority of these cities. Ekaterinburg, is one of them. In order to abridge harmful pollution in Ekaterinburg and further centralize economic importance of the city, this paper proposes to implement the concept of urban sustainable development /ref. / by introducing alternative energy sources, which would progressively displace traditional fossil fuels. A number of actual cases, where the concept was successfully implemented, were studied and analysed to demonstrate how different shares of renewables can become effective substitutes to conventional energy sources in the cities strongly dependent on them: 1. Energy strategy of Pecs (Hungary); 2. International low carbon city (ILCC) project (Shenzhen, China); 3. Electric power system template of Tangshan city (China). Further, regional environmental and economic specifics of Ekaterinburg were studied to understand power consumption needs and energy generation possibilities, which led authors to conclude on the alternative energy sources feasibility, plot specific flow chart for RES implementation in Ekaterinburg's power network and outline recommendations for future works.

1. Introduction

Existing statistical estimates of demographic increase and rapid urban development lead to significant changes in structure and volumes of energy consumption. According to R. York [1], 1 % growth in Europe population magnifies energy demands by 2.7 %, thereafter reaching ca. 2.18 Mtoe per year by 2025, which exceeds the levels of 2000 in almost 1.5 times. Along with substantial economic consequences, energy consumption has an impact on quantities of hazardous substances discharged in the atmosphere.

Developing countries have become among the most reflective examples of such a development scenario. Due to intense industrial and urban progression coupled with population increase, China and India are nowadays leaders in carbon dioxide emissions: only in 2010, their share in the global atmosphere pollution with CO_2 were 10.4 % and 9.4 % respectively. To compare, Russia, USA and the EU have contributed 5.8 %, 4.1 % and 2.2 % respectively [2].

Furthermore, according to the UNO [3], forecasting the respective decrease in rural population in Russia, China and USA by 38.5 %, 47.3 % and 15.6 %, the emissions numbers are only foreseen to grow.

Progressively cities become main consumers of electrical power, and consequently – ground zero for environmental contamination. With a current share of 75 %, the urban centers are forecasted to reach almost 90 % of the energy use in the nearest future [4]. The numbers allow reasonably assume that replacement of the urban fossil energy with alternative energy sources will substantially improve ecological environment, reducing content of CO_2, SO_2 and nitrogen oxides (NO_x) in the atmosphere.

Thus, it is suggested to investigate how the concept of sustainable development, successfully implemented in a few megapolises, would compensate for increased energy demands and mitigate unwanted ecological disaster and economical outcomes on a national and international levels. This paper outlooks possibility of renewable energy sources implementation in energy networks of Ekaterinburg city in Russia and attempts to build a flowchart of necessary transformations in power infrastructure. It also constructs the basement for future works in need to effectively overcome challenges to achieve sustainable development of a city.

Related research works [5–7] usually focus on finding ways to solve three challenges found relevant to the discussion:

- Complexity of energy transportation utilizing existing network facilities, especially to remote locations [8–10],
- Shortfalls of financial means to build up developed power networks in regions with easy access to vast volumes of renewables [11, 12],
- Control and reduction of hazardous substances emitted into the atmosphere [13, 14].

Taking all of these into account the next section will determine sub-tasks specific to Ekaterinburg conditions.

2. Study of Ekaterinburg city specifics

Ekaterinburg is one of the largest and most dynamically growing cities in Russia. Its favorable geographic location determines its national importance as a transportation hub between the Central Russia and Siberia, and one of the most important industrial, transportation, financial, scientific and cultural centers in the country.

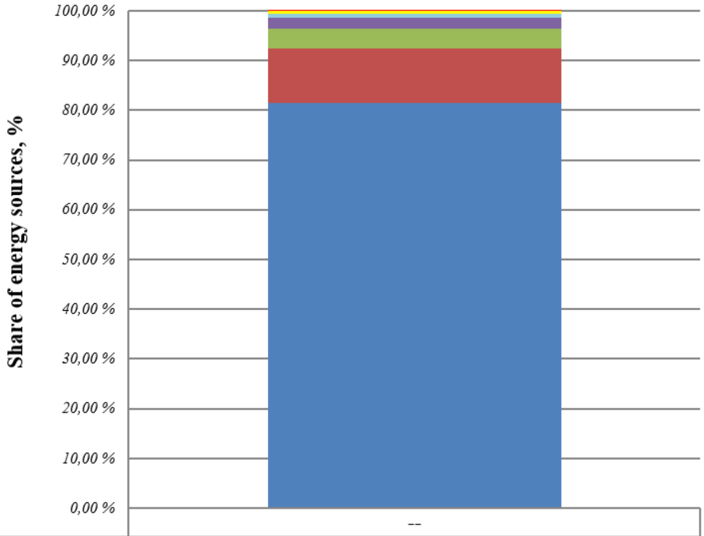
As Siemens reported [15] electrical energy feeding the city is produced by power plants working on natural gas. Shortfalls are mainly covered by nuclear energy delivered from neighboring Beloyarsk power station. Detailed distribution of Ekaterinburg's power sources is presented in Figure 1.

Based on available data of the population and total energy demands in the region [16], energy annual consumption per capita was estimated as 10.5 MWh. As reported by the UN [3] the numbers are considerably higher due to the administrative, financial and industrial importance of the city. Based on our estimates and available UN reports, the dependencies of population, energy consumption and IPI is demonstrated in Figure 2.

Ekaterinburg carries extensive network of public transport working on fossil fuels and partly on electricity. Electrical transportation means share equals 42 %. This includes trams (18 %), subway (10 %), trolley busses (8 %), and electrical train (6 %). Municipal lighting network has poor effectiveness where 60 % and 36 % of illumination devices has a light output ratio lower than 50 and 90 lumens per watt accordingly, and only 4 % is above 90 lumens per watt.

Arrest of development takes place due to the overall poor energy efficiency in the city. Besides, unfavorable environmental situation was declared by TROICA project experiment [17] where hazardous pollutant emissions in Ekaterinburg were deeply investigated. It was reported that annual nitrogen discharge N is totaled to enormous 6300 tons, carbon monoxide CO – 133000 tons, methane CH_4 – 40000 tons. At low wind conditions in the city, the significant level of air pollution was declared.

Taking all of these into account next section will examine prospects of RES (renewable energy sources) utilization in Ekaterinburg and define key elements of an action plan for urban power network development.



Oil	0,10 %
Nuclear Energy	0,60 %
Hydroenergy	0,80 %
Other sources	2,10 %
Oil Products	4,00 %
Coal	10,90 %
Natural Gas	81,50 %

Figure 1. Primary sources of electricity and heat generation in Ekaterinburg city, %

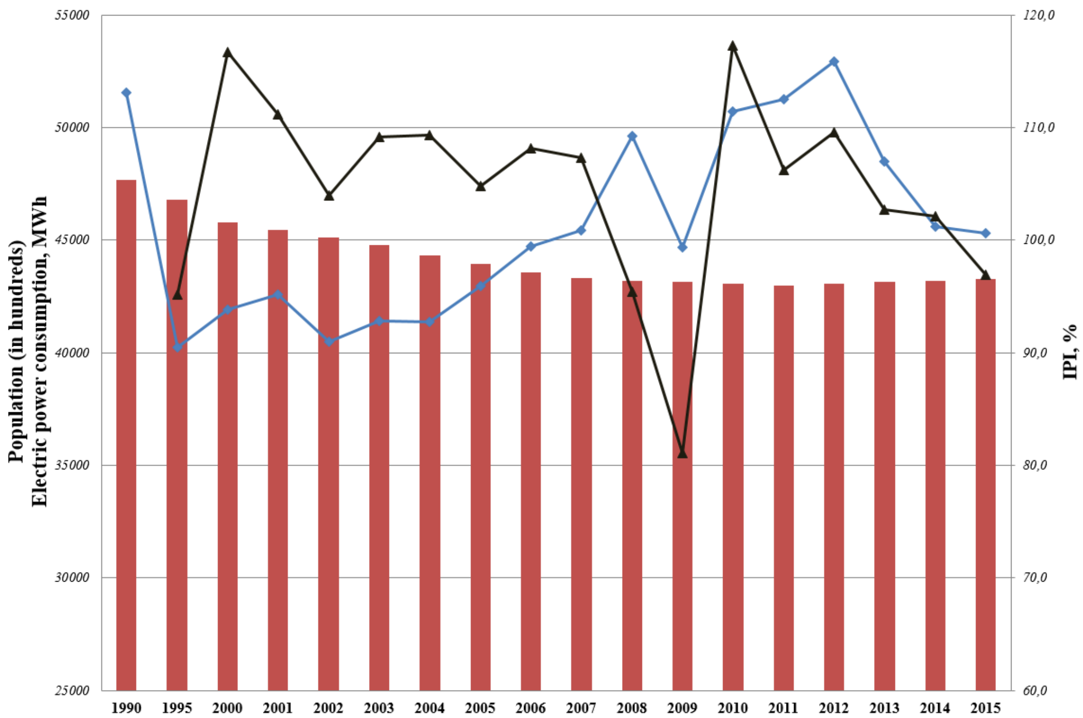


Figure 2. Correlation between population, its energy usage and industrial production index in Sverdlovsk region, 1990–2015

Producing ca. 50 % of electricity Novosverdlovskaya thermal power plant is located within the city limits and together with neighboring Sredneuralskaya TTP they form central heating system of Ekaterinburg. Providing 95 % of residential buildings are heated by the network, approximately 3500 km of heating flowlines have spanned in the web all over the city. Due to the high depreciation rate thermal energy losses count on a 25 % level, which governs very low efficiency of the system.

3. RES availability in Ekaterinburg city

Unlike conventional energy plants, the energy volumes produced on a renewable power plant are changing with the weather. Understanding of climate conditions in the city is therefore essential to analyze efficiency of the renewables. It is necessary to note, that the research on Ekaterinburg RES potential is still being carried out by the authors. Therefore, the article uses results of existing third party studies, which only touch upon solar and wind energy opportunities relevant for the region.

In the context of how efficient solar energy would be, several researches were carried out [18, 19] and concluded that:

- Sunlight, suitable for solar energy production, is available for 1900–2100 hours per year,
- Maximum solar activity falls on July (over 295 hours), its minimum – on December with only 36 hours,
- Solar energy efficient economic life adds up to 9 months (from April to September),
- Testing of solar concentrators in the city were successfully executed and found efficient with 4560 MJ/m^2 of energy produced by solar radiation annually, 645 MJ/m^2 as max and 101 MJ/m^2 as min of solar radiance in June and December respectively.

It is necessary to notice that clouded sky is a frequent event in the region. However in accordance with the technical acceptability of the solar radiation by Veynberg's criteria, implication of solar energy to the electricity generation network is considered as acceptable if for most of the year flow rate of the solar radiance exceeds 0.42 kWh/m^2.

Introducing solar capacitors in the primary central heating system would compensate for heat losses in the heating pipelines and would set conditions for efficient maintenance of the power plant in summer time.

Besides solar energy, highly dependent on whether the sky is clear on a day, hydroelectric power from river Eset, appears to be an attractive alternative indifferent to weather fluctuations thanks to the constant current and deep waters. However due to relatively weak water flow the river can only sustain pumps of the central heating system [20, 21].

Due to the low wind speed, averaged as about 4 m/s at 0–100 m elevations, wind energy generation is deemed efficient only for small, low-power wind mills [22]. For the sake of this study, and despite limited use of efficient wind-powered generators is theoretically feasible, Ekaterinburg is not considered suitable for wind energetics infrastructure development.

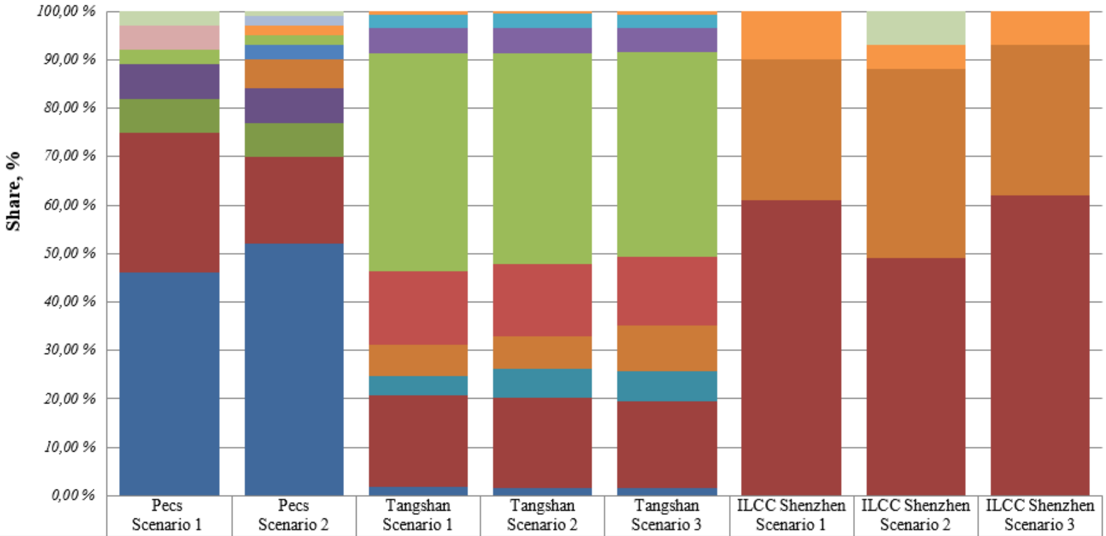
To carry out feasibility study of how various renewable energy sources could further be embedded into the city's infrastructure, it is suggested to analyze examples of similar existing international projects to extract methods and transfer relevant experience.

4. International practices

This section outlooks three projects implemented in major cities abroad where sources of energy to sustain these cities were replaced from fossil fuels to renewables. The detailed summary of the projects are presented below and outlined in Figure 3.

4.1. Pecs

Based on the national energetics development strategy, the concept of clean Pecs city (Hungary) was introduced in 2013 [23]. The concept utilized computer modeling in EnergyPRO software [24] to compare two different scenarios of the city development. The first model reflected current status of the city, highly dependent on traditional energy, and anticipated to feed growing demands with energy produced from biological wastes and wood processing leftovers. The second model assumed supreme engagement of the renewables.



	Pecs Scenario 1	Pecs Scenario 2	Tangshan Scenario 1	Tangshan Scenario 2	Tangshan Scenario 3	ILCC Shenzhen Scenario 1	ILCC Shenzhen Scenario 2	ILCC Shenzhen Scenario 3
Other sources	3,00 %	1,00 %					7,00 %	
Associated gas	5,00 %							
Geothermal Energy		2,00 %						
Solar Energy		2,00 %	0,60 %	0,59 %	0,73 %	10,00 %	5,00 %	7,00 %
Domestic Waste			2,84 %	2,77 %	2,67 %			
Industrial Wastes			5,34 %	5,20 %	5,02 %			
Coal	3,00 %	2,00 %	44,85 %	43,68 %	42,21 %			
Mixed: coal + natural gas			15,24 %	14,84 %	14,34 %			
Biogas		3,00 %						
Wind Energy		6,00 %	6,35 %	6,75 %	9,24 %	29,00 %	39,00 %	31,00 %
Hydroenergy			4,12 %	6,06 %	6,35 %			
Nuclear Energy	7,00 %	7,00 %						
Oil Products	7,00 %	7,00 %						
Natural Gas	29,00 %	18,00 %	18,93 %	18,44 %	17,81 %	61,00 %	49,00 %	62,00 %
Biomass Energy	46,00 %	52,00 %	1,73 %	1,68 %	1,62 %			

Figure 3. Distribution of power generation in Pecs, Tangshan and Shenzhen cities in accordance with projects, %

The models computed optimal share of various energy sources in order to minimize CO_2 emissions and forecasted alternative energy as about 66 % in proportion to fossils in best case scenario by already 2020, reducing CO_2 emissions by 26 % which equals to 62 thousand tons of carbon dioxide.

The following can be borrowed from this project to develop a flowchart of transformations required for sustainable development of Ekaterinburg:

- It is necessary to develop energy strategy for the city, similar to the concept in Pecs, however making even a stronger accord on the renewables efficiency,
- Use of specific software to model and assess performance of the selected distribution between different energy sources.

4.2. Tangshan

The project around the Chinese city Tangshan has modeled three cases of alternative energy sources implementation in the city infrastructure until 2025–2029. The models have assumed different subsidy assistance and therefore acceptable emission levels of hazardous substances [25]. The first case suggested acceptable emissions in quantities corresponding to the current values, and complete absence of financial support. Second and third scenarios set 10 % and 15 % respective reductions in maximum acceptable contamination levels.

The research has indicated magnitude of investments required to effectively implement renewables in the city's power sector. It was also shown that subsidy assistance reduce CAPEX of the most expensive third case by only 7.15 %, which demonstrates that subsidizations are not the most necessary factor to successful development of a project.

Hence, the development of a similar project in Ekaterinburg can utilize Tangshan experience in modeling a range of possible economic and ecological indicators based on different shares of renewables. The result should outline precise requirements to an expected net project cost and unit cost of energy produced.

4.3. Shenzhen

Shenzhen is one of the largest megapolises in China, concentrating approximately 40 % of the national GDP. As in many more similar big cities, air in Shenzhen is contaminated far above the tolerable levels. To improve ecological situation in the city, International Low Carbon City (ILCC) project was recently carried out [26].

Hybrid Optimization Model for Electric Renewable (HOMER), based on the software developed in the USA National Laboratory of Alternative Energetics, was selected as the main principle used in the project development. Similarly to Tangshan project, the model has analyzed different scenarios of ILCC execution and forecasted their economic and ecological effect with the following set of variable parameters: net project cost (NPC), cost of unit energy produced (COE) and fraction of energy produced by renewables, which by programming default can not fall below 30 %.

After simulating more than 32000 cases, three optimal scenarios were selected. They are presented on Figure 3. The first scenario, anticipating entire energy generation within the city, appeared as the most expensive with expected CAPEX of \$ 653.2 mln. and COE of \$ 0.187/kWh. The second case assumed part of the energy is produced outside of the city and delivered via existing infrastructure. The results showed to be having the best financial indicators – \$ 511.7 mln. NPC and \$ 0.128/kWh COE. The third scenario suggested to use city electrical transport as energy storage facilities and reached best ecological consequences – 78000 tons of carbon dioxide, as opposed to 97000 and 90000 tons for first and second cases. To develop this scenario the forecasted NPC and COE of \$ 567.7 mln. and \$0.150/kWh have fallen in between two first cases.

This example perfectly demonstrates that the highest investments do not necessarily allow to achieve desired results. And in order to maximize economic efficiency of Ekaterinburg city project, a thoroughly developed plan is required.

5. Work flow chart for RES implementation in Ekaterinburg city

It is necessary to designate the essential steps required for sustained and productive development of the city power system. Those are identified as follows:

1. Building up energy strategy on a city level, similar to the one developed in the Pecs city. This will require a team of people specialized in energy sector, ecology and economics. The result of their work will form specific goals and limitations of the strategy.
2. Strategic planning – a step when the expert team will set the acceptable levels for variable parameters and delineate project execution timeframe.
3. Economic analysis should reveal key financial figures – NPC and COE, similarly to Tangshan and Shenzhen projects. The analysis should work through a large number of modeled cases, with and without possible subsidy assistance, in order to reveal just a few rational solutions.
4. Technical analysis will further determine feasibility of alternative energy sources to maximize project efficiency. Results will be used as a basement for technical scope of work to build or modify energy generation and transportation systems.
5. Feasibility study of the planned transformations, using a dedicated software (EnergyPRO or similar), to assess performance of a suggested distribution between various energy sources. The study will allow to accurately determine characteristics of the city energy demands and supply, and prove efficiency and sustainability of the renewables share in the total energy production system.

To successfully develop the project on a short term, and accomplish all steps above on a long term planning, the authors recommend to carry out further detailed researches on every stage above. In addition it is suggested to evaluate long-term stability of the ecological, economic and social characteristics which are seen as dynamic and unstable in some conditions under the urban development process [27], which may influence the project, sensitive to those parameters.

6. Conclusions

In response to the experience of existing projects and analyses carried out in this study the following conclusions can be made:
1. Renewable energy sources is a valid alternative to partially displace traditional fossil energy to sustain Ekaterinburg power demands,
2. To a robust RES development in Ekaterinburg, key lessons were learnt from similar projects, having success in other parts of the world,
3. Working flow chart was developed to outline an overall plan and set required minimum for transformations of existing infrastructure to achieve sustainable progress of the metropolis,
4. A foundation for further scientific works required to increase share of the RES in Ekaterinburg's energy sector was laid.

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