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Energy from Biomass for Sustainable Cities

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Abstract. One of the major challenges of sustainable urban development is ensuring a sustainable energy supply while minimizing negative environmental impacts. The European Union Directive 2009/28/EC has set a goal of obtaining 20 percent of all energy from renewable sources by 2020. In this context, it is possible to consider the use of residues from forest maintenance, residues from livestock, the use of energy crops, the recovery of food waste, and residuals from agro-industrial activities. At the same time, it is necessary to consider the consequent environmental impact. In this paper an approach in order to evaluate the environmental compatibility has presented. The possibilities of national priorities for commissioning of power plants on biofuel and other facilities of distributed generation are discussed.

1. Introduction

Over the past four decades considerable changes have occurred in the world economy as regards material extraction, trade and the welfare of the world's population. Figure 1 shows trends in GDP, population, material extraction, exports and RME exports. According to [1], global consumption of mineral resources, metals and other materials has tripled and continues to grow at an accelerating pace. On the one hand, it matches the population growth and improving living standards overall. On the other hand, the growing use of material resources is accompanied with an increasing environmental footprint, faster changes in climate and air pollution. The situation in urban areas causes the biggest concern as the clustering of transport, energy and production facilities results in pollutants entering the breathing zone, which has a negative effect on people's health.

The implementation of the Sustainable Development Goals set by the Resolution, adopted by the UN General Assembly on 25 September 2015 [2], requires that nations independently develop their own specific sustainable development strategies, projects and programs. At same time, provisions should be made for alternative options of creating new technologies that combine economic growth and the minimum environmental impact.

Priorities in national solutions addressing the issue of reducing toxic emissions from stationary and mobile sources vary in regions that have a shortage of hydrocarbons, and in countries that boast sufficient fossil fuel reserves. In the former case it is necessary to intensify research on technologies that increase the accessibility of alternative energy sources. It has to be noted that in general the production and use of biofuels have been constantly growing in Europe and Eurasia, increasing 4.3 times over a decade to 13.726 mln. tonnes of oil equivalent in 2015, as reported by [3]. Countries with hefty conventional energy reserves should focus on making technological processes and the economies in general more energy efficient and on improving the quality of traditional fuels. This is not in disagreement with the need to develop other industries, diversify production and to further embrace alternative energy sources. Figure 2 illustrates the contribution of some countries to global extraction of conventional energy resources and production of biofuels in 2015.

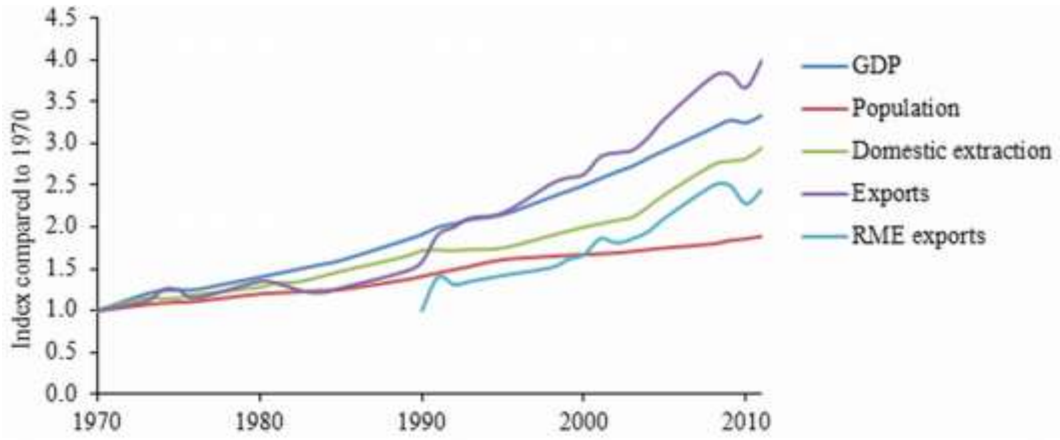

Figure 1. Trends in GDP, population, domestic extraction (DE), exports and raw material equivalents (RME) of exports, 1970–2010 (based on [1])

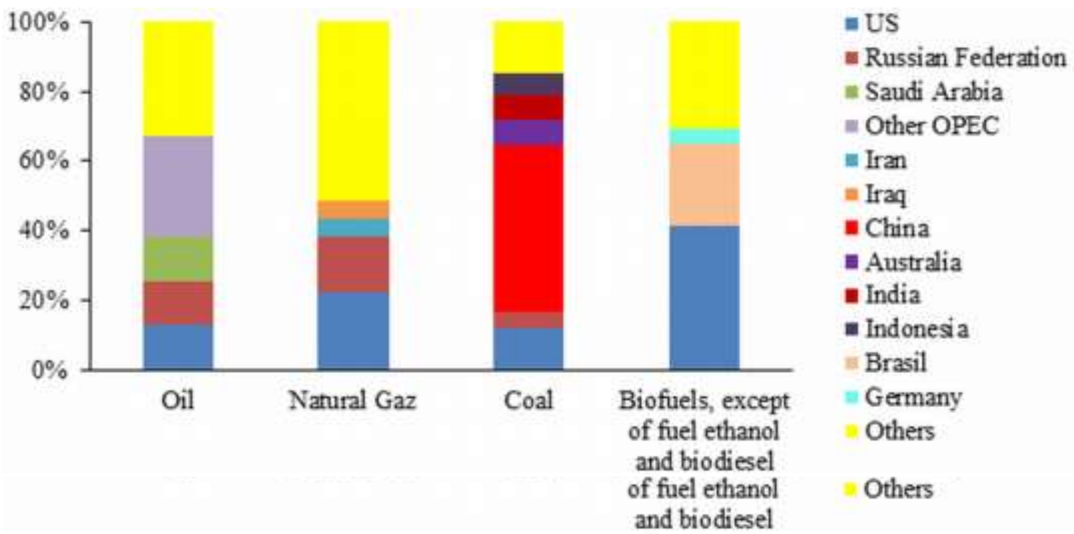

Figure 2. The main contributors to the production of traditional energy resources and the production of biofuels in 2015 (based on [3])

The objective of European Union Directive 2009/28/EC is to obtain 20 % of all energy from renewable sources – for example, wind power, solar, biomass, etc. – by 2020. Of these energy sources, the bioenergy obtained from renewable energy plants (based on biogas produced by the anaerobic digestion of manure, and by burning energy crops such as vegetable oil, wood, and solid biomass) are being strongly encouraged under the European legislation, but their effects on air quality raise serious concerns.

In fact, on the one hand there are important positive aspects such as limitation of greenhouse gas (GHG) emission, use of secondary materials, improvement of local activities, right destination of organic sludges, and limited cost. On the other hand, the impacts on land use need for chemical and imported resources, and, above all, formation of secondary pollutants (dust, nitrogen oxides, and VOC) should be carefully considered in terms of their lower prosperity, higher costs, and specific local conditions. Other forms, such as hydro or solar energy have not been considered at all, even if they could contribute to the total renewable energy budget. Therefore, in the present work, the authors evaluate not only the potential energy production from biomass plants (and its use as substitution of the fuel for the domestic house boiler) but also their environmental compatibility. In some cases, the two goals of renewable energy production and improved air quality conflict with each other, and it is necessary to consider both the avoided emissions of GHGs and the effect of biomass combustion on local air quality in the vicinity of the plant itself. In literature, there is a lot of material on the subject ([4–6]) concerning also both biofuel [7] and biodiesel [8]. In this study a general methodology in order to define the environmental compatibility and in order to define future energy compatibility planning has been shown.

2. Energy from biomass: state of art

Bioenergy production plants must be evaluated on the basis of their capacity to satisfy both local and regional needs for thermal and electrical energy. Such evaluation requires the consideration of a given plant's contribution to reducing GHG emissions and climate change, and of its effect on local environmental quality (air pollutant concentrations, use of natural resources, re-emission of residuals [9]).

In order to study the ability of different forms of biomass to satisfy these general requirements, a number of scenarios has been constructed, to cover large spans of both time and land area [10, 11]. Two key inputs to such analyses are the amount of woody biomass available for large-scale energy production and its price. One short-term study, [12], describes public and private initiatives for investigating regional energy scenarios, based on agricultural biomass in two countries in the south west of Germany. That study focused on the development of more sustainable approaches to energy crop cultivation and on the use of cogeneration systems. The most practical and economical approach to bioenergy production is to find sustainable methods of satisfying the energy production requirements. A study with this aim, [13], discussed the different aspects of sustainability: the utilization of natural resources (land, water, and fertilizers), the effect on climate change, the potential introduction of local air pollutants, and the necessity of disposal, or if possible, reuse, of residual wastes from biomass production. To analyze the effects on land use and the transformation of soils, the carbon balance and CO_2 emissions data must be considered. A detailed analysis with reference to bioethanol production from corn, [14], shows that, considering the complete cycle of biomass production and transformation, it is possible to define the global impact of a particular strategy.

Using a more general approach, [15] discussed all the aspects of energy utilization and its major environmental impacts from the standpoint of sustainable development, including anticipated patterns of future energy use and subsequent environmental issues. Renewable energy technologies and efficient energy utilization were identified as the most effective potential solutions to current environmental impacts. Those practical examples of implementation are useful due to their conclusions and recommendations.

3. Environmental compatibility: methodological approach

In order to determine the potential energy from local biomass and the resulting environmental impacts, it is necessary to use the following tools:

- energy balance;
- environmental balance.

Firstly, by using the tool of *energy balance*, we can know if the use of local biomass could satisfy the local energy requirements and if it is possible to export it. Using the currently available biomass it is possible to calculate the available power (Figure 3).

Secondly, in order to evaluate the environmental benefits deriving from biomass use, it is necessary to estimate both the atmospheric emissions of the existing boilers, and the expected emissions after the installation of biomass plants. The *environmental balance* can be computed according to the following formula: **local / global emissions (added / eliminated) = biomass plant emissions – substituted emissions.**

The environmental balance is divided between two scales, one on the local scale and the other one on the global scale. More specifically, at the local level we considered the emissions avoided for the thermal energy produced by the plant and used for district heating. On the global scale, we considered two different components: the value of avoided emissions for the thermal energy and the value of avoided emissions for the electrical energy produced by the plant. For the environmental balances it is necessary to take into account emission factors for the various analyzed pollutants, for the different types of biomass used (liquid or solid), and for the various steps in the process. An emission factor is defined as the weight of pollutant issued by a source referred to the entity of energy production (MJ, kWh).

For these calculations, the generally considered parameters are:

- on the local scale: dust, nitrogen oxide, and sulphur oxide,
- on the global scale: dust, nitrogen oxide, sulphur oxide and carbon dioxide.

However, in an environmental balance, the assumption that the amount of CO_2 absorbed during plant growth was equivalent to the greenhouse gas emissions released during energy conversion is an excessive hypothesis. In fact, it should be noted that, for a detailed analysis of the environmental effects in terms of CO_2, we have to consider the emissions of other gases such as CH_4 emissions and N_2O produced during pre and post storage of biomass to produce biogas and the indirect emissions deriving from agricultural processes, such as harvesting and transport. In this way, we take into account the environmental effects at the level of combustion of biomass and the whole process: from harvesting to the collecting of biomasses to transportation and use of biomasses. The assessment is only referred to CO_2.

Generally for the emission factors used to estimate the emission of CO_2, it is possible to refer [16]. Regarding the transport of biomasses, it is possible to consider the emission factors of transport derived by European model COPERT 3, which is about 413.5 g CO_2/km with a capacity of 9 tons of transportable biomass (Figure 4).

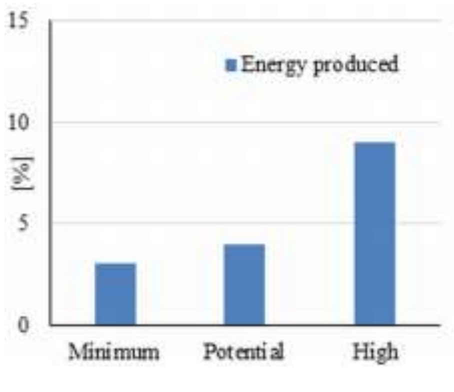

Figure 3. Example of results of the energy balance

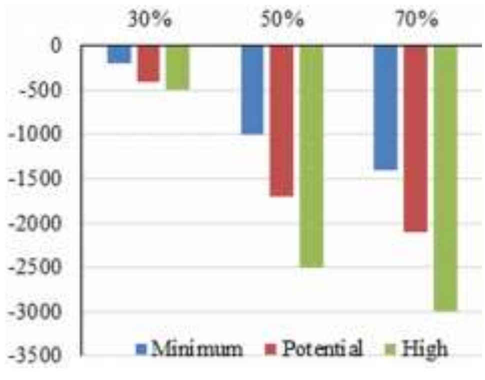

Figure 4. Example of results of the environmental balance

4. Taking national priorities into account

Biofuel power plants and other types of renewable energy sources constitute distributed (small-scale) generation installations that are particularly flexible and adaptable to changing demand and location. Such installations are in the closest proximity to the load center, which ensures a high level of reliability and cost effectiveness of the grid. In many cases they require less per unit investment; it takes months rather than years to build them and their payback period does not exceed three years. Full automation makes it possible to keep them running in optimum modes and, as a result, to ensure high energy and environmental effectiveness. The development of distributed generation in regions leads to a decrease in demand for backup capacity in energy systems.

It is necessary to emphasize that, when incorporated in regional power grids, such facilities, cannot be viewed as an alternative to the grid; they must not be set in opposition to one another as their functions complement each other. At the same time, the optimal share of the regional grid capacity in electric power supply will differ across the country depending on such factors and limitations as operating mode, availability of resources, climate and environment (e.g., peak loads, demand for electricity where there is no heat load at cogeneration plants, possibility of developing generation based on renewable energy sources). The key function of regional grids in the structure of the power supply system is to compensate for the excessive economic inertia of the national grid that is built around large thermal power plants, NPPs and hydropower plants. As a result, the installed capacity put into operation in the regional and national grids is aligned as much as possible with the pace of demand growth, while the cost, reliability and environmental characteristics improve across the national grid.

Standing at 1%, the share of RES in the energy system of Russia is insignificant yet (figure 5). When assessing the effectiveness of small-scale generation development, one has to bear it in mind that Russia has an excess capacity of over 20GW (around 8% of total capacity) [17]. There is, therefore, no need for new power plants, be it fossil fuel ones or renewable installations, in the country. This does not mean, though, that some regions of Russia do not have to deal with a pressing issue of optimizing the structure of electricity generation capacity in order, for example to meet peak demand or improve the environmental situation.

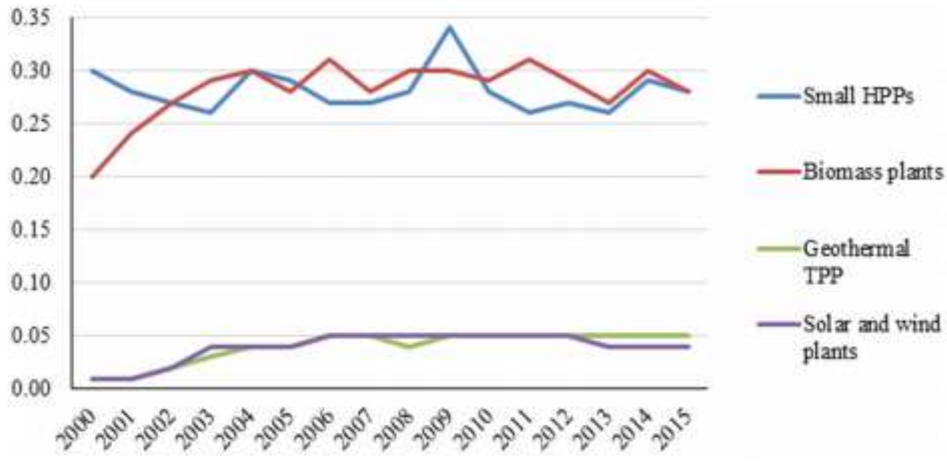

Figure 5. Share of RES in total electric power output in Russia in 2000–2015, % (based on [18])

In terms of greenhouse gas emissions and Russia's obligations under the Paris Agreement, Russia is in a drastically different situation than other countries: over 80 % of its energy is produced from zero-carbon and low-carbon fuels (NPPs, gas-fueled TPPs, hydropower plants). In the countries that have taken the lead in embracing renewable energy sources, the situation is different: the share of coal in China's energy balance is over 60 %; in the USA and Germany around 40 %.

One has to remember that the areas of decentralized energy supply (15 % of total generation) cover over two thirds of the territory (remote areas of the Far North, Siberia, the Far East). The development of the electric power industry there naturally implies the predominant use of local energy sources and RES.

It should be understood that despite the decentralized nature of the energy systems, it is in these regions that active industrial development is bound to start soon. Work on specific projects of integrating renewable energy with large-capacity installations should start today. The task of designing local grids that include renewable energy installations is focused on hybrid energy systems (HES) that consist of an array of primary energy sources, a system of installations transforming primary energy into electrical energy, mechanical energy and heat; various types of consumers, energy transmission and distribution systems. HESs should be created as a coherent combination of consumers cum power generators who form the technological foundation of smart micro-grids [19].

The authors' research on the prospects of renewable energy in Russia shows that the list of relevant institutional, organizational and economic decisions includes:

- forming a clear energy policy of a region, effective mechanisms of its implementation and establishing professional bodies of administration and regulation;
- project design and forecast support of the regional energy sector development;
- creating a mechanism of attracting investment, providing funding for motivational offers (incentives) and making sure that appropriate technological solutions are available on the energy equipment market;
- implementing a set of technical measures to adapt the electric power distribution system of the region to the connection of additional generators;
- developing an accessible equipment market;
- deployment of information systems of operating mode control, equipment monitoring and cost accounting.

5. Conclusion

In the context of energy consumption growing worldwide, one of the priorities of the development of civilization is to find ways of minimizing the impact of power generating facilities and transport on the environment by means of adopting the most effective technologies.

When building a strategy of small-scale generation development on the basis of RES, it is necessary to take into account specific national priorities that stem from climate conditions, the vastness of territory and industrial architecture. Every region of a country that is as diverse in this sense as Russia has its own optimum share of renewable energy sources. At the same time, using renewable energy resources might be particularly relevant for big cities, especially those ambitiously embracing smart technologies, as an element of the green economy and environment.

In terms of investment and operational arrangements, it seems highly promising to establish specialized local grids with hybrid energy systems that operate in collaboration with "pro-active consumers".

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