Assessing environmental impacts of energy supply systems

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Abstract. The fact that humanity quality of life has steadily increased during the years is currently an unarguable reality. This development has obviously been possible because of the development of many industrial activities, which have had the intended goal to support growing humanity quality of life. Made experience has emphasized that industrial activities can have, beside positive desired impacts on humanity quality of life, also negative undesired ones. Such undesired impacts of technological applications are especially remarkable on environment and society. In this context energy supply systems have to be especially taken into account as actually being essentially for getting a corresponding humanity quality of life. Considering sustainable development of humanity, a concept being currently much debated on various levels, chances and risks of energy supply systems have to be attentively approached. There are energy supply systems based on fossil fuels and on renewable energy ressources. Not only economic and technological assessment criteria have to be considered when assessing energy supply systems but also environmental and social ones. By using various methods and instruments of Technology Assessment, a pretty recently developed subject, assessments of environmental impacts of energy supply systems can be carried out. Such environmental impact assessment studies are performed by applying specific analytical methods and instruments, as for instance calculating corresponding environmental footprint, applying life cycle assessment, or considering potential rebound effects in environmental field. In this contribution general notions about energy supply systems and their potential environmental impacts will be presented as well as future odds in order to minimize such impacts.
Key Words: energy supply system, environmental impact, sustainable development, coal-based power plant, pollutant emission.

Introduction. Various energy supply systems, independently if there is about electrical power supply or heat supply, are playing an important role in manifold applications and in different human activity fields, and by this are actually unthinkable anymore out of our lifes. It is a reality that currently most of the energy supply systems are based on fossil fuels in order to deliver electrical and thermal energy needed in carrying out different industrial activities, especially production processes, but also for providing specific services, as in the field of education, healthcare, commerce or tourism.

Nowadays there are lot of debates regarding limited availability of fossil fuels on a global level, even if with regional differences connected to their availability, in order to succeed assuring power supply and heat energy on well known ways, our current energy supply systems being mostly based on fossil fuels, especially coal. As a consequence, the attention in last time has been concentrated on real existing odds for getting power supply by using renewable energy resources, as water, solar and wind energy, as well as bioenergy (Jischa 2014). At this point it is to be emphasised that from existing known renewable energy resources, water energy has since long been used in form of hydroelectric power plants (Nagel 2019).

In this context it is to be mentioned that since several years the process of analysing and assessing environmental impacts of energy supply systems has started in the efforts of keeping as low as possbile corresponding environmental impacts. The Conference for Environment, that took place 1972 in Stockholm, has been first notable scientific event, where relationships between developing and applying sophisticated technological applications and resulted environmental pollution have been debated (Jischa 2014). On the other side the first report to the Club of Rome „Limits to Growth", published also in 1972, has brought these relationships into serious debates on scientific level, but not only (Meadows et al 1972). Accordingly was finally understood that besides wanted impacts of technological advance, undesired negative effects can appear. Actually it is to be remarked that humanity is currently confronting with several global challenges, which can be mainly divided into three categories, as it can be remarked in Figure 1:

growth of world population, increase of energy and resources consumption as well as environmental pollution (Tulbure 2013). Usually they are called as "old" problems, because in the meantime other issues have arisen, being called "new" problems on a global level. In this category can be stated for instance issues related to new technologies, to developing and applying biotechnologies. to designing technologies for space activities or to using most debated information and communication technlogies, ICTs (Lengsfeld et al 2003; Prunariu & Tulbure 2017).

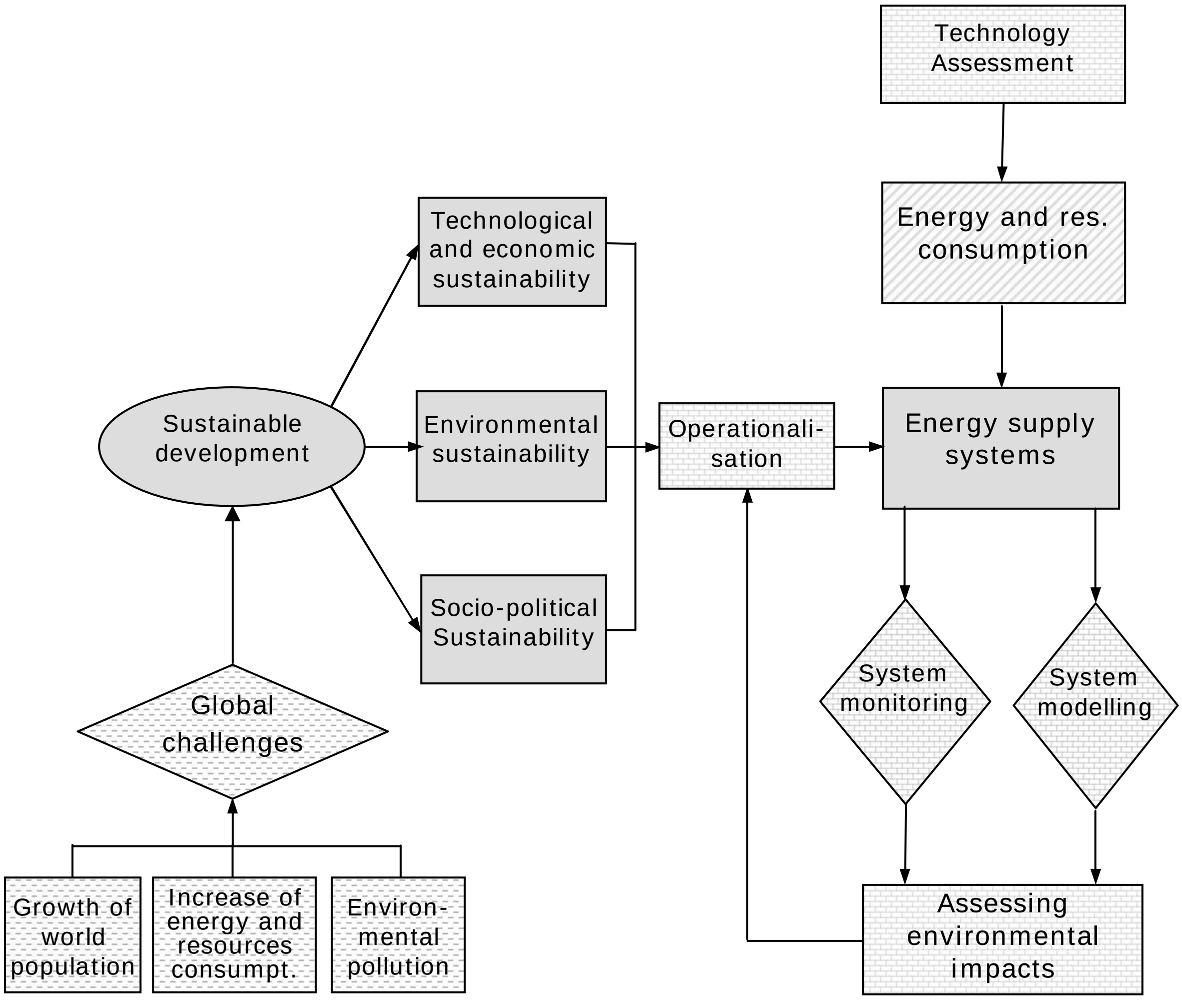

Figure 1. Global challenges and the role of energy supply systems for operationalising Sustainable Development.

Anyway as a consequence of all these debates regarding global challenges, that should be solved, the concept of sustainable development has been for the first time defined 1987 in the Brundtland Report (Hauff 1987). After defining it the concept of sustainable development has been pretty fast accepted as a potential answer to the complex global technological, environmental, economic and social challenges. This concept has been deeply treated during the Conference for Environment and Development in Rio de Janeiro 1992 as well as approached in the conference closing document „Agenda 21“ (Agenda 21 1992). With the concept of sustainable development has been further profoundly dealt during the Johannesburg Conference, well known as “Rio + 10” Conference in 2002 (Jischa 2014). The general Brundtland definition has been worldwide accepted, but made experiences since that time have pointed out that its definition alone could not offer a concept to be successfully applicable to various concrete situations. This issue has been recognized not only on global and national level, but on regional and local level too. This recognised situation has had as a result the fact, that interesting debates followed during the "Rio + 20" Conference, which took place in 2012 again in Rio de Janeiro ("Rio+20" Conference; Tulbure 2013).

Connected to debated issues, regarding assuring needed energy for operating diverse economic activities or for consumption from the side of the population with minimum possible environmental impacts of energy production and supply, there is a need to firstly analyse existing energy supply systems on a regional or national level regarding their environmental impacts. By this analysis it is possible to recognise existing odds to reduce environmental impacts by various measures, as for instance measures of technical, organisational, administrative, institutional, educational or social type to be taken on sectoral or an local level (Nagel 2019).

Material and Method. As it is well known, operationalizing sustainable development actually means in the concrete considered case of operating energy supply systems translating sustainable development goals into technical, organizational, administrative, institutional, educational or social measures on the level of singular companies as well as into monitoring and controlling instruments with regard to succeed in carrying out specific activities with reduced impacts on environment and society. In the approached context of present article sustainability operationalization actually means establishing most relevant sustainability targets by operating energy supply systems with minimum impacts on environment and society, independently of the type of used systems, as presented in Figure 1 (Tulbure 2003). It follows that analysing and assessing environmental impacts of specific energy supply systems by system monitoring and modelling is a first condition for elaborating strategies to reduce these impacts (Jischa 2014; Nagel 2019).

Energy supply systems. Needed energy supply can be provided from a great diversity of systems. Their usage has implications for greenhouse gas emissions at the current time. That is why it would be necessary to consider system design and selection in a detailed way (Nagel 2019). At this stage it is more than difficult to make projections regarding paths of technological development of various energy supply systems in the future, but analysing this issue in terms of their relevance to greenhouse warming is a more than actual and needed matter (Jischa 2014). Worldwide energy supply is currently obtained basically in three ways, as it can be remarked in Figure 2:

1. combustion of fossil fuels such as coal, oil, and natural gas;
2. nuclear fission;
3. non fossil fuel based resources such as biomass or hydroelectric power.

The usage level of each of these primary energy resources has major impact on greenhouse gas emissions, primarily because of the differing CO_2-levels that these resources introduce into the atmosphere by their usage (Nagel 2019).

In the context of debates regarding greenhouse gas emissions as well as global warming it is particularly relevant to analyse how fossil fuels are used since they are currently main energy source for human beings. In the last time have been worldwide carried out several estimations concerning carbon contained in fossil fuels, and hence the potential for mankind to provoke variations of CO_2 concentration in the atmosphere (Jischa 2014). It is estimated that presently the atmosphere contains about 750 Gt of carbon as CO_2 (NAP 1992). The mass of carbon in the recoverable resources of mineral oil and natural gas is about 250 Gt, what means that it is notable smaller than the mass of carbon in the atmosphere of 750 Gt carbon (NAP 1992). In a simple calculation procedure knowing the average CO_2 concentration in the atmosphere as being currently about 400 ppm, this means that actually an increase of concentration with 1 ppm CO_2 in the atmosphere is caused by an increase of the mass of carbon of about 1.87 Gt carbon. Consequently a scenario of doubling the CO_2 atmospheric concentration, what is examined in climate models, could not be got even if all of available mineral oil and gas were burned. On the other side the world recoverable coal resources are very large, and if mankind is to induce perturbations of CO_2 concentrations in the atmosphere up to and beyond a doubling, this will be because of burning large quantities of coal (NAP 1992).

Electricity supply systems. Electricity can be generated in specific power plants from coal, oil, natural gas, nuclear energy, and a variety of renewable energy resources including hydraulic resources, wind, geothermal, and solar photovoltaic energy (Nagel 2019).

As presented in Figure 2, there are several types of electricity supply systems with regard to the type of used primary energy resource:

1. coal-fired power plants;
2. nuclear power plants;
3. hydropower plants;
4. wind power stations;
5. photovoltaic solar power plants;
6. biomass power plants.

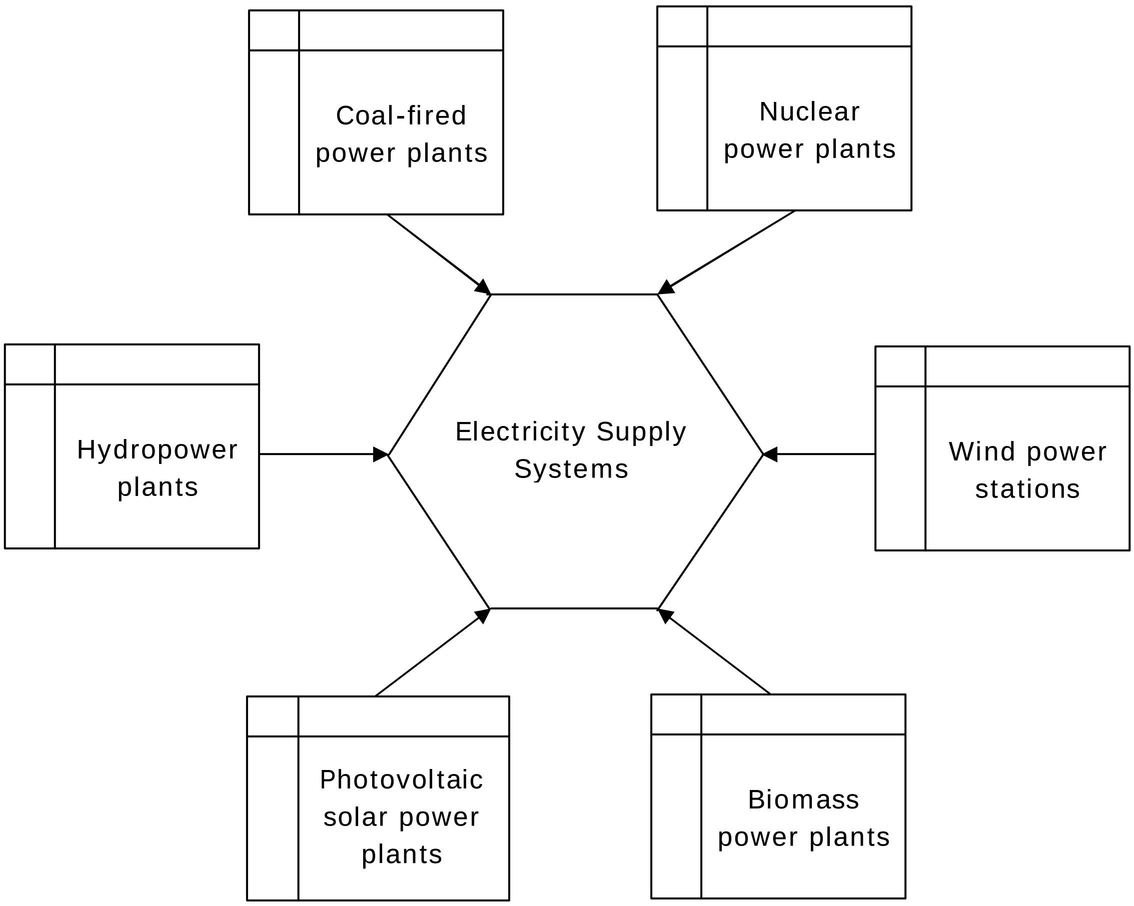

Figure 2. Different types of electricity supply systems depending on used primary energy resource.

C*oal-fired power plants* are operating on the base of coal burning in order to generate electricity. On a global level coal-fired power stations generate over a third of the world's electricity, and at the same time cause several problems because of significant air pollution (Nagel 2019). The coal is burned in a pulverized coal-fired boiler, the furnace heat converts boiler water to steam, which is then used to spin turbines that turn generators. By this chemical energy stored in coal is converted firstly into thermal energy, then into mechanical energy and, finally, into electrical energy (Nagel 2019). Coal-fired power stations have during their operation a considerable environmental impact, as presented in Figure 3 and emit over 10 Gt of carbon dioxide each year, almost one fifth of total emissions, so are actually the largest source of greenhouse gases, which are causing global warming (Jischa 2014).

Hydropower plants are operating by using the power derived from the energy of moving water, that may be harnessed for useful purposes. Actually since long hydropower from many kinds of watermills has been used as renewable energy resource for irrigation and operation of diverse mechanical installations. Supplementary to this usage odds in the late 19th century, hydropower became a source for generating electricity (Jischa 2014).

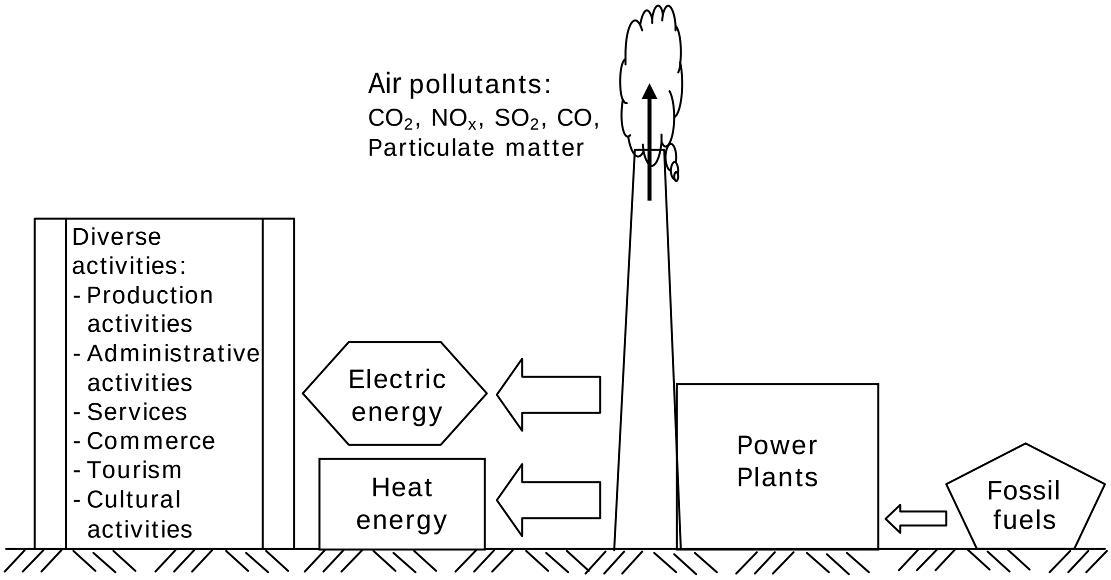

Figure 3. Air pollution of fossil fuels based energy supply systems.

Nuclear power plants are using heat produced during nuclear fission to heat water, which is used to produce steam. The steam is used to spin large turbines that generate electricity. In nuclear fission, atoms are split apart to form smaller atoms, releasing energy. Fission takes place inside the reactor of a nuclear power plant. At the center of the reactor is the core, which contains uranium fuel (Nagel 2019).

Wind power stations are groups of wind turbines in the same location used to produce electricity. Wind power stations called also *wind farms* can vary in size from a small number of turbines to several hundred wind turbines covering an extensive area, as recent developments are demonstrating on a global level (Jischa 2014). Wind farms can be either onshore or offshore.

Photovoltaic solar power plants, also known as solar parks or solar farms, are large-scale photovoltaic systems, PV systems, designed for the supply of merchant power into the electricity grid. They are differentiated from most building-mounted and other decentralised solar power applications because they supply power at the utility level, rather than to local users. The generic expression utility-scale solar is sometimes used to describe this type of application. The solar power source is got via some photovoltaic modules that convert light directly into electric energy (NAP 1992).

Biomass power plants are operating on the base of biomass. Biomass is plant or animal material used for energy production, electricity or heat, or in various industrial processes as raw substance for a range of products. Biomass can be directly burnt or converted to gas before burning. Direct combustion power plants burn the biomass fuel directly in boilers that supply steam for the same kind of steam-electric generators used to burn fossil fuels (Nagel 2019). In biomass gasification, biomass is converted into a gas, usually into methane, that can be then used for fuel steam generators, combustion turbines, combined cycle technologies or fuel cells.

Technology Assessment. A holistic definition for the complex process of assessing various technological applications, known as Technology Assessment (TA) has been possible after multitude of tryings in this regard, and is defined as being the methodical, systematic, organised process of:

- analysing a technology and its developmental possibilities;
- assessing the direct and indirect technical, economic, health, ecological, human, social and other impacts of this technology and possible alternatives;
- judging these impacts according to defined goals and values, or also demanding further desirable developments;
- deriving possibilities for action and design from this and elaborating these, so that well-founded decisions are possible and can be made and implemented by suitable institutions if need be (VDI-Richtilinie 2000).

Made experiences in last years have emphasised that a concrete sustainability challenge especially related to a technological issue is to be approached by delivering a TA-study. Such studies of Technology Assessment have as main objectives to analyse if the use of certain technologies has undesired negative impacts on different fields. Going into details this actually means delivering a comprehensive study if potential impacts of using a certain technology application are not in conflict with the goals of sustainable development (Grunwald 2002; Jischa 2014). On a global level this means to define general goals for the whole world, things which happenned more or less with the Rio-Conferences. On national level this means to define goals by paying attention to specific national conditions. On regional or local level concrete measures are actually contained in Local Agendas 21 (Agenda 21 1992). Applying sustainable development on sectoral level, this actually means on the level of companies, of industrial processes or of products, is to be carried out by using technology assessment, concretely by deploying its appropriate tools (Tulbure 2018). Applying sustainability on sectoral level by using technology assessment actually means approaching complex dynamic technological, economic, environmental, and social systems in order to try discovering developments which can bring instabilities in the behaviour of analysed environment (Jischa 2014).

From made presentation should be obvious that technology assessment tries to give an answer to the question regarding technologies that humanity needs, how are these technologies to be designed, and how do they integrate into environment and society. Therefore, a multidimensional assessment problem can be considered as a logical measurement operation when considering the multitude of technological development odds in order to find optimum ways in this direction (Grunwald 2002; Tulbure 2003; Jischa 2014).

Engineers are not only developing and using technologies, but also evaluating potential developments in technological field. Assessments of engineers have been up to now almost without exception focused on technical aspects and on economic aspects following legal and financial boundary conditions (Grunwald 2002). Considering achieving sustainability of human society other criteria have to be simultaneously considered, like environmental quality, quality of life, human values. This fact can become pretty challenging when applying technology assessment in activities of engineers when evaluating technologies. Advance has been registered in the last 25 years in the field of technology assessment, especially due to several studies which have been carried out in the USA, Japan, Germany and other European countries, nevertheless there is still need in designing new integrative methods for technology assessment (Grunwald 2002; Tulbure 2013; Jischa 2014).

Environmental impact assessment. In order to succeed delivering environmental impact assessment studies, being actually a main goal of technology assessment, several methods and tools of technology assessment can be used and applied for concrete practical situations when assessing different economic activities, and industrial processes

(Grunwald 2002; Tulbure 2013; Jischa 2014). Regarding environmental impacts of certain industrial processes or economic activities, as in the example of this article, analysing coal-based energy supply systems, as presented in Figure 3, there is a need to go into details regarding concrete data of different variables and parameters involved in analysed processes. By collecting data regarding studied processes, and by applying suitable models for delivering environmental impact assessments (Tulbure 1997), it is possible to emphasise pollutants emissions in the environment, air, water or soil. Concretely, in the given example of this article, a model for environmental impact assessment for air pollutants will be used (Tulbure 1997) and applied for the power plants of Oltenia Energy Complex, as the ones from Figures 4 and 5 (CEO 2020). Assessing environmental impacts of energy supply systems can be further detailed by calculating the environmental footprint of produced electric energy [t CO_2- emissions/kWh] (Tulbure 2013). If analysed power plants have desulphurisation and denitrification units, then NO_x and SO_2 emissions are not registered anymore.

The analysis of potential environmental impacts has as a goal to safeguard applying activitites which have as minimal environmental impacts as possible. Going into details it has to be taken into account, that potential results and consequences of a project have to be searched, described and evaluated, and that results of the analysis have to be delivered to the authorities which have to decide basing on the results (Jischa 2014). For assessing potential environmental impacts of diverse economic activities, and industrial processes, following tools can be especially applied (Tulbure 2013; ISO 14001):

- environmental management systems;
- life cycle assessment;
- eco-audit;
- ecobalance.

Experimental. From mentioned different types of electricity supply systems, the most important electricity supplier in Southern part of Romania, Oltenia Energy Complex has in its structure 4 coal-fired power plants. Going into details regarding mentioned coal-fired power plants, these are mentioned in the following and most relevant characteristic data of each of the power plants are given in Table 1 (Directia Energie a Complexului Energetic Oltenia 2017):

- Power Plant Rovinari (see Figure 4);
- Power Plant Turceni (see Figure 5);
- Power Plant Isalnita;
- Power Plant Craiova II.

Table 1

Characteristic operating data of singular power plants of Oltenia Energy Complex

Power plant	*Start of operating*	*Installed capa-city of a power block [MW]*	*Number of power blocks*	*Power plant total capacity [MW]*
Rovinari	1972-1978	330	3	990
Turceni	1978-1987	330	4	1320
Isalnita	1964-1968	315	2	630
Craiova II	1987	150	2	300
Overall				3240

By the fact that all these four mentioned power plants are coal-fired power plants, they have during their operation for electrical energy production certain environmental impacts, especially through air pollutants emissions, as it can actually be remarked in Figures 4 and 5.

Figure 4. Coal-fired power plant Rovinari.

Figure 5. Coal-fired power plant Turceni.

Results and Discussion. By knowing produced electric energy by each coal-fired power plant and the efficiency factor of each energy converting system, data given in Table 2, with the goal of estimating environmental impacts of debated coal-based energy supply systems pollutants emissions can be calculated, especially CO_2 emissions. Taking into account mentioned details, by knowing specific average carbon content in used coal for operating these power plants, pollutants emissions can be got when burning necessary lignite quantity for supporting electricity production in each power plant (Tulbure 1997).

In order to succeed getting an overview about environmental impacts of debated coal-based energy supply systems, as presented in Figure 3, having operating data as given in Table 1, there is a need to know other specifications regarding produced electrical energy by considered power plants. Having data regarding effectively yearly produced electrical energy by these power plants, as given in Table 2 (CEO 2020, pp. 10), by knowing lignite calorific value (SREM 2016) and average efficiency of coal-based power plants (Machidon 2017), by applying a corresponding engineering-based mathematical model (Tulbure 1997), the lignite mass being consumed in power plants can be got, data mentioned in Table 2. By applying mentioned model for environmental impact assessment corresponding air pollutant emissions can be emphasised (Tulbure 1997), by knowing specific average carbon content in used coal for operating these power plants (Luca 2013), see Table 2. By this the environmental footprint of produced electric energy, this means pollutants emissions for producing one kWh electric energy, for each power plant can be calculated, results given in Table 2 as well. It can be remarked that the values of specific environmental footprint are almost at the same level for all considered power plants of Oltenia Energy Complex, what shows that preoccupations are the same in all considered power plants to impact the environment as low as possible. In order to succeed reducing environmental footprint of produced electric energy the value of delivered electricity should be increased by maintaining same pollutant emissions or these should be decreased by maintaining same value of produced electricity (Jischa 2014). With this goal several measures of technical, organisational, administrative, and institutional art could be worked out especially on sectoral level. Anyway by such detailed analysis weak points in the process of energy production can be detected, and measures can be got to reduce environmental impacts and by this the environmental footprint of produced electric energy (Jischa 2014).

By similar algorithm pollutants emissions can be estimated for other activities as well, and by applying presented tools for environmental impact assessment, potential environmental impacts of technological applications and their environmental footprints can be assessed with the final goal of their mitigation (Grunwald 2002; Tulbure 2013).

Table 2

Estimated yearly pollutant emissions by considered energy supply systems and corresponding environmental footprints

Power plant	*Produced electric energy [GWh]*	*Efficiency of coal-based power plant [%]*	*Estimated yearly coal consumption [Mio tons]*	*Calculated yearly CO_2-emissions [Mio tons]*	*Environmental footprint of electric energy [t CO_2/MWh]*
Rovinari	5667.73	35	7.77	18.51	3.266
Turceni	3690.87	35	5.06	12.06	3.267
Isalnita	1892.67	35	2.59	6.18	3.265
Craiova II	1122.88	35	1.53	3.66	3.259
Overall	12374.15	35	16.95	40.41	3.265

Conclusions. In the context of energy supply systems the operationalisation of sustainable development could mean for industry and engineers leading technology assessment studies especially environmental impact assessments of technological applications. Recognised environmental impacts associated with different economic activities have increased the general interest of engineering scientists for using and developing methods and tools of technology assessment. In order to better understand potential environmental impacts such tools should be applied with the final goal of reducing these impacts or even of avoiding them from the very beginning. It is without question that industrial activities have the direct goal to support increasing humanity quality of life, nevertheless beside their positive impacts, these can also have negative, and sometimes unthinkable ones on environment and society. Energy supply systems based on coal-fired power plants have their undoubtful usefulness regarding electric energy supply, their spin-off being but unwanted impacts on environment, as it has been emphasised in this article by air pollution through CO_2-emissions. On the other side there are several tools of technology asessment in order to evaluate potential impacts of economic activities with the goal to try improving energy supply processes. Applying way of such methods has been emphasised, where assessment difficulties and advantages of applying technology assessment methods for assessing environmental impacts of energy supply systems have been pointed out. Appropriate strategies for reducing corresponding environmental footprint of produced electric energy have been emphasised. It has been clear that main role is played by aspects related to human mentalities related to the usage way of diverse devices consuming electric energy. The field of changing human mentalities regarding the usage way of such devices and services is much more complex than obtaining a less pollutant industrial process and overrun technical competencies of engineers. In this field interdisciplinary cooperation would be foremost necessary for optimizing energy supply systems, and by this for getting less environmental impacts.

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