Tomasz Nitkiewicz

INCORPORATING SPATIAL PLANNING ASPECTS INTO A DEA-BASED METHODOLOGY FOR SUSTAINABILITY EVALUATION OF ENERGY SYSTEMS

The concept of sustainable development has recently spread out on all the areas of human activity, providing the new paradigms and specific rules for each of them. The report of the World Commission on Environment and Development (Brundtland) for the first time has specified the essence of sustainable development as an enabling strategy "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). One of the key features of sustainable development is the integration of three elements: economic growth, social cohesion and natural environment protection. Lastly, he concept of sustainable development has recently become the major priority of worldwide policy thanks to global engegement of policy makers and international institutions. And that development is sustainable, and promises balanced growth, just distribution of wealth and care for the future.

SUSTAINABLE ENERGY DEVELOPMENT

TSustainability is a complex concept of world development and it requires worldwide commitment to its implementation. Therefore, to make sustainable development real the involvement of every interest group is absolutely necessary. It means that every country, every branch, every enterpirse or even every single person has to respond to the sustainability call. Only complete global involvement will bring true effects. These are the reasons why sustainable energy development is critically important particularly considering the importance of energy for future global development. Thus the provision of adequate energy services at affordable costs, in a secure and environmentally benign manner, and in conformity with social and economic developmental needs, is an essential element of sustainable development. This was recognised by Agenda 21. In this respect, Chapter 9 of the Agenda clearly states:

Energy is essential to economic and social development and improved quality of life. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption, and on growing reliance on environmentally sound energy systems, particularly new and renewable sources of energy. All energy sources will need to be used in ways that respect the atmosphere, human health, and the environment as a whole (IOŚ, 1998).

But current energy systems are not sufficiently reliable or affordable to support widespread economic growth. The productivity of one-third of the world's people is compromised by lack of access to commercial energy, and perhaps another third suffer economic hardship and insecurity due to unreliable energy supplies; wide disparities in access to affordable commercial energy and energy services are inequitable, run counter to the concept of human development and threaten social stability (UNDP, 2000).

The following criteria are proposed in order to provide energy with sustainability boost (OECD/IEA , 2001):

- Energy policies must balance the economic, social and environmental dimensions of sustainable development.
- They must contribute to the management of risk and the improvement of flexibility, in order to avoid serious disruptions of the energy system and the economic, social and environmental systems in which it functions.
- Energy policies should result from processes in which information and research are consciously managed and decision-making is well integrated, with broad stakeholder involvement.

Energy services are essential for sustainable development. The way in which these services are produced, distributed and used affects the social, economic and environmental dimensions of any development achieved. Although energy itself is not a basic human need, it is critical for the fulfillment of all needs. And lack of access to diverse and affordable energy services means that the basic needs of many people are not being met.

ENERGY AND SUSTAINABILITY: KEY FEATURES

Energy has deep and broad relationships with each of the three pillars of sustainable development – the economy, the environment and social welfare. It remains a strategic commodity: social and economic development can be attained only so long as a secure, reliable and affordable supply of energy is ensured. Energy services help to fulfil basic needs such as food and shelter. They contribute to social development by improving education and public health and, overall, help alleviate poverty. Access to modern energy services can be environmentally beneficial, for example, by reducing deforestation and decreasing pollution through more efficient energy use (WEHAB, 2002).

These different dimensions are intrinsically linked. Sustainable development is dependent upon balancing the interplay of policies and their effective implementation to achieve economic, environmental and social needs. Economic growth requires a secure and reliable energy supply, but is sustainable only if it does not threaten the environment or social welfare. Environmental quality is more readily protected if basic economic needs are also met, and social development needs both economic growth and a healthy environment. Sometimes the policies are mutually reinforcing and sometimes they are in conflict, and trade-offs will often need to be made. Lower fuel prices widen access to energy, but also encourage inefficient utilisation of energy resources and accelerated resource depletion. Conversely, if energy prices are raised too quickly in an effort to combat environmental concerns, energy may become too costly and thus placed beyond the reach of those who need it most.

The path to a more sustainable energy future is not static. It must be continuously redefined and rebalanced with revised forecasts, reassessment of progress, identification of new problems and the development of new technical solutions and technologies. All countries – developed and developing – will need to design their own policy mix; it is clear that national circumstances will affect the scope for action and the appropriate policy choices in and between countries. The policy makers' task is to assess the risks to, and from, today's energy systems. They must determine what changes would advance economic, social and environmental objectives. Policymakers must look to the long term, taking action today to avoid longer-term social, economic or environmental disruptions, while retaining flexibility to alter the course of action when the existing path proves to be unsustainable.

Projecting the current energy situation and energy policies into the future suggests growing pressures on the global economy and the environment. Governments need to develop policies to address the projected 57% increase in the predominantly fossil-fuel based global energy demand over the next 20 years (OECD/IEA , 2001). Governments also need to take action to modify longer-term trends in greenhouse gas emissions within the framework of the United Nations Framework Convention on Climate Change. Policies will need to take into account that the energy demand of non-OECD countries will soon surpass that of OECD countries, and that developed countries' already high levels of energy demand will continue their upward trend.

Policies will also need to address potential decline in energy security as the sources of oil and gas production become more concentrated in regions of geopolitical uncertainty. Capital markets and governments will need to seek ways to mobilise the enormous resources to meet growing energy needs.

Sustainability demands that we seek to change present trends. The challenge is to fuel world-wide economic growth with a secure and reliable energy supply, without spoiling our environment. It is possible. Energy supply needs to be further de-carbonised, diversified and the energy intensity of economic growth reduced. Global energy security can be enhanced through collective efforts and efficient but well-regulated markets can make energy affordable.

The transition to a sustainable energy future will be complex and will take time. And we need to change not only the structure of the energy sector, but also behaviour in our societies and economies. But what is the relationship between energy and spatial planning? The relationship is two-directional. Firstly we need to consider the needs resulting from spatial structure and habitat density. The higher the density and the larger the number of energy consumming facilities the higher the demand for energy. Moreover, spatial structure also influences the type of energy producing facilities that are mostly desirable or adequate to meet social needs. For example, high density urban forms would prefer combined heat and power systems, which provide them simultanously with heat and power. It is important to mention that not only the type of energy facilities is considered but also its efficiency. On the other hand, energy structure is highly dependent on landscape, resources availability or climate conditions. Therefore, the choice of energy supply installations is limited to those that meet basic spatial criteria.

TOWARDS A SOLUTION

IEA has identified some conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable development. These include (OECD/IEA , 2001):

- Safeguarding energy supplies;
- Promoting further improvements in energy efficiency;
- Ensuring that energy markets operate in a competitive and transparent manner with minimum distortions;
- Creating a stable framework for decision-making, one that includes clear signals to the market;
- Continuing to liberalise energy markets with frameworks to protect the environment and enhance social welfare;
- Encouraging the systematic introduction of the best technological solutions where energy investments are made;
- Participating in a global effort to provide electricity for those currently without access;
- Ensuring high safety; and
- Sponsoring energy research and development, information exchange and dissemination.

The focus of this paper is on the different aspects of energy efficiency and its possible improvments. The efficiency is treated widely here and could comprise not only technical or technological aspects but also social or environmental ones. Considering energy efficiency in such a vast way the assumption could be made that it is one of crucial conditions for sustainable energy development to which I turn to next

SUSTAINABLE ENERGY MANAGEMENT

Summing up sustainable energy development is one of the areas of global sustainability, embracing technological, environmental, economic and social aspects of energy production and use. The process of the implementation of sustainable energy development priorities requires conceptual and physical support and control on different levels of management. All managerial activities, being the driving forces for making energy sectors more sustainable, could be called "sustainable energy management". The levels of sustainable energy management reflect the structure of a given energy sector and could be classified using geographical, economic or generic criteria. No matter which criteria are used the management process starts on the most general and global level, where strategic issues and basic objectives are defined, and ends on the single-plant level, where the real actions are undertaken to realize these strategic objectives. It is important to notice the significant difference between sustainable energy management on these two levels mentioned. Global level management uses strategic planning as a main tool, while single-plant level uses recources, policy guidelines and requirements to act operationally and implement the strategy. Global level sustainable energy management concentrates on the public welfare and on providing clean and cheap energy for every citizen, and therefore has to confront both sides of equilibrium: supply and demand. Single-plant level concerns mainly corporate sustainability, with all its economic, social and environmental aspects, which generally implies it is only concerned with the supply side of the equilibrium.

To illustrate the dependence between the management levels we can consider the Polish electricity production sector. The two-level division presented here is used only to visualize the concept. In practice, management structures are more complex and extensive. Policy level responsibilities lie with competences within government and its sector-specific agendas it is also influenced by worldwide energy policy and international committments. Single-plant level concerns only electricity producers and their decision-making capabilities, which are, in fact, highly afected by nationwide energy policy. What's more some competences lie with regional governments, which represent the national government interests in a particular region, but which, on the other hand, are also responsible for developing their own energy policy. Thus, sustainable energy management is quite a complex issue and involves a number of decision-makers and interest groups.

APPROACHES TO SUSTAINABLE ENERGY DEVELOPMENT EVALUATION

The process of implementing sustainable energy management requires constant verification and improvement. Therefore, different types of indicators and measures are needed to evaluate the whole process and to identify its progress and key problems. In order to develop indicators of sustainable energy development (ISED) the concept of three dimensions of sustainability was used. The following 16 topics have been identified as the main issues to be addressed in connection with sustainable energy development under different dimensions of sustainability (Piontek, 2002):

Social dimension:

- Energy disparities
- Energy affordability and accessibility

Economic dimension:

- Economic activity levels
- Energy production, supply and consumption
- Energy pricing, taxation and subsidies
- End-use energy intensities
- Energy supply efficiency
- Energy security

Environmental dimension:

- Global climate change
- Air pollution
- Water pollution
- Wastes
- Energy resource depletion
- Land use
- Accident risks
- Deforestation

Additionally the institutional dimension was added in order to provide sustainability implementation activities with organizational and administrative support.

Figure 1 is a simplified illustration of the interrelations between these various sustainability dimensions of the energy system. The environmental state associated with the energy system results from the impact of driving forces originating from the economic and social dimensions of the energy system. The social state of the energy system is, in turn, influenced by certain driving forces originating from the economic dimension of the energy system. The institutional dimension can affect all three other dimensions - social, economic and environmental – through corrective response policy actions affecting the sustainability of the whole energy system.

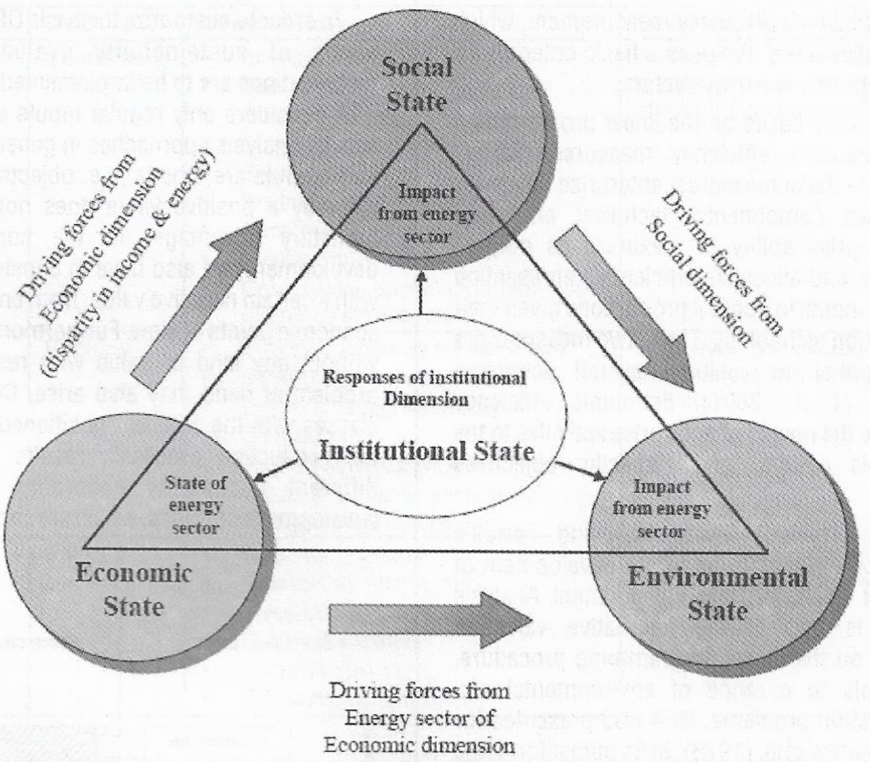

Figure 1. **Energy in the context of sustainable development** (Source: IAEA/IEA, 2001)

A new conceptual model, specifically tuned to the energy sector, was developed to identify and categorise ISED in a framework consistent with the environmental models of the OECD, the EC, and the IEA. The new model is based on the "cause, symptom, and solution" approach, which is in close conformity with the DSR framework and in keeping with all the four dimensions of sustainable development. And it provides a systematic scheme for identifying the cross linkages among various indicators of sustainable energy development (IEA, 2002). ISED model arranges the identified DSR indicators and the links among them according to the economic, social and environmental dimensions of sustainability. The indicators identified for the institutional dimension are classified only as corrective policy measures or Response Actions, which are determined by State indicators of the institutional dimension together with additional State indicators of the other three sustainability dimensions.

The Driving Force indicators in this framework have been split into two sub-categories: Direct Driving Forces and Indirect Driving Forces. This allows a distinction to be made between the factors which have a direct influence on the State indicators (Direct Driving Forces) and those (Indirect Driving Forces) which affect the State indicators indirectly by influencing one or more Direct Driving Forces. Besides providing a better understanding of the inter-linkages among various indicators, this approach is helpful in keeping the number of Direct Driving Force indicators limited for each dimension of sustainability. The model also helps identify for each Response Action (with a few exceptions), the primary target Driving Force indicator of the corresponding sustainability dimension as well as the set of other Driving Force and State indicators on which the Response Action would have a positive impact. The ISED conceptual model is appropriate to the implementation of sustainable energy development on a global level. It concerns all aspects of energy production and use from the perspective of a whole energy system.

DEA APPROACH TO EFFICIENCY EVALUATION

These kind of indicators presented above are not always enough to measure sustainability of energy sector companies. Their construction offers us only pure values of certain variable or eventually only a portion of two of them. In order to evaluate companies' level of sustainability we also need some more complex measures. In fact, a number of them could be used here. The majority of the attempts to measure corporate sustainable development fall into one of five categories, namely using standardized economic criteria, physical impact categories, linear programming methods (such as productive efficiency), economic valuation methods on its own or as part of business management review processes.

Special efficiency measures seem to offer wide cover for sustainability aspects. Therefore, I have elected to use linear programming methods to evaluate the energy sector from a sustainability point of view. That choice also is justified by its feasibility to efficiency measurement, which already has been discussed above as a basic criterion for sustainable development in energy sectors.

Methods, which are based on the linear programming procedure, use Farrell's efficiency measures (Farrell, 1957). According to these measures, enterprise efficiency is built upon two components: technical efficiency, representing enterprise ability to maximize its outputs using given inputs, and allocative efficiency, representing its ability to use its inputs in optimal proportions given their prices and production technology. These two measures are often joined together to evaluate overall economic efficiency (Coelli et al., 2001). Economic efficiency measures compare the results of enterprise activities to the optimal achievable results, given specific objectives (Cherchye, 2001).

Nonparametric efficiency analysis using Farrell's measure has become popular due to the development of Data Envelopment Analysis. Data Envelopment Analysis (DEA hereafter) is one of the alternative valuation techniques based on the linear programming procedure, which is applicable to a range of environmental and sustainability valuation problems. DEA was presented for the first time by Charnes et al. (1978). In its purest form, the unique valuation principle of DEA does not depend on either stated or revealed preferences. Rather, it reexamines the value problem and asks what kind of prices would favour this particular firm or project.

DEA is a method to deal with productivity or efficiency evaluation when multiple inputs and outputs need to be taken into account. The relatively new approach embodied in DEA does not require the user to prescribe weights to be attached to each input and output, as in the usual index number approaches, and it also does not require prescribing the functional forms that are needed in statistical regression approaches to these topics.

DEA utilizes techniques such as mathematical programming which can handle large numbers of variables and relations (constraints) and this relaxes the requirements that are often encountered when one is limited to choosing only a few inputs and outputs because the techniques employed will otherwise encounter difficulties. Relaxing conditions on the number of candidates to be used in calculating the desired evaluation measures makes it easier to deal with complex problems and to deal with other considerations that are likely to be confronted in many managerial and social policy contexts. Moreover, the extensive body of theory and methodology available from mathematical programming can be brought to bear in guiding analyses and interpretations. It allows also for the reduction of the data noise and external influences on the results (Golany and Roll, 1989). It also can be brought to affect existing computations because much of what is needed has already been developed and adapted for use in many prior applications of DEA as well as in sustainability measurement.

In order to customize the basic DEA methodology to the needs of sustainability evaluation some crucial modifications are to be implemented. First of all traditional DEA considers only regular inputs and outputs. DEA and activity analysis approaches in general assume that inputs and outputs are 'goods', i.e. objects with a positive value whereby a positive value does not necessarily mean a monetary advantage. In the context of sustainable development, we also have to consider 'bads', i.e. objects with a certain negative value, from environmental, social or economic points of view. Furthermore, 'neutrals' as objects without any kind of value with respect to the decision problem at hand may also arise. Combining these three classes with the criteria, "positioned as input or output in the production process", results in six categories of different desirability according to the sustainable development priorities, which are shown in the Figure 4.

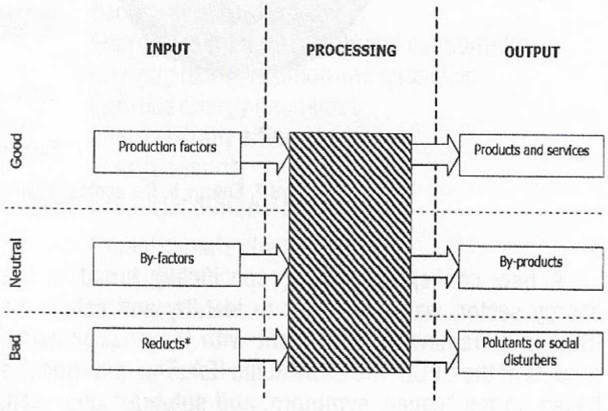

Figure 2.

Categorisation of sustainable development relevant objects according to the standard DMU case

(Source: own elaboration based on ALLEN, 1999)

As shown on Figure 4, only some of inputs are minimized. From the point of view of sustainable development some of the inputs are maximized while others remain unchanged. That is, all the outputs are not maximized because they are not significant for efficiency purposes.

The customization presented above only involves variables. But in order to include them into DEA some transformations of DEA models are required. Two kinds of transformations are used here. First, one is based on decomposing overall productive efficiency into several components, like those presented by Färe et al. (1995 and 1996). Second, transformation is based on the measurement of the sustainability of development by several types of indicators, encompassing different aspects of sustainability as presented in Callens and Tyteca (1998).

They derived an indicator defined as a ratio between a weighted sum of quantities that are considered desirable, to a weighted sum of quantities that are viewed as inputs and whose intervention has to be minimized. Later, Tyteca

	Level	DMU	Competences	Evaluation areas
Stage 1	International	Countries	▪ Energy policy ▪ Fuel supply ▪ Energy sources ▪ Supply-demand equilibrium ▪ Energy safety ▪ Environmental energy policy ▪ Price policy ▪ Availability ▪ Countrywide spatial arrangements of energy infrastructure	Pointing out general directions of sustainable energy development and identifying major threats and drawbacks
Stage 2	National	Regions	▪ Energy-supporting infrastructure ▪ Investments policy ▪ Environmental monitoring ▪ Distribution ▪ Availability ensurance ▪ Local spatial arrangements of energy infrastructure	Identyfying the efficiencies and inefficiences in the electricity production structure
Stage 3	National	Plants	▪ Risk management ▪ Operational efficiency ▪ Investments needs ▪ Business partners ▪ Social responsibility ▪ Economic performance	Measuring the different aspects of efficiency of single power and CHP plants

Table 1. **Characteristics of the efficiency evaluation process of Polish electricity production sector**

(1999), continues to exploit the ratio concept and derives several indicators that encompass different aspects of sustainability.

Before explaining the methodology we have to make some assumption. First of all, most of the authors (e.g. Callens and Tyteca, 1998) agree that so far it is not possible to define any indicator based on sufficient conditions for sustainable development of the company. But instead, it is possible to build up indicators on the necessary conditions that firms must fulfill in order to be sustainable. Necessary conditions are viewed as being efficient in the use of resources, in the pollutants released to the environment, in the social role played by firms as reflected by their rate of employment in the working conditions, and in the care taken with respect to future generations in the negotion of long-term objectives.

Secondly, sustainability implies efficiency with respect to some targets. But because it could be difficult to define such targets in reference to a more global level, we consider efficiency with respect to some observed level of technology. In this context if we consider a set of industrial subsystems performing the same kind of production using the same kinds of inputs, some will perform better than others as judged by certain prespecified criteria. Units in this set, which are fully efficient of course, cannot be immediately considered as sustainable. But, on the other hand, they can be identified as more sustainable than the inefficient ones. Therefore, indicators provided allow us to rank the industrial subsystems relative to each other and give recommendations about where improvements are possible and where priority efforts should be made.

STAGES OF EFFICIENCY EVALUATION OF ENERGY SECTOR

Since sustainable energy development depends on the commitment of different decision-making level units, the efficiency evaluation of the energy sector in Poland is divided into 3 stages. Every stage represents different perspectives on energy development and management. General idea of the approach used to divide the evaluation process into stages is presented in Table 1.

As shown in Table 1, efficiency evaluation stages are defined as follows:

- Stage 1. Efficiency evaluation of Polish energy sector as a whole in comparison with its international counterparts
- Stage 2. Evaluation of the internal (regional) structure of Polish energy sector
- Stage 3. Efficiency evaluation of electricity producers

Stage 1 is dedicated to the evaluation of energy efficiency in Poland in the context of international standards and practices. The major objective of this stage is to comapare the energy efficiency of the Polish electricity production sector to its international counterparts. It is important to notice that this kind of comparison should be made with highly similar technology used by the examined countries. Therefore, it is essential to limit the number of countries to those with similar technologies to ensure a proper reference set. The efficiency evaluation, here, shows what aspects of the Polish energy sector lags behind world leaders and where intervention is needed and highly recommended.

Stage 2 is constituted internally and is determined by the administrative division in Poland. In which case, for the purposes of this research, regions were assumed as decision-making units. Justification of such an approach lies in regional diversification on the grounds of electricity production on the one hand, and in regions' competences in regulating energy markets on the other. The results of efficiency evaluation here will refer to the internal sustainability of electricity production and its adjustment to demands.

Stage 3 refers to lowest level of energy sector management and involves single plants as decision-making units. Of course, the decisions of managerial boards in power plants are highly dependent on general energy policy. But still there is a strong and significant margin of their autonomy evident when effectiveness and efficiency evaluation is concerned; detailed models of this process have been presented elsewhere (Adamczyk & Nitkiewicz, 2007:125-143).

DEA-BASED MODELS FOR EFFICIENCY EVALUATION

Every DEA model covers different aspects of sustainable energy development. The division was based of the three pillars of sustainable development: economic growth, social cohesion and environment protection. Therefore, at every stage DEA-based models are used in order to obtain efficiency scores describing economic, social and ecological aspects of sustainable energy development.

Table 2 presents the characteristics of all the DEA-based models used for the evaluation of energy efficiency in Poland. Every model is characterized by its type (decomposing, ratio or classic DEA model), dimension (environmental, social or economic) and variables used and their assignment. In fact, variables and their assignment have vital significance for the interpretation of the results obtained. It is also important to mention the difference between the efficiency scores obtained from varying models. From decomposing models we get efficiency scores dedicated to one of the variables only. Efficiency scores obtained from classic DEA models cover all the inputs equally. Finally, scores obtained from ratio

	Sustainability aspect	Model class	Variables used			
			Inputs	Outputs	Undesirable outputs	Reducts
Stage 1	Economic	Decomposing model	▪ coal use ▪ installed capacity	▪ electricity production	▪ **electricity losses**	
	Social	Decomposing model	▪ coal use ▪ installed capacity	▪ **electricity consumption** ▪ electricity production		
	Environmental	Decomposing model	▪ coal use ▪ installed capacity	▪ electricity production	▪ **CO_2 emissions**	
Stage 2	Social	Classic DEA model	▪ **coal use** ▪ **installed capacity**	▪ electricity production		▪ employment
	Environmental	Decomposing models	▪ coal use ▪ installed capacity ▪ employment	▪ electricity production	▪ **pollutants emissions**	
	Environmental	Ratio models	▪ **coal use** ▪ **installed capacity** ▪ **employment**	▪ **electricity production**	▪ **pollutants emissions**	
	Environmental	Classic DEA model	▪ **coal use** ▪ **gas use** ▪ **other fuels use** ▪ **installed capacity** ▪ **employment**	▪ electricity production		
Stage 3	Economic	Classic DEA model	▪ **installed capacity** ▪ **employment**	▪ **electricity production** ▪ **ratio of CO_2 emissions allowance to the actual emissions**		
	Social	Classic DEA model	▪ **installed capacity**	▪ electricity production		▪ employment
	Environmental	Decomposing models	▪ installed capacity ▪ employment	▪ electricity production	▪ **CO_2 emissions**	
	Environmental	Ratio model	▪ **installed capacity** ▪ **employment**	▪ **electricity production**	▪ **CO_2 emissions**	
	Spatial	Classic DEA model	▪ **installed capacity** ▪ **employment** ▪ **transport of fuel**	▪ electricity production		
	Spatial	Ratio model	▪ installed capacity ▪ employment ▪ transport of fuel	▪ electricity production	▪ **CO_2 emissions**	

Bold fonts indicate investigated variable

Table 2. **Charateristics of DEA-based models proposed in the efficiency evaluation**

models are related to all the variables used. Thus the interpretation of every model is determined by its assignment variables, but the interpretation also is strongly linked to the type of model used.

To widen the analysis of spatial planning issues additional models were constructed. It is not an easy task to find variables that can fit DEA requirements and at the same time can describe the spatial aspects of sustainability in a proper way. Some of the potential variables have been investigated. But, for the moment, one of the potential variables is the distance (km) between the energy producing facility and the coal mine. The significance of it, from a spatial planning perspective, is to measure the conformity of the energy production method used against the availability of resources. This has some wider interpretation for the ecological and economic context of spatial planning. That is, bringing the power facilities closer to the coal mines will significantly decrease the transportation costs and partly eliminates the pollution emmisions from transportation.

CONCLUSION

Presented models do not cover all aspects of the Polish electricity production sector and its orientation on sustainability. The above proposed methodology could be used to deepen future research. But this only would be possible if reliable information on other variables is available (for all units taken into account). Nevertheless, bearing in mind that the main objective of the research is related to the performance of whole sector, we can avow that the results obtained are significant enough to be used in the evaluation of energy efficiency in the context of sustainable development. And thanks to the above proposed methodology, sustainable energy management is provided with vital information that can be useful to all sustainable energy management levels.

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