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Evaluating Economic Externalities of the Energy Development: a Comparison of IO and CGE Models

Vidas Lekavičius, Arvydas Galinis
Lithuanian Energy Institute, Lithuania

Abstract: *Input-output (IO) models are the most popular and relatively simple method for the evaluation of economic externalities of the energy development, but the limitations of IO analysis might result in overestimation of possible positive impacts (jobs created, etc.).On the contrary, computable general equilibrium (CGE) modelling is quite complicated in terms of initial cost of application, but it could provide more reliable results. Therefore, the choice of relevant methodological framework in real applications must balance easiness of application and reliability of results. In this paper, we apply both methods for the same case in order to assess the reasons of differences in results. The comparison of models shows that the main differences are caused by partial equilibrium and fixed prices assumptions in the IO model. Therefore, its application is relevant only in cases when the markets of interest are modelled. The magnitude of differences in results obtained from different models depends on both the specification of a particular case and additional assumptions that are used in more complex model.*
Keywords: *Computable general equilibrium, economic externalities, energy development, energy economics, input-output analysis.*

I. Introduction

The development of the energy sector as well as any other activity is related with some additional effects or externalities. The main attribute of an externality is the fact that the difference between private and societal cost and benefit is neither internalised by market forces nor makes considerable impact on the decisions that are made by economic actors. Theoretically, the externalities could be classified according to their impact direction (positive, negative), type (consumption, production externalities), impact area (environmental, health, economic externalities), etc. Economic externalities, which are in the focus of this paper, may have impact on economic indicators either directly or through economic relations. New jobs created or impacts on tax collected to the budget might be mentioned among examples of economic externalities. Evaluation of such effects is not a straightforward task due to the fact that it covers not only the projects or sectors under consideration, but also their interdependencies or economic relations with the remaining economy. Thus, not only the properties of a particular project must be analysed, but also the structure of the economy and possible interactions of economic agents.There exist different methodologies which are employed in the analysis related to economic externalities: direct impact analysis, input-output (IO) analysis, computable general equilibrium (CGE) modelling, and econometric modelling. Direct impact analysis is probably the least complicated approach, but it is limited to the close environment of projects analysed. Thus, it is valid do state that it deals only with a part of the real breadth of economic externalities. Moreover, direct impacts not necessarily correlate with the total net impacts: impact directions may even be opposite. Therefore, direct impact analysis could serve only as a ground for more comprehensive analysis. Econometric models might be built in different complexity levels from relatively simple spreadsheet-based models to econometrically estimated CGE models. The main disadvantage of econometric modelling is the need of high quality time series which availability is often limited. Also, the fact that time series data in principle fail to reflect the impact of relatively new or emerging technologies can limit the applicability of econometric modelling [1].

The most popular methods in the field are IO analysis and CGE modelling. Input-output analysis is relatively simple method for the evaluation of economic externalities of the energy development, but the limitations of IO analysis might result in overestimation of possible positive impacts (jobs created, etc.). On the contrary, computable general equilibrium modelling is quite complicated in terms of initial cost of application, but it could probably provide more reliable results.Researchers compare the results obtained using different methodological frameworks since these methods have been developed and comparisons are done in different areas such as water scarcity [2], regional disaster [3] and tourism [4]. However, their results are heavily dependent on the specifications of the models used. Thus, the more "pure" analysis is needed. Also, the more relevant practical question should be focused on the balance between easiness of application and reliability of results. In other words, the choice of the most suitable methodological approach must take into account not only the quality and theoretical completeness, but also the cost of application. The nature of this kind of multi-criterial decision is also captured by G. R. West, who states that the choice between a simple and easily understandable model versus a more complex and more theoretically appealing model depends on the application [5]. This is also the case with disaggregated models: usually, disaggregation provides some additional benefits in terms of accuracy and, sometimes, new insights, but too much detailed analysis has is not performed due to high cost or data limitations. The purpose of this research is to assess the reasons of differences in results of evaluation of economic externalities caused by the development of the energy sector based on IO analysis and CGE modelling. For this, we apply both methodologies to study the same case and compare the results obtained. Such approach gives an opportunity not only to analyse the situation in a particular case, but also to draw more general conclusions regarding the use of different methods. In this research we are trying not only to analyse a particular energy economics case, but also to look to the general situation and possibilities for conclusions for the remaining sectors.The remaining part of this paper is structured as follows: second section provides the overview of the methodological approaches considered, third section presents the case analysed, and fourth section is devoted to the results and discussion. The conclusions are drawn in the fifth section.

II. IO and CGE for the Analysis of Economic Externalities

The origins of both IO analysis and CGE modelling lie in the same early works. The first elements of the principles that are used in these methods can be found in Francois Quesnay's "Tableau économique" and Leon Walras' "Elements of Pure Economics". In modern age, the works of Wassily Leontief and Ragnar Frisch were among the initial impulses to develop the contemporary understanding about the significance of intersectoral relationships and input-output analysis [6]. CGE models have been started to develop after Second World War and Leif Johansen's MSG model of Norway, published in 1960, is now usually recognized as the first CGE model [7].In principle, IO analysis could be treated as predecessor of CGE modelling at least in terms of basic principles for reflection of intermediate consumption and the idea of economy-wide analysis. Therefore, it is worth to start the description of both analytical approaches with the presentation of the structure of an input-output table and the main identities it involves. The simplified structure of an input-output table is presented in Table 1.

Table 1. The basic structure of an input-output table

		Intermediate production			Final consumption by government, households etc.	Fixed capital formation	Total final demand	Total output (use)
		Activity 1	…(*j*)	Activity n				
Intermediate inputs	Activity 1	x_{11}	…	x_{1n}	F_1	GF_1	Y_1	X_1
	… (*i*)	…	…	…	…	…	…	…
	Activity n	x_{n1}	…	x_{nn}	F_n	GF_n	Y_n	X_n
Added value		V_1	…	V_n				
Total domestic output		DO_1	…	DO_n				
Imports		Imp_1	…	Imp_n				
Total input (supply)		X_1	…	X_n				

Each row in input-output table shows consumption of production by different actors (economic activities, institutional sectors, etc.). The consumption can be either intermediate (when product is used to produce other products in activities or commodities in case if commodity by commodity IO table is used instead of activity by activity version) or final (when commodities are consumed in institutional sectors (government, households, rest of the world) or in formation of fixed capital). This can be expressed by the following equation:

$$\sum_{j=1}^{n} x_{ij} + Y_i = X_i \qquad (1)$$

Total final demand is equal to the sum of final consumption by institutional sectors and fixed capital formation:

$$Y_i = F_i + GF_i \qquad (2)$$

Similar equation could be used in order to provide an explanation of formation of columns (cost structure of each sector):

$$\sum_{i=1}^{n} x_{ij} + V_j + Imp_j = X_j \qquad (3)$$

If commodity market is cleared (in praxis, changes in inventories are balancing elements), total input must be equal to total output (sum of rows in the column must be equal to the sum of columns in the row):

$$X_i = X_j \qquad (4)$$

The use of each particular input in the production of certain commodity is reflected by technical coefficients:

$$a_{ij} = \frac{x_{ij}}{X_j} \quad (5)$$

Economic linkages can also be expressed in a matrix form:

$$X = AX + Y \quad (6)$$

In equation (6) X is total output matrix, A – technical coefficients matrix, and Y – total final demand matrix. This equation can be reformulated into the core equation of input-output analysis:

$$X = (I - A)^{-1} \times Y \quad (7)$$

Here *I* is the identity matrix (a matrix with 1 on the main diagonal and 0 elsewhere). The matrix $(I - A)^{-1}$ is known as the Leontief inverse or the total requirements matrix [8]. The elements of the total requirements matrix measure the direct and indirect output levels from each sector of the economy required to satisfy the given levels of final demand [9].

Classical form of IO analysis has not too much to do with prices, which are assumed to be stable. However, prices are included in every element of IO table if it reflects monetary flows. In that case the following identity is valid:

$$x_{ij} = q_{ij} \times p_{ij} \quad (6)$$

Here q_{ij} is a quantity of products in physical units and p_{ij} is a price per physical unit of a certain product. In this way, input-output tables cover not only monetary but also physical flows. Also, it is worth to note that in principle IO models could be formulated not only in matrix form reflected by equations (6) and (7), but also as linear programming problems. In the context of evaluation of economic externalities of the energy development this option is very attractive due to the possibility to integrate IO analysis into such traditional energy planning models as TIMES, MESSAGE, etc.

Putting simply, computable general equilibrium extends input-output framework by covering economic transactions in the entire economy and allowing for price changes. This is done by using flexible mathematical functions (Cobb-Douglas, Constant elasticity of substitution, etc.) that allow for substitution among different production factors, commodities consumed and other elements (depending on the specification of the model) and by using social accounting matrices (SAM) instead of IO tables. The shift from IO analysis to CGE modelling is associated not only with the above mentioned extensions, but also quite a big amount of complexity, the need to use superior computational and analytical capabilities.As mentioned, using either IO or CGE modelling in the analysis of different economic externalities is quite common, but it is worth to note, that economic externalities are in some papers called differently: economywide effects [10], full effects [11], cost and benefits (according to the extended understanding of their concept) [12], economic impact [13, 14], economic and social impact [15], social impact [16], impact on the economy [17], macroeconomic effects [18], welfare impacts [15, 19, 20]. However, all these notations fall into concept of economic externalities inasmuch as they are not the main driver of the decisions that are made.

The literature which analyses the application of different methods is not very common as it requires ability to employ these methods in specific cases. For instance, a comparison of CGE and IO models in the field of water scarcity has shown that that the size of production loss in CGE model is lower than in IO model [2]. The similar issues are discussed also regarding the case of regional disaster, where the lowest output losses in almost every model set-up is observed in CGE model [3] and tourism – in this case results of IO model are generally higher [4]. Thus, the conclusions set in different cases are quite similar: IO models tend to overestimate or provide higher (positive or negative, depending on the case analysed) impacts, while CGE modelling provides more balanced results. This opinion is also supported by [21] where it is stated that despite its complexity CGE models allow for recognition of resource constraints.The analysis principles are quite similar in both methods: information about counterfactual scenario is depicted in modelling parameters depending on the scenario analysed. In case of the analysis of economic externalities caused by the development of the energy sector, new energy structures are depicted either in IO table or SAM.

III. The Case Analysed and Models Used

The case analysed is vividly illustrated by Fig. 1, which includes base case social accounting matrix and new energy structure to be introduced (ENERGY') on the left. This new energy structure could be interpreted as resulting of the energy development (e.g., different energy production technologies are used in the energy sector).

	PROD1	PROD2	ENERGY	LAB	CAP	HH	
PROD1	3	2	2			2	9
PROD2	1	4	3			8	16
ENERGY	1	3	1			5	10
LAB	1	4	1				6
CAP	3	3	3				9
HH				6	9		15
	9	16	10	6	9	15	
	9	16	10	6	9	15	
	0	0	0	0	0	0	

ENERGY'
4
1
1
2
2

Figure 1. The case analysed

To keep the things as simple as possible, the SAM used here consists of three commodities (PROD1, PROD2, and ENERGY), labour (LAB) and capital (CAP) as production resources, and households (HH) as the representative agent. The new energy structure requires more PROD1 inputs, less PROD2 inputs, while self-consumption of energy remains stable. Also, the new energy structure is less capital intensive and more labour intensive. Commodities together HH as final consumption element form IO table within the SAM which will be further used for the illustration of analysis results. For IO analysis IO table is used and balanced according to the principles described above. The structure of the CGE model is depicted in Fig. 2.

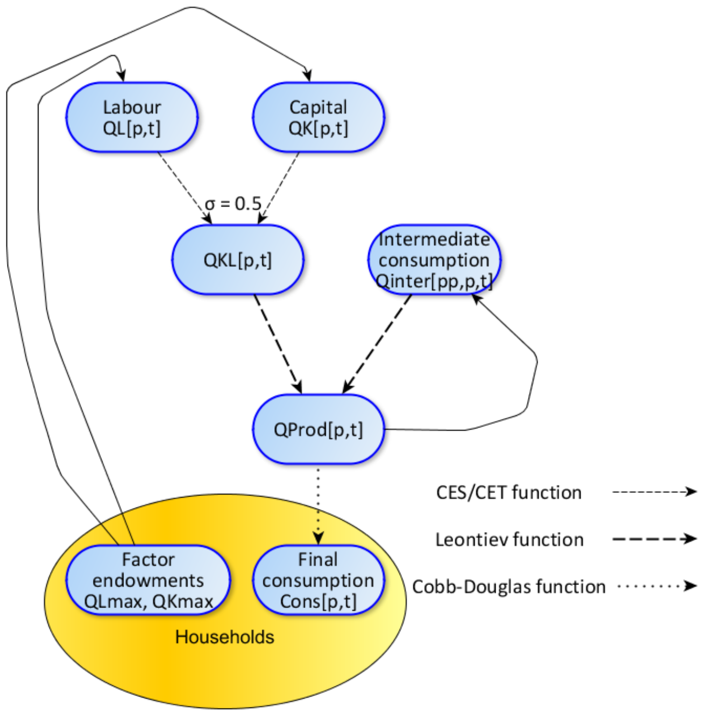

Figure 2. The structure of the CGE model

The production structure in the simple CGE model used here is the same as it is described in the SAM: labour and capital are used as production resources which for composite labour-capital resource using CES function. Composite labour-capital resource is then coupled with intermediate consumption via Leontiev function and consumable product or commodity is formed. This commodity could either be used in final intermediate consumption in order to produce new products or by households who spend their funds that are obtained from selling production resources. The final consumption demand is modelled using Cobb-Douglas function. Initial prices are set to 1, factor endowments reflect the base case levels (QL=6, QK=9) and energy price is set as numeraire The CGE model is formulated as a mixed complementarity problem and, using especially developed tool, implemented in GAMS (General Algebraic Modelling System) [22] environment.

IV. Results and Discussion

The IO analysis assumes fixed prices; therefore changes in the SAM (or the part of IO table) reflect also the physical quantity changes that might be expected as a result of different energy structure in input-output analysis. The results obtained in IO analysis are depicted in Fig. 3.

	PROD1	PROD2	ENERGY'	LAB	CAP	HH	
PROD1	3.818	1.709	3.927			2.000	11.455
PROD2	1.273	3.418	0.982			8.000	13.673
ENERGY	1.273	2.564	0.982			5.000	9.818
LAB	1.273	3.418	1.964				6.655
CAP	3.818	2.564	1.964				8.345
HH				6.000	9.000		15.000
	11.455	13.673	9.818	6.000	9.000	15.000	
	11.455	13.673	9.818	6.655	8.345	15.000	
	0.000	0.000	0.000	-0.655	0.655	0.000	

Figure 3. The results of IO analysis

The comparison of base case SAM (Fig. 1) and counterfactual in IO analysis (Fig. 3) shows that the changes in the energy structure cause changes in intermediate consumption and demand of production resources. The final consumption is not affected by the changes in the energy structure, due to the fact that there is no price signals in IO model. The changes in output of different commodities can be explained by the changes in the energy structure. The consumption of PROD1 increases, because of two factors: increased intermediate consumption in the energy sector, and relatively large consumption of PROD1 in production of PROD1 itself. The output of PROD2 decreases due to opposite reasons, while energy output also decreases by 0.182 units. This change is determined by the fact that PROD1 is less energy intensive than PROD2. As output of PROD2 decreases, the consumption of energy and, consequently energy output also decreases. Another key result that appears from IO analysis is the changes of consumption of production resources. In the left column of the SAM that is depicted in Fig. 3 one can see the demand for labour (6.655 units) and capital (8.345 units). Thus, the demand for labour increases, while the demand for capital decreases, compared to the situation in the base case (Fig. 1). Such demand changes can be explained by similar, but not so straightforward, reasons at it is the case with the consumption of commodities: although PROD1 is less labour intensive than PROD2, the increase of output of PROD1 causes increase of labour use in the production of PROD1 by 0.273 units. Labour demand by PROD2 decreases by 0.582 units due shrinking output of PROD2, and labour demand in energy production increases by 0.964 units. All these changes result in net increase of labour demand by 0.655 units. On the contrary, net demand for capital decreases by the same amount mainly due to decreased demand for capital in energy and PROD2 production. Demand changes not necessarily would result in consumption changes, at least in the case when the availability of resources is limited. In this case, there might be true that there is no means to increase labour supply. As indicated in the lower part of Fig. 3 which is not a part of IO table, labour and capital markets fail to clear. In reality, if the availability of one or another good is limited, its price should increase until the level which satisfies the demand. CGE modelling could help in dealing with such issues as they can provide changes in relative prices. The results of CGE modelling in terms of prices (which have been set at 1 in the base case) are presented in Figure 4.

Relative prices

pL	1.235
pK	0.846
pProd1	0.962
pProd2	1.028
pEnerg	1.000

Quantities

	QProd1	QProd2	QEnerg	HH	Total
QProd1	3.832	1.674	3.909	2.082	11.497
QProd2	1.278	3.349	0.977	7.792	13.395
QEnerg	1.278	2.512	0.977	5.006	9.772
QKL	5.110	5.860	3.909		
Total	11.497	13.395	9.772		
QLAB	1.112	3.102	1.786		6.000
QCAP	4.032	2.810	2.158		9.000

FIGURE 4. Price and quantity changes in CGE modelling

According to the results of CGE modelling, in addition to quantity changes, there are changes in relative prices. Energy price remain stable, inasmuch as it is set as numeraire, but other relative prices are changed considerably. This is first of all related to the demand changes: the relative labour price increases, while capital price decreases. Also, there are some differences in commodity prices, but they are determined by production cost (cost of resources) changes rather than demand changes. Therefore, the price for labour intensive PROD2 increases. In terms of quantities, the results are also different in comparison with both base case and results of IO analysis. In the case of CGE modelling, the output of PROD1 is higher due to positive effect of price decrease which slightly increases final consumption of PROD1. On the contrary, final consumption of PROD2 decreases in association with the price increase.
The social accounting matrix that has been obtained as a result of CGE modelling is depicted in Fig 5.

	PROD1	PROD2	ENERGY'	LAB	CAP	HH	
PROD1	3.687	1.611	3.760			2.002	11.060
PROD2	1.313	3.442	1.005			8.010	13.770
ENERGY'	1.278	2.512	0.977			5.006	9.772
LAB	1.373	3.829	2.205				7.407
CAP	3.410	2.377	1.825				7.611
HH				7.407	7.611		15.018
	11.060	13.770	9.772	7.407	7.611	15.018	
	11.060	13.770	9.772	7.407	7.611	15.018	
	0.000	0.000	0.000	0.000	0.000	0.000	

Figure 5. SAM in the case of CGE modelling

In this case, all the markets clear (the lower part of Fig 5). In other words, there are no market distortions: oversupply of capital and shortage in labour as it was the case with IO analysis.One of the most popular indicators in the analysis of economic externalities of the energy development is the changes in employment levels. In the present case IO analysis shows new jobs created (0.655 units in Fig. 3), while in the CGE model fixed labour endowment is assumed and thus there are no additional work places. On the other hand, positive impact on labour market is reflected by labour price increase and increased flow to LAB in Fig. 5. To sum up, the models used here reflect boundary options when all the effect are either counted as change in physical quantities or only as relative price changes. In this context explicit modelling of labour market by introducing so called wage-curve [23] to CGE models seems to be relevant approach in terms of reflecting real-world conditions.

V. Conclusion

Although CGE and IO methodologies are different in terms of complexity and the cost of application, the basic data requirements for the analysis of economic externalities are quite similar. Therefore, IO analysis could be treated as a basis for more comprehensive analysis. The comparison of simple CGE and IO models presented in this paper confirms the opinion that IO analysis tends to overestimate possible impacts, especially in the case of the use of limited resources. CGE model provides similar results in terms of impact directions, but numerical values are different due to reaching general equilibrium. CGE model is capable to reach market clearing and calculate the impacts on relative price changes. However, due to full employment assumption it is able to provide only a hint about the impact direction in case of imperfect competition in the labour market.The models provide contradictory results in terms of employment levels and the changes in wages (labour price). If the questions related to the particular market (e.g., labour) are analysed, such a market must be modelled explicitly in order to provide both theoretically and practically relevant results.

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