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Changes in Energy Output in a Regional Economy: A Structural Decomposition Analysis

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Abstract

In the input-output literature, structural decomposition analysis (SDA) has largely been used to disentangle changes in key variables over time. This paper uses the demand-driven input-output model and proposes a simple method to decompose the changes in energy gross output into different determinants. Specifically, the total changes in energy output are divided into two elements: technological changes, showing the effects of changing the technological coefficients of the input-output model, and structural changes, showing the effects of changing the final demand components. The empirical application, which is for the Catalan economy, uses two input-output tables that cover an entire decade (2001 and 2011). The results show a positive contribution of technology to increasing energy output, while the contribution of the final demand for energy is negative. In addition, the various energy activities exert a different repercussion on energy gross output changes. This highlights the importance of using detailed methods in the study of energy issues.

Keywords

Energy Output, Input-Output Analysis, Structural Decomposition Analysis, Technological Coefficients, Final Demand.

1. Introduction

Energy has become a strategic issue in the world economy in the twenty-first century. As production activities require energy for use in the transformation processes, energy availability is crucial for ensuring the production of goods and services that consumers demand. Moreover, private welfare is directly related to energy uses and the modern standards of living require increasing energy use.

Energy will face global challenges in the near future, which will require worldwide strategies. First, it will be necessary to fill the gap between energy production and growing energy demand. Second, the development of new forms of energy to ensure reliability, environmental sustainability and inexpensiveness will be crucial. To achieve all these goals, major efforts must be made towards developing alternative energy sources, reducing the environmental impacts of energy production and energy consumption, promoting energy savings, increasing energy efficiency and obtaining new transportation systems.

In recent decades, the input-output model has proved to be a helpful framework for analysing energy issues. For instance, Proops (1988) used the input-output method to define indicators of both direct and indirect energy consumption. Hawdon and Pearson (1995) applied the input-output model to the United Kingdom and showed the interrelations among energy issues, the environment and the economy. Alcántara and Roca (1995) proposed an input-output method for measuring the demand for energy and carbon dioxide emissions in Spain. Lenzen (2001) constructed a generalized input-output model in which investment and imports were separated from final demand and internalized into intermediate demand, and presented an empirical application of energy multipliers for Australia. Manresa and Sancho (2004) estimated sectoral energy intensities and CO_2 emissions for the Catalan economy, using an extension of the input-output model: the SAM (social accounting matrix) model. In addition, Llop and Pié (2008) defined a price version of the input-output model for Catalonia to analyse the economic impact of alternative measures that could be implemented in the energy sector.

The input-output model has also largely been used to unmask the factors that underlie the changes in an extensive set of variables over time, by defining intertemporal approaches. Thanks to the usefulness of the input-output SDA methods, a large set of contributions has been published based on different economies at different periods of time. In particular, the research efforts undertaken to date have provided comprehensive and precise knowledge of the properties of the SDA methods and their usefulness in both economic and environmental research. In this field, Rose and Casler (1996) reviewed the literature produced so far. Dietzenbacher and Los (1998) discussed some of the problems inherent in the non-uniqueness of the computational SDA methods. Dietzenbacher and Los (2000) discussed the possible dependency between decomposed determinants that may lead to incorrect conclusions when the co-related determinants are treated independently. Dietzenbacher and Stage (2006) showed that the hybrid input-output model that combines monetary and physical units may provide results that depend on the choice of units rather than on changes in economic determinants. For environmental SDA methods, Su and Ang (2012) examined the new methodological improvements dealing with energy and pollutant emissions which have been developed in the last decade, and provided guidelines on method selection.

As structural decomposition analysis has proved to be very helpful in unravelling the long-term drivers of economic indicators, a wide range of issues have been analysed in this type of literature. These issues include technological changes, changes in output, international trade issues and changes in private consumption. The SDA has also proved to be extremely useful for disentangling the factors that explain the changes observed in energy, such as the drivers behind energy usages and energy efficiency.

In the contributions on SDA applied to energy, Gowdy and Miller (1987) examined the changes in the US energy uses during the period 1963-1977, taking into account both technological and demand changes. Casler and Hannon (1989) used the energy input-output model to explore the reasons behind the changes in the US energy intensities, distinguishing between the direct and indirect energy substitutions. Han and Lakshmanan (1994) analysed the modifications in Japanese energy intensities between 1975 and 1985, and explicitly defined the contribution of energy imports. Wier (1998) explored the changes in Danish gas emissions during 1966 and 1988, identifying changes in final demand, changes in input-output coefficients, changes in energy intensities and finally changes in emissions from the household sector. Kagawa and Inamura (2001) evaluated the sources of changes in Japanese energy demand between 1985 and 1990. Llop (2007) used an environmental input-output model for Spain to separate the effects of changing the emission coefficients and the effects of changing the input-output structural coefficients within the total changes in emission multipliers between 1995 and 2000. In another study on the Spanish economy, Guerra and Sancho (2011) analysed the effects on energy uses and emission levels caused by efficiency gains, changes in final demand and changes in input requirements. More recently, Lan et al. (2016) compare the global energy footprint by identifying various drivers and its distribution across different countries. This study, which provides unique insights into the energy changes in all countries, is applied to 186 economies and covers the period between 1990 and 2010.

To the best of my knowledge, all the SDA contributions applied to energy focus on explaining the changes in (physical) energy uses and (physical) energy efficiency. Nevertheless, it would be equally interesting to study the drivers behind the (monetary) gross output changes of energy. By taking into account that energy is strategic for the economy and the society, a thorough knowledge about the different forms of energy and its determinants over time is essential for meeting both the economic and social challenges regarding energy.

The purpose of this paper is to identify the underlying factors that contribute to changing energy gross output in an economy, with a particular focus on the various activities that make up the energy sector. In particular, as energy is used by both production activities and final consumers (i.e. households, government and the foreign sector), different economic agents can be responsible for the alteration of energy production. Bearing this in mind, it is interesting to analyse the patterns that explain the changes in energy output, by disentangling the effects caused by the various agents involved (i.e. production sectors and final consumers) and by the two possible sources of demand (i.e. intermediate demand and final demand). This analysis is particularly appropriate for understanding the driving factors in the energy (economic) variables.

The empirical application is for the Catalan economy and uses two regional input-output tables, covering the period 2001-2011. The results show that the decomposed effects behaved differently: final demand contributed negatively to energy output while technological changes contributed positively. As a result of these two (opposed) impacts, energy output experienced a slight increase in real terms during the decade studied. In addition, the various energy activities are very heterogeneous in relation to the individual temporal drivers observed in the regional economy.

The rest of the paper is organised as follows. The next section shows the structural decomposition analysis used to decompose the total changes in energy gross output. Section 3 describes the regional input-output tables used for the Catalan economy, and Section 4 contains the empirical application. Finally, the last section of the paper concludes.

2. Changes in Sectoral Output and Decomposition

The standard representation of the demand-driven input-output model, in matrix notation, is:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{Ly}, \tag{1}$$

where $\mathbf{x}$ is the vector of sectoral gross output, $\mathbf{y}$ is the vector of final demand, $\mathbf{A}$ is a $n \times n$ matrix of technological coefficients (calculated by dividing the industry-by-industry direct requirements by the sectoral output), and $\mathbf{I}$ is the identity matrix. In expression (1), $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{L}$ is the $n \times n$ matrix of input-output multipliers, or the Leontief inverse, and shows the overall effects (direct and indirect) on sectoral output caused by unitary and exogenous increases in the final demand of sectors.

The study of changes in gross output involves a comparison of variables for two different periods of time. These periods are hereinafter denoted using the subscripts 0 (first period) and 1 (last period). Moreover, as the model covers various years, there is the need to remove the distorting effects of price changes on the relevant variables. This means that in order to avoid the influence of prices, all the information in the input-output tables has to be expressed in terms of the prices of a single year.

The so-called double deflation method enables price effects to be eliminated by revealing the changes in variables in real terms. Assuming that each sector produces a single homogenous good, then the sectoral gross output, intermediate demand and final demand are deflated by the corresponding price index for this sector. Let p_i be the ratio of the current price level and the base-year price level for sector *i*. We denote by **P** the diagonal matrix containing the elements p_i on its main diagonal and zeros elsewhere. Expression (1) can therefore be defined in constant prices as follows:

$$\mathbf{x^d} = \mathbf{A^d}\,\mathbf{x^d} + \mathbf{y^d} = (\mathbf{I} - \mathbf{A^d})^{-1}\mathbf{y^d}\,, \qquad (2)$$

where $\mathbf{x^d} = \mathbf{P}^{-1}\mathbf{x}$ is the vector of deflated gross production, $\mathbf{y^d} = \mathbf{P}^{-1}\mathbf{y}$ is the vector of deflated final demand and finally, $\mathbf{A^d} = \mathbf{P}^{-1}\mathbf{AP}$ is the matrix of deflated input-output coefficients.

Let us now assume that all the components in the input-output model are in constant prices and let us also assume an identical sectoral disaggregation in the two periods analysed.[1] By taking the first difference in expression (1), it follows that:[2]

$$\begin{aligned} \Delta\mathbf{x} &= \mathbf{L_1 y_1} - \mathbf{L_0 y_0} \\ &= \mathbf{L_1}(\mathbf{y_0} + \Delta\mathbf{y}) - (\mathbf{L_1} - \Delta\mathbf{L})\,\mathbf{y_0} = \mathbf{L_1}\Delta\mathbf{y} + \Delta\mathbf{L}\mathbf{y_0} \qquad (3.a) \\ &= (\mathbf{L_0} + \Delta\mathbf{L})\mathbf{y_1} - \mathbf{L_0}\,(\mathbf{y_1} - \Delta\mathbf{y}) = \Delta\mathbf{L}\mathbf{y_1} + \mathbf{L_0}\Delta\mathbf{y}, \qquad (3.b) \end{aligned}$$

where $\Delta\mathbf{x}$, $\Delta\mathbf{y}$ and $\Delta\mathbf{L}$ contain the first differences of the elements in vector **x**, vector **y**, and matrix **L**, respectively. Note that although expressions (3.a) and (3.b) are equivalent, the results provided are necessarily different because the weights used to calculate the contribution of the two increased components are different. Dietzenbacher and Los (1998) showed that the average of the two polar decompositions yields a good approximation of the average of all the possible decompositions. In particular, the average of expression (3) is equal to:

$$\Delta\mathbf{x} = \tfrac{1}{2}\Delta\mathbf{L}(\mathbf{y_0} + \mathbf{y_1}) + \tfrac{1}{2}(\mathbf{L_0} + \mathbf{L_1})\Delta\mathbf{y}. \qquad (4)$$

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[1] In what follows, the superscript **d** is avoided for the sake of simplicity.

[2] See Miller and Blair (2009) for a detailed presentation of SDA decompositions of sectoral output.

Next, we can go further in the decomposition of expression (4) by dividing the changes in the matrix of multipliers ($\Delta\mathbf{L}$) into the changes in the matrix of technical input-output coefficients ($\Delta\mathbf{A}$). If both sides of $\mathbf{L_0} = [\mathbf{I} - \mathbf{A_0}]^{-1}$ are post-multiplied by $[\mathbf{I} - \mathbf{A_0}]$ and the derivative respect to time is taken, it follows that:

$$\begin{aligned}
&\Delta\mathbf{L} - \mathbf{L_0}\Delta\mathbf{A} - \Delta\mathbf{L}\mathbf{A_0} - \Delta\mathbf{L}\Delta\mathbf{A} = 0;\\
&\Delta\mathbf{L} - \mathbf{L_0}\Delta\mathbf{A} - \Delta\mathbf{L}\mathbf{A_0} - (\mathbf{L_1} - \mathbf{L_0})\Delta\mathbf{A} = 0;\\
&\Delta\mathbf{L} = \mathbf{L_1}\Delta\mathbf{A}\mathbf{L_0}. \qquad (5.a)
\end{aligned}$$

Alternatively, changing the matrix and the period of post-multiplication gives rise to the following equivalent expression:

$$\Delta\mathbf{L} = \mathbf{L_0}\Delta\mathbf{A}\mathbf{L_1}. \qquad (5.b)$$

By substituting (5.a) and (5.b) into (4):

$$\begin{aligned}
\Delta\mathbf{x} &= \tfrac{1}{2}\Delta\mathbf{L}(\mathbf{y_0} + \mathbf{y_1}) + \tfrac{1}{2}(\mathbf{L_0} + \mathbf{L_1})\Delta\mathbf{y}\\
&= \tfrac{1}{2}(\mathbf{L_1}\Delta\mathbf{A}\mathbf{L_0}\mathbf{y_0} + \mathbf{L_0}\Delta\mathbf{A}\mathbf{L_1}\mathbf{y_1}) + \tfrac{1}{2}(\mathbf{L_0} + \mathbf{L_1})\Delta\mathbf{y}\\
&= \tfrac{1}{2}(\mathbf{L_1}\Delta\mathbf{A}\mathbf{x_0} + \mathbf{L_0}\Delta\mathbf{A}\mathbf{x_1}) + \tfrac{1}{2}(\mathbf{L_0} + \mathbf{L_1})\Delta\mathbf{y}. \qquad (6)
\end{aligned}$$

Following this expression, the changes in sectoral gross output ($\Delta\mathbf{x}$) have been calculated as the addition of two different components. The first component reflects how sectoral output is modified by changes in the technical coefficients of the input-output model, and the second component reflects how changes in final demand modify sectoral gross output. In expression (6), the total changes in production have therefore been disentangled as the aggregation of two components with different economic interpretations: *technological changes* ($\tfrac{1}{2}(\mathbf{L_1}\Delta\mathbf{A}\mathbf{x_0} + \mathbf{L_0}\Delta\mathbf{A}\mathbf{x_1})$) and *structural changes* ($\tfrac{1}{2}(\mathbf{L_0} + \mathbf{L_1})\Delta\mathbf{y}$).

In order to individually quantify the effects of changing all the input-output coefficients used in the model, matrix $\mathbf{\Delta A}$ can be decomposed by showing all the possible modifications that have taken place. In specific terms, the individual effects of technical coefficients can be examined by writing matrix $\mathbf{\Delta A}$ as the following sum:

$$\mathbf{\Delta A} = \mathbf{\Delta A}_{\mathbf{11}} + \mathbf{\Delta A}_{\mathbf{12}} + \mathbf{\Delta A}_{\mathbf{13}} + \ldots + \mathbf{\Delta A}_{\mathbf{nn}} = \mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Sigma}_{\mathbf{j}}\mathbf{\Delta A}_{\mathbf{ij}}, \qquad (7)$$

where each $n \times n$ matrix is made up of the single non-zero entry showing the change in the *ij*th element, Δa_{ij}, and zeros elsewhere.

Additionally, the changes in the vector of final demand can be written as:

$$\mathbf{\Delta y} = \mathbf{\Delta y}_{\mathbf{1}} + \mathbf{\Delta y}_{\mathbf{2}} + \ldots + \mathbf{\Delta y}_{\mathbf{n}} = \mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Delta y}_{\mathbf{i}},$$

where each decomposed vector is made up of the single non-zero entry showing the change in the final demand of sector *i*. Changes in final demand can be further decomposed. If there are *k* categories of demand instead of a single total value, then each element in vector $\mathbf{y}$ responds to $y_{i1} + y_{i2} + \ldots + y_{ik,}$, with y_{ik} being the amount of category *k* in the final demand from sector *i*. We can therefore disentangle the changes in final demand by adding vectors containing the single non-zero entry showing the change in the final demand of the *ik*th element and zeros elsewhere, as follows:

$$\mathbf{\Delta y} = \mathbf{\Delta y}_{\mathbf{11}} + \mathbf{\Delta y}_{\mathbf{12}} + \ldots + \mathbf{\Delta y}_{\mathbf{1k}} + \ldots + \mathbf{\Delta y}_{\mathbf{n1}} + \mathbf{\Delta y}_{\mathbf{n2}} + \ldots + \mathbf{\Delta y}_{\mathbf{nk}} = \mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Sigma}_{\mathbf{k}}\mathbf{\Delta y}_{\mathbf{ik}}. \qquad (8)$$

Using the divisions in (7) and (8), expression (6) can be re-written as:

$$\begin{aligned}\Delta\mathbf{x} &= \tfrac{1}{2}[\mathbf{L}_{\mathbf{1}}\mathbf{\Delta A x}_{\mathbf{0}} + \mathbf{L}_{\mathbf{0}}\mathbf{\Delta A x}_{\mathbf{1}}] + \tfrac{1}{2}[\mathbf{L}_{\mathbf{0}} + \mathbf{L}_{\mathbf{1}}]\mathbf{\Delta y} \\ &= \tfrac{1}{2}[\mathbf{L}_{\mathbf{1}}(\mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Sigma}_{\mathbf{j}}\mathbf{\Delta A}_{\mathbf{ij}})\mathbf{x}_{\mathbf{0}} + \mathbf{L}_{\mathbf{0}}(\mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Sigma}_{\mathbf{j}}\mathbf{\Delta A}_{\mathbf{ij}})\mathbf{x}_{\mathbf{1}}] + \tfrac{1}{2}[\mathbf{L}_{\mathbf{0}} + \mathbf{L}_{\mathbf{1}}](\mathbf{\Sigma}_{\mathbf{i}}\mathbf{\Sigma}_{\mathbf{k}}\mathbf{\Delta y}_{\mathbf{ik}}). \qquad (9)\end{aligned}$$

Expression (9) measures the effects of separately changing all the components in the model and maintaining the changes occurred in all other components constant, as it shows the contribution of every single change to total output changes. Note that this decomposition facilitates the interpretation of results because among the huge set of elements within an input-output model, the calculation in (9) makes it possible to individually illustrate the contribution of each one to output modifications over time.

3. Databases

The empirical application is based on the latest two input-output tables available for Catalonia (one for 2001 and one for 2011), published by the regional statistics office (IDESCAT). These two databases provide statistical coverage of the regional economy for an entire decade.[3]

Before the empirical calculations, the original tables underwent a transformation process. The official 2001 input-output table is limited to an extended use matrix at basic prices. This means that neither the make matrix nor the symmetric matrix is available for 2001. To avoid this statistical gap, the symmetric input-output table was indirectly calculated in a process involving the estimation of the 2001 make table for Catalonia. This estimation took into consideration the structure of the make matrix for the Spanish economy[4] and some other indirect information concerning sectoral production in the regional economy provided by the IDESCAT. Subsequently, by using the extended use table and the previously estimated make table, a sector-by-sector symmetric table for 2001 was obtained.[5] As the regional statistics office directly

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[3] IDESCAT (2015a, 2015b).

[4] INE (2015a).

[5] Miller and Blair (2009) describe the calculations required to obtain a symmetric input-output table by using the use and the make matrices.

provides a symmetric input-output table, the only transformation required for the year 2011 was the application of an identical sectoral aggregation as in the 2001 database.

The resulting two input-output tables have the same structure, consisting of twenty-eight differentiated activities, five of which represent the energy sectors (Table 1): extraction of minerals (sector 4), coke, petroleum and fuels (sector 5), electricity (sector 6), gas (sector 7) and water (sector 8).

[PLACE TABLE 1 HERE]

To avoid price distortions, the 2001 input-output table was rescaled to the 2011 price levels (expression (2)). In specific terms, vector **x** of gross output, vector **y** of final demand and matrix **A** of structural coefficients were valuated at the 2011 price levels. For the service activities, the elements in the diagonal matrix **P** were obtained from the consumption price index for the regional economy (INE, 2015b). For the industrial activities, the elements in **P** were obtained from the production prices index (INE, 2015c).

4. Empirical Application for the Catalan Economy

The analytical method defined in Section 2 shows the decomposition of gross output in all sectors of production. However, as the interest in this study lies in analysing energy production and its driving temporal determinants, the results in the next tables are limited to show the accounts for the five energy activities in the Catalan input-output databases (j = 4, 5, 6, 7, 8).

[PLACE TABLE 2 HERE]

Table 2 shows the main economic indicators for the energy activities. In this table, the 2001 values have been rescaled to the 2011 price levels. For the aggregated energy sector, the intermediate inputs increased by around 27% (from 8,780.8 million euros in 2001 to 11,137.8 million euros in 2011). The intermediate demand rose by 8.8% (with values of 18,812.4 and 20,470.6, respectively) and the final demand for energy decreased in real terms by a percentage of around -14.8%. This decrease in demand is mainly explained by the significant reduction in the energy exports, which is quantified by -46.1% (5,127.7 million euros in 2001 and 2,762.9 million euros in 2011). Finally, Table 2 shows that the total energy output was almost stable during the period analysed, and shows an increase of 136.2 million euros, which represents a variation of around 0.5%.

A closer look at Table 2 suggests that the different energy activities evolved asymmetrically during the period studied. In particular, minerals and electricity reduced the intermediate inputs, while coke, petroleum and fuel, gas and water increased the intermediate costs. On the other hand, the final demand for electricity and gas decreased (by -52.5% and -27.5% respectively) and increased in the other subsectors. Finally, the last row in Table 2 shows that the gross output of electricity remained quite stable, the output of gas, water and minerals increased (by 28.3%, 50.1% and 10.6% respectively) and the output of coke, petroleum and fuel decreased by -14.6%. In the light of these results, there is a heterogeneity in the intertemporal changes in the various energy accounts, and no general trends can be traced from the figures in Table 2.

Table 3 contains the summarised results of the SDA decomposition. In specific terms, this table divides the changes in the energy gross output into the contribution of the technological changes (i.e. changes in the input-output technical coefficients) and the structural changes (i.e. changes in the final demand for energy).

[PLACE TABLE 3 HERE]

Two main results can be seen from Table 3. The first is based on the fact that the two decomposed elements have a different sign. While the contribution of technological changes to energy production was positive (318.6 million euros), the contribution of structural changes was negative (-182.47 million euros). At the individual level, changes in the technological relations contributed positively in all subsectors except in coke, petroleum and fuel (-2,474.8 million euros). However, changes in final demand behaved negatively in electricity and gas (-1,393.7 and -103.0 million euros respectively) and positively in the other energy activities.

The second result in Table 3 is based on the fact that the different energy subsectors behaved differently in terms of their output changes during the period analysed. More specifically, extraction of minerals, gas and water increased the real output (638.9, 665.3 and 567.4 million euros, respectively), while the other two energy subsectors (coke, petroleum and fuel and electricity) reduced the real output by -1,549.9 and -185.6 million euros. The aggregation of these individual (and opposed) output changes results in a small overall increase of 136.1 million euros. In addition, the energy activities show different patterns in the two isolated effects. While in minerals and water both the technological and the structural component are positive, in electricity and gas a positive technological change is combined with a negative structural change and in coke, petroleum and fuel a (large) negative technological change is combined with a positive structural change.

We can further analyse the factors underlying the intertemporal drivers of energy by showing by how much the changes in matrix **A** of input-output coefficients contributed to energy output modifications. Table 4 summarises the results for the coefficients of the five energy accounts reflected in the model. Specifically, this table groups the coefficients' changes into three different categories, which have a different economic meaning. The changes in the column coefficients reflect the modification in the cost structure, or the *production effect*, and show how the energy activities have changed their intermediate purchases of products. The changes in the row coefficients reflect the modification in the selling structure, or the *substitution effect*, and show how the energy accounts have modified their intermediate output relations. The last two columns in Table 4 show the joint modifications in rows and columns, or the *mixed effect*, and reflect the changes in the total intermediate relations (i.e. purchases and sales) of the energy activities. In Table 4, the values in parenthesis are the percentage of variation from the corresponding initial value.

[PLACE TABLE 4 HERE]

In the coefficients column, there is an increase in the structure of the intermediate purchases in coke, petroleum and fuel (35.6%), gas (75.8%) and water (29.8%). These activities therefore show an increase in the proportion of their sectoral output that goes to buying inputs of production to the rest of activities. However, the column coefficients decreased in extraction of minerals (-36.8%) and to a lesser extent in electricity (-2.8%), meaning that these two sectors reduced the fraction of their output spent on intermediate production from the other sectors.

In general, the row coefficients evolved positively during the period, illustrating an increase in the proportion of energy output sold to the rest of the production system. The increase is especially significant in water (157.9%) and gas (51.8%). The exception to this general increase is coke, petroleum and fuel, where intermediate output coefficients fell by -38.6%. This may show that the Catalan production system has substituted the intermediate uses of fuels by other forms of energy.

The last two columns in Table 4 contain the joint row and column changes in coefficients, on average terms and for each of the energy accounts. These figures reproduce the same sign as the row changes, which predominate over the column changes in the total technological effects. As a result, the technological component is positive in all energy activities except in coke, petroleum and fuel. An interesting outcome is therefore that the proposed decomposition method shows a different temporal adaptation of the structure of intermediate costs and intermediate output in the various energy activities. Another result from the last column of Table 4 is that the contribution of the technological component to output change is the combination of different drivers within the technology of production, which are different in magnitude and sign in terms of the cost structure (column changes) and the selling structure (row changes) of energy sectors.

The impact of the coefficient changes on energy output helps us to understand the effects within the production system. Hereinafter, the analysis turns to the changes in the final uses of energy. In specific terms, Table 5 disentangles the various elements that compound the final demand for energy.

[PLACE TABLE 5 HERE]

Once again, there are asymmetrical effects in terms of both the different sectors and the different elements within the final demand. By components, the reduction in energy exports (-2,364.8 million euros) is significant, which generated a reduction in output of -3,832.2 million euros. This is mainly explained by the reduction in the exports of electricity, which show a negative contribution on output of -2,714.6 million euros, and in the exports of gas, which show a negative contribution of -1,121.1 million euros.

The other demand components in Table 5 evolved positively, especially final consumption, which with a rise of 716.4 million euros, positively contributed to increasing energy gross output (1,198.6 million euros). The increase in final consumption is significant in coke, petroleum and fuel (670.4 million euros) and to a lesser extent in gas (310.4 million euros). On the contrary, the rest of energy activities show a reduction in final consumption during the period analysed.

In relation to the various energy accounts, there is a significant reduction in the final demand for electricity, explained by a reduction in electricity exports and to a lesser extent in private consumption, which is quantified at -1,970.8 million euros. This negative contribution to the energy output amounted to -1,393.7 million euros, a reduction of -4.7% compared to the 2001 figures for total energy output. Another interesting result in Table 5 is that the negative effect of the electricity demand predominates over the other activities and the resulting final structural component is slightly negative (-182.4 million euros).

The structural decomposition shows the importance of breaking down the overall changes in energy output into their driving determinants. The changes in output are the result of a combination of a huge amount of individual effects, which are extremely difficult to identify by limiting the analysis to the final aggregated impacts. The results in these tables clarify which is the individual contribution of hidden effects, that cannot be identified in general and aggregated studies of the energy sector.

5. Conclusion and Policy Implications

This paper has analysed the changes in Catalan energy gross output during the period 2001-2011, by dividing total changes in energy production into two different components: technological changes and structural changes. The technological changes show the effects of changing the intermediate coefficients in the input-output model. The structural changes show the effects of changing the final uses for energy. In addition, the method proposed in the paper enables individual quantification of the contribution of all the elements in the input-output model (i.e. the changes in all the sector-by-sector coefficients and in all the sector-by-component elements of final demand).

The results showed a moderate increase in the energy gross output during the period, which was the result of combining a negative contribution of the final demand and a positive contribution of the intermediate coefficients. In terms of the different energy activities, there is a different sectoral repercussion on the changes in energy output. The technological changes positively contributed in all sectors, except in coke, petroleum and fuel. On the other hand, the changes in the demand for electricity and to a lesser extent gas contributed negatively to energy output changes.

One important finding is therefore that intertemporal changes in the regional energy output are mainly explained by changes in exports of electricity and by technological changes (i.e. intermediate sales and purchases) of coke, petroleum and fuel. In the light of these results, special attention should be paid to these specific areas of the energy system in order to define successful energy policies in the regional economy.

The analytical framework proposed in this paper clarifies some aspects within the complex process of changes in gross output. In particular, the input-output SDA analysis is an appropriate method for disentangling the driving forces of temporal modifications in energy variables. This information is obviously extremely useful for gaining further knowledge in order to be able to attribute environmental responsibilities, as it enables the different agents involved in energy usages and their changes over time to be identified. The outcomes in the paper therefore suggest a need for using disaggregated and detailed methods to gain further insights into the driving forces of changes in energy.

In the coming decades, the challenges in energy issues can only be met if important research efforts are made to help the energy policy-making process. The need for new energy sources, less energy-intensive production systems and environmental-friendly forms of energy will be the focus of interest for academics, politicians and regulators. The message of this paper is that it is necessary to focus on the underlying factors affecting energy production and energy consumption as a means to clarify the complex aspects involved in energy issues.

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Table 1. Sectors of Production

1	Agriculture	15	Automobiles and transport material
2	Livestock	16	Other industries
3	Fishing	17	Construction
4	Extraction of minerals	18	Commerce
5	Coke, petroleum and fuel	19	Railway transport
6	Electric energy	20	Land transport
7	Extraction and distribution of gas	21	Maritime transport
8	Distribution of water	22	Air transport
9	Food production	23	Services linked to transport activities
10	Textiles	24	Finance
11	Manufactures of wood	25	Education
12	Paper	26	Medical assistance and social services
13	Chemistry	27	Public administration
14	Electric equipment and machinery	28	Other private services

Table 2. Indicators of the Energy Sector, Catalonia. Million Euros

	4. Extraction of minerals		**5. Coke, petroleum, fuel**		**6. Electricity**		**7. Gas**		**8. Water**		**Total Energy**	
	2001	**2011**	**2001**	**2011**	**2001**	**2011**	**2001**	**2011**	**2001**	**2011**	**2001**	**2011**
Intermediate inputs	379.2	270.4	3,663.9	4,295.2	3,096.0	2,975.5	1,172.6	2,675.3	469.1	921.4	**8,780.8**	**11,137.8**
Value added	286.8	332.2	548.2	322.9	1,942.1	3,143.1	775.2	143.3	607.0	781.5	**4,159.3**	**4,723.0**
Intermediate outputs	5,831.3	6,419.0	5,921.5	3,724.0	5,205.2	6,990.4	1,348.9	2,289.4	505.5	1,047.8	**18,812.4**	**20,470.6**
Private consumption	7.8	3.6	2,239.3	2,909.8	1,924.6	1,744.1	413.9	724.4	627.5	547.6	**5,213.1**	**5,929.5**
Public consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.1	**0.0**	**77.1**
Investment	-11.8	5.0	-41.6	-7.2	0.0	0.0	2.6	0.0	-0.8	0.0	**-51.5**	**-2.2**
Exports	198.2	237.0	2,514.8	2,457.4	1,831.7	41.3	583.0	0.0	0.0	27.2	**5,127.7**	**2,762.9**
Total demand	194.3	245.6	4,712.5	5,360.0	3,756.2	1,785.4	999.6	724.4	626.7	651.9	**10,289.3**	**8,767.3**
Total output	6,025.6	6,664.5	10,634.0	9,084.0	8,961.4	8,775.8	2,348.5	3,013.9	1,132.2	1,699.7	**29,101.7**	**29,237.9**

Table 3. Changes in Energy Output, Catalonia (2001-2011). Million Euros

	Technological Changes	**Structural Changes**	**Total Changes**
4. Extraction of minerals	361.56	277.40	638.96
5. Coke, petroleum and fuel	-2,474.82	924.83	-1,549.99
6. Electricity	1,208.14	-1,393.77	-185.63
7. Gas	768.42	-103.04	665.37
8. Water	455.33	112.12	567.45
Total Energy	**318.63**	**-182.47**	**136.16**

Table 4. Technological Changes in Energy Output, Catalonia (2001-2011)

	Column Changes		Row Changes		Total Changes	
	Coefficients	Production (Million Euros)	Coefficients	Production (Million Euros)	Coefficients[a]	Production (Million Euros)
4. Extraction of minerals	-0.02369 (-36.89%)	-241.61 (-0.83%)	0.33070 (44.33%)	727.97 (2.50%)	0.005482 (40.32%)	361.56 (1.24%)
5. Coke, petroleum and fuel	0.12436 (35.69%)	1,134.84 (3.90%)	-0.24124 (-38.63%)	-3,518.50 (-12.09%)	-0.002087 (-15.35%)	-2,474.82 (-8.50%)
6. Electricity	-0.01003 (-2.87%)	-191.14 (-0.66%)	0.10429 (25.68%)	1,563.46 (5.37%)	0.001683 (12.38%)	1,208.14 (4.15%)
7. Gas	0.38279 (75.83%)	1,258.45 (4.32%)	0.05769 (51.85%)	1,561.92 (5.36%)	0.007866 (57.86%)	768.42 (2.64%)
8. Water	0.12457 (29.84%)	265.50 (0.91%)	0.09711 (157.91%)	756.54 (2.60%)	0.003959 (29.12%)	455.33 (1.56%)

a Average individual changes.

Table 5. Structural Changes in Energy Output, Catalonia (2001-2011)

	Private Consumption		Public Consumption		Investment		Exports		Total Demand	
	Value	Production (Million Euros)	Value	Production (Million Euros)	Value	Production (Million Euros)	Value	Production (Million Euros)	Value	Production (Million Euros)
4. Extraction of minerals	-4.18 (-53.74%)	-4.54 (-0.02%)	0.00 (0.00%)	0.00 (0.00%)	16.76 (142.53%)	18.18 (0.06%)	38.76 (19,55%)	42.06 (0.14%)	51.34 (26.43%)	277.40 (0.95%)
5. Coke, petroleum and fuel	670.46 (29.94%)	1,024.44 (3.52%)	0.00 (0.00%)	0.00 (0.00%)	34.38 (82.68%)	52.53 (0.18%)	-57.36 (-2.28%)	-87.64 (-0.30%)	647.49 (13.74%)	924.83 (3.18%)
6. Electricity	-180.45 (-9.38%)	-273.62 (-0.94%)	0.00 (0.00%)	0.00 (0.00%)	0.00 (0.00%)	0.00 (0.00%)	-1,790.35 (-97.75%)	-2,714.69 (-9.33%)	-1,970.81 (-52.47%)	-1,393.77 (-4.79%)
7. Gas	310.45 (74.99%)	596.99 (2.05%)	0.00 (0.00%)	0.00 (0.00%)	-2,61 (-100.00%)	-5.02 (-0.02%)	-583.05 (-100.00%)	-1,121.19 (-3.85%)	-275.21 (-27.53%)	-103.04 (-0.35%)
8. Water	-79.87 (-12.73%)	-144.64 (-0.50%)	77.10 (100%)	139.63 (0.48%)	0.77 (100.00%)	1.39 (0.00%)	27.20 (100.00%)	49.26 (0.17%)	25.19 (4.02%)	112.12 (0.38%)
Total Energy	716.41 (13.74%)	1,198.63 (4.12%)	77.10 (100.00%)	139.63 (0.48%)	49.3 (95.73%)	67.08 (0.23%)	-2,364.8 (-46.12%)	-3,832.20 (-13.17%)	-1,522.0 (-14.79%)	-182.47 (-0.63%)