Energy Intensities and Carbon Dioxide Emissions in a Social Accounting Matrix Model of the Andalusian Economy

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Summary

The aim of this article is to calculate energy intensity and carbon dioxide (CO_2) emissions in Andalusia, the largest and most populated region of Spain. Energy intensities for five energy commodities used in production activities are calculated using a social accounting matrix (SAM) model with three alternative scenarios, each utilizing differing closure rules. More interestingly, by using 2005 data and updating the values of exogenous accounts, the article also provides estimates of CO_2 emissions ten years out from the 1995 base year. Finally, counterfactual experiments are performed to quantify the overall reduction in direct energy coefficients that would have made it possible to maintain constant production-sector emissions from 1995 to 2005. The results indicate that there is a strong interdependence among energy sectors and the most intensive energy users; they also indicate the importance of induced effects when factor accounts and private consumption are endogenous. The estimates obtained concerning CO_2 emissions are close to official estimates, both from 1995 and 2005. The counterfactual experiments indicate that a 26.5% cut in the size of direct energy requirements would have made it possible to maintain constant emissions. They also indicate that efforts to curtail emissions should be focused on improving efficiency in coal extraction and combustion and oil refining.

Introduction

Energy is a key input in production and consumption activities. Primary energy (coal, petroleum, natural gas, and enriched uranium) is transformed into secondary energy (refined oil, manufactured gas, and electricity); most production branches, as well as consumers, use both of these energy types and are responsible for a great deal of carbon dioxide (CO_2) emissions.

The main motivation for this work is the need to know the energy consumption of different sectors and consumers, and therefore the sectoral and consumer responsibilities in the generation of emissions. Our main interest lies in having enough information about the mechanisms and intervention points for improving efficiency to effectively achieve reductions in emissions. In short, the focus of this work is to calculate energy intensities in production sectors, along with associated CO_2 emissions, and assess the proportional responsibility of production and consumption activities in total emissions. Andalusia, the largest and most populous region of Spain, is taken as the economic frame of reference.

Energy intensities of production can be calculated using a standard input-output (IO) model (Leontief 1966). Similar calculations can be done with social accounting matrix (SAM) models, which extend the interindustry Leontief model to take into account income generation and spending. The concept of SAM was first introduced by Stone (1962) as a useful device to understand national accounts. Later, Pyatt and Round (1979) put forward the fix-price multiplier setup, which has since been extensively employed. Resosudarmo and Thorbecke (1996)

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pioneered the use of SAM models to study the impact of polluting substances on the welfare of households in Indonesia. Weale (1997), Xie (2000) and Alarcón and colleagues (2000) also applied SAM models to Indonesia, China, and Bolivia, respectively. More recently, Lenzen and Schaffer (2004) compared the size of type I and type II multipliers for different degrees of endogeneity, or closure rules, using an environmental SAM of Brazil.

In Spain, most energy studies (Alcántara and Padilla 2009; Alcántara and Roca 1995; Labandeira and Labeaga 2002) have employed IO models to estimate energy intensities and CO_2 emissions. Manresa and Sancho (2004) were the first to employ a SAM model to calculate energy intensities in Catalonia, a region of Spain, for the year 1987. They also presented estimates of CO_2 emissions for the same year, obtained with a standard IO model, and calculated the impact of arbitrary cutbacks in emissions (by 10%) to the size of direct energy coefficients in production activities.

This article calculates energy intensities, CO_2 production, and final emissions for Andalusia in 1995 using a SAM model in which labor, capital income, and household accounts are included in the endogenous subset. The choice of this level of endogenization is based on two facts. First, private consumption uses a significant part of the energy spent in the region and, therefore, is one of the main causes of CO_2 emissions into the atmosphere. Because of this, we decided to include consumption within the endogenous accounts and, consequently, labor and capital; the goal was to incorporate the chain of production to wage to consumption to production into the circuit (Lenzen and Schaffer 2004). Second, Keynes' distinction between savings and the decision to invest means that while an increase in income raises both consumption and savings, it does not necessarily boost investment. Therefore, in our closure rule investment is exogenous and labor, capital income, and household accounts are endogenous accounts. We use this closure rule throughout our analysis, although when calculating energy intensities we present three closure levels to better illustrate the different points of view on this question. In the first level, only production branches are endogenous; the second level adds activities, private consumption, labor, and capital income; the third level adds investment to the endogenous subset.[1]

We extend the study of intensities to CO_2 emissions generated by the consumption of energy goods in the regional economy. This is because, as already noted, the main objective of this work is to gain information about what the mechanisms and intervention points should be for improving efficiency while looking to achieve the targets set in the Kyoto Protocol. To this end, we conducted a series of simulations and experiments to determine how sensitive the level of emissions is to either changes in various components of exogenous final demand or to changes in energy intensities. These simulations are divided into two types: the first tells us how each element of exogenous final demand influences the generation of emissions. This was accomplished through experimentation with exogenous shocks of each element and the system as a whole. Instead of arbitrarily quantifying these shocks, we have taken the values of these variables from the last year available (2005). These values afford a comparative analysis of emissions between the two periods as long as the production structure has remained constant. The second type of simulation presents the results of several counterfactual experiments in order to quantify the efficiency gains (overall reductions in the size of direct energy coefficients in all productive sectors) that would have made it possible to keep emissions constant from 1995 to 2005.

As is well known, SAM models get their name from the social accounting matrix that is used to define each model. The matrix used to develop the Andalusian SAM employed in this article (SAMAND-95) was constructed by Cardenete and Moniche (2001) using the 1995 Andalusian IO table and the regional accounts elaborated by the Andalusian Statistical Institute. Andalusian data for final demand in 2005 also come from the regional accounts of the Andalusian Statistical Institute. Emissions coefficients for intermediate and final uses are derived from the information provided by the energy IO table of Spain for 1985, and energy price changes are obtained from the National Institute of Statistics (INE). Finally, physical emission coefficients come from Eurostat (2005).

The structures of the SAMAND-95 (Cardenete and Moniche 2001) and the SAM models used in this article to calculate energy intensities are in the next section, which presents the energy intensities for all production sectors under three alternative closure rules. The procedure used to estimate CO_2 emission coefficients for energy inputs, the estimates of 1995 intermediate and final emissions, the simulations done with data from 2005, and the results of energy saving counterfactual experiments are presented in the section titled "CO_2 Emissions Estimates for the Andalusian Economy." Conclusions and possible extensions of this research are summed up in the final section.

Social Accounting Matrices and Models

IO tables give a detailed account of interindustry transactions in an equilibrium setup in which total supply matches the sum of intermediate and final demand. A SAM completes the information of an IO table, introducing balanced accounts for factors, institutions, and other auxiliary accounts in order to close the process of income distribution and income spending. As Stone (1962) pointed out, a SAM is an efficient and transparent device that presents the circular income flow of an economy over a period of time by means of a square flow matrix. Each row and corresponding column in the matrix provide the resources and uses of an account; accounts represent industries, factors income (labor and capital), institutions, tax instruments, and so forth. Because total resources (income) equals total uses (expenditures) for every account, the information in a SAM can be interpreted, in some cases, through zero benefit conditions, budget constraints, and market clearing equations.

Table 1 presents the structure of the SAM of Andalusia employed in this study. Rows represent income and columns represent uses of income. Bold text corresponds to the main blocks (intermediate consumption, primary inputs, and final demands)

Table 1 Simplified structure of the SAMAND-95

	Production	*Primary factors*	*Resident sectors*	*Capital account*	*Foreign sector*
Production	**Intermediate consumption**		**Private and public consumption**	**Gross capital investment**	**Exports**
Primary factors	**Gross value added**				Wages and property income
Resident sector	**Production taxes**	Net resident income	Current and capital transfers	Taxes on capital	Current and capital transfers
Capital account		Fixed capital consumption	Net resident financial capacity		Foreign savings
Foreign sector	**Imports**	Wages and property income	Current and capital transfers		

Note: Bold text corresponds to the main blocks of a standard input-output table. Source: Personal development and elaboration.

of a standard IO table. Distribution and income spending transactions appear in the other nonempty, non-bold cells. Every account draws its income from production, primary factors, resident sectors, and the foreign sector; every account uses income to finance production, resident sectors, the capital account, and the foreign sector. If we take the resident sectors, for example, they use production taxes, net resident incomes, current and capital transfers, and wages and property income to finance private and public consumption, current and capital transfers, net resident financial capacity, and foreign current and capital transfers.

The information in a SAM can be used to develop a SAM model in the same way that IO tables are employed to develop IO models. Let $Y = (Y_{ij})$ be the $N \times N$ matrix of income flows among the N accounts in the SAM economy and let

$$a_{ij} \equiv \frac{Y_{ij}}{\sum_{i=1}^{N} Y_{ij}} = \frac{Y_{ij}}{Y_j}, i, j = 1, 2, \ldots, N \quad (1)$$

be the average income flow from account j directed to account i. Given this definition, the total income of account i can be written as the product of average income flows directed to account i multiplied by the corresponding income levels

$$Y_i \equiv \sum_{j=1}^{N} \frac{Y_{ij}}{Y_j} Y_j \equiv \sum_{j=1}^{N} a_{ij} Y_j, i = 1, 2, \ldots, N. \quad (2)$$

In order to transform the set of identities in equation (2) into an interesting set of equations for a subset of variables $M \subset N$, the set of accounts is partitioned into two subsets: $\{1, 2, \ldots, M\}$, or the subset of endogenous accounts, and $\{M+1, M+2, \ldots, N\}$, the subset of exogenous accounts. It is assumed that the matrix of average income flows is constant and therefore independent of prices or the income scale. Therefore the identity can be expressed as

$$Y_i = \sum_{j=1}^{M} a_{ij} Y_j + \sum_{j=M+1}^{N} a_{ij} Y_j, i = 1, 2, \ldots, N. \quad (3)$$

Or, using matrix notation, as

$$\begin{aligned} y_m &= A_{mm} y_m + A_{mn} y_n \\ y_n &= A_{nm} y_m + A_{nn} y_n, \end{aligned} \quad (4)$$

where A_{mm}, A_{mn}, A_{nm}, and A_{nn} are the matrices obtained from A for the chosen endogenous–exogenous partition,

$$A = \begin{pmatrix} A_{mm} & A_{mn} \\ A_{nm} & A_{nn} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \ldots & a_{1M} & a_{1M+1} & a_{1M+2} & \ldots & a_{1N} \\ a_{21} & a_{21} & \ldots & a_{2M} & a_{2M+1} & a_{2M+2} & \ldots & a_{2N} \\ & \ldots & & & & \ldots & & \\ a_{M1} & a_{M2} & \ldots & a_{MM} & a_{MM+1} & a_{MM+2} & \ldots & a_{MN} \\ a_{M+11} & a_{M+12} & \ldots & a_{M+1M} & a_{M+1M+1} & a_{M+1M+2} & \ldots & a_{M+1N} \\ a_{M+21} & a_{M+21} & \ldots & a_{M+2M} & a_{21} & a_{M+2M+2} & \ldots & a_{M+2N} \\ & \ldots & & & & \ldots & & \\ a_{N1} & a_{N2} & \ldots & a_{NM} & a_{NM+1} & a_{NM+2} & \ldots & a_{NN} \end{pmatrix}. \quad (5)$$

The income vector of the endogenous accounts can then be calculated from the first subset of equations,

$$y_m = (I - A_{mm})^{-1} A_{mn} y_n = B_{mm} A_{mn} y_n = B_{mm} d_m, \quad (6)$$

where $B_{mm} = (I - A_{mm})^{-1}$ is the square generalized multiplier matrix and d_m is the vector $A_{mn} y_n$ of exogenous income directed to the endogenous accounts. The element b_{ij} in the matrix B_{mm} can be interpreted as the income accruing to account i when the vector of exogenous income directed to account j increases by just one unit. Thus the column sums of the matrix B_{mm}, $b_{.j} = \sum_{i=1}^{M} b_{ij}$, can be interpreted as total income accruing to all endogenous accounts. Because prices are assumed to be constant, they can be set equal to one for the subset of production sectors $P \subset M$ by choosing the appropriate units. Then b_{ij} can be interpreted as the amount of commodity i required directly and indirectly to produce one more unit of net output of commodity j and $b_{jj} - 1$ as its intermediate demand by all sectors

$$(B_{mm} - I) d_m = A_{mm} y_m. \quad (7)$$

Obviously the solution to equation (6) depends on the partition chosen: the larger the subset $M \subset N$ of endogenous accounts, the greater the income directed to all accounts when there is a one unit increase in exogenous income directed to the endogenous accounts.

Energy Intensities in the Andalusian Economy Under Alternative Closure Rules

Let $E \subset M$ be the subset of energy sectors and B_{em} be the $E \times M$ submatrix of B_{mm}. The element b_{ej} can be interpreted in the usual way, as the amount of energy e required (directly and indirectly) to produce one more net unit of commodity j, and B_{em} as the energy intensities matrix. Alternatively, the multipliers b_{ej} can also be interpreted in value terms as the cost in energy e required to produce one monetary unit more of net output j (the monetary unit is peseta in this case).[2] Thus for each sector j, the sum $c_j^E = \sum_{e \in E} b_{ej}$ gives the total energy costs required to produce one net peseta by sector j.

Table 2 presents the energy intensities matrix, B_{em}, in the first five columns, calculated when the subset of endogenous accounts includes only the 27 productive sectors in the SAMAND-95. For each sector, the numbers indicate the monetary cost of each energy factor (coal, oil, and natural gas; oil refining; electricity; and manufactured gas and water steam) required to produce just one extra unit (peseta) of net output in that sector. For instance, 0.0016 units of coal, 0.0871 units of oil refining, and so forth, are (directly and indirectly) required to produce one net unit of transport and communications services.

Table 2 clearly indicates that there are strong interdependencies among energy sectors. Coal is most intensively used in the production of electricity, coal, and water. Oil and natural gas are mainly used by the manufactured gas and water steam and refined oil sectors. Major uses of refined oil are refined oil itself, transport and communications, and fishing. Electricity is most intensively used in the production of electricity, water, and construction materials. Manufactured gas and water steam is the only commodity where a nonenergy sector (chemicals) is the most intensive user, although the figure is relatively low. Oil refining and natural gas are imported, and therefore no energy inputs are used to produce them.

The "Compound effect 1" for each sector is simply the sum of the numbers in the first five columns of the table, and can be interpreted as the total energy expenditure required to produce one extra net unit of income by the corresponding sector. Throughout the table, sectors in the first column appear ordered by the size of compound effect 1. Three energy sectors—electricity, oil refining, and manufactured gas and water steam—are the most energy intensive sectors, followed by water, transport and communications, construction materials, the rest of extractive industries, coal, fishing, and construction.

The next two columns, Compound effect 2 and Compound effect 3, report the values of the compound effect in two alternative scenarios: first, when labor, capital income, and household accounts are included in the endogenous subset, and second, when the capital[3] account (savings and investment) is also endogenous. The rationale for this two-step presentation of the results, as we explain earlier in the article, relies on Keynes' distinction between savings and investment decisions. Although an increase in income raises both consumption and savings, it does not necessarily boost investment. Adopting a neoclassical view, compound effect 3 makes investment endogenous. The last two columns in table 2 indicate the marginal change in the compound effect that can be attributed to the new endogenous accounts: factors income and consumption in the first case and investment in the second case make up the additional endogenous accounts in each column.

Making both labor and capital income and the private consumption accounts endogenous increases, as expected, the size of the compound effect, but does not change the ranking of categories with the largest energy impact until the sixth position (construction materials). Notice, however, that changes between compound effects 1 and 2 are larger both in absolute and relative terms for nonenergy sectors: market services, nonmarket services, commerce, and other services are among those that register a major increase. Adding the capital account to the endogenous accounts, as shown in Compound effect 3, reinforces the role of nonenergy sectors, although changes are smaller, as is investment in comparison to consumption. The major increases in this case are, again, market services, nonmarket services, commerce, and other services.

Carbon Dioxide Emissions Estimates for the Andalusian Economy

Estimates of CO_2 emissions in production activities and final consumption are presented in this section, based on a set of emission coefficients constructed by the authors. First, emissions are calculated in the base year (1995) and compared with the regional government estimates for the same year (Consejería de Medio Ambiente de Andalucía, 1997). Next, several simulations are performed to calculate emissions caused by the growth in final demand from 1995 to 2005. Finally, the change in the efficiency required to counteract the increase in emissions is estimated.

Emission Coefficients

Following Manresa and Sancho (2004), the row vector of emissions coefficients, c_e^T, is derived from the data available in two IO tables of the energy subsystem of the Spanish economy in 1985 and CO_2 emission coefficients per terajoule (TJ)[4] for each energy commodity, $\bar{c}_e$, provided by Eurostat (2005).[5] The flows in the physical table are in terajoules, $\bar{X}_{ej}^{85}$, and those in the value table in are millions of 1985 pesetas, $p_e^{85}\bar{X}_{ej}^{85}$. Thus the emissions per million pesetas spent in each energy commodity can be calculated for 1985 by applying the physical emissions coefficients, $\bar{c}_e$, to the ratio of terajoules per million pesetas spent:

$$\bar{c}_e \frac{\bar{X}_{ej}^{85}}{p_e^{85}\bar{X}_{ej}^{85}}. \quad (8)$$

Table 2 Energy intensities matrix and compound effects

Sectors	*Coal*	*Oil and natural gas*	*Oil refining*	*Electricity*	*Manufactured gas and water steam*	*Compound effect 1*	*Compound effect 2*	*Compound effect 3*	*Compound effect 2 minus compound effect 1*	*Compound effect 3 minus compound effect 2*
Electricity	**0.1579**	**0.0102**	**0.0247**	**0.5662**	**0.0002**	**0.7592**	**0.8132**	**0.8414**	**0.0540**	**0.0281**
Oil refining	**0.0018**	**0.4887**	**0.1955**	**0.0178**	**0.0028**	**0.7066**	**0.7296**	**0.7416**	**0.0230**	**0.0120**
Manufactured gas and water steam	**0.0046**	**0.5166**	**0.0045**	**0.0455**	**0.0052**	**0.5764**	**0.6195**	**0.6420**	**0.0431**	**0.0225**
Water	0.0172	0.0061	0.0138	0.1702	0.0009	0.2083	0.2846	0.3244	0.0763	0.0398
Transport and communications	0.0016	0.0359	0.0871	0.0156	0.0007	0.1409	0.2051	0.2386	0.0643	0.0335
Construction materials	0.0105	0.0134	0.0289	0.0538	0.0031	0.1097	0.1554	0.1793	0.0457	0.0238
Rest of extractive industries	0.0054	0.0112	0.0265	0.0505	0.0007	0.0944	0.1248	0.1407	0.0304	0.0159
Coal	**0.0268**	**0.0045**	**0.0105**	**0.0343**	**0.0004**	**0.0764**	**0.0913**	**0.0991**	**0.0149**	**0.0078**
Fishing	0.0008	0.0188	0.0456	0.0079	0.0004	0.0735	0.1234	0.1494	0.0499	0.0260
Construction	0.0035	0.0131	0.0306	0.0230	0.0013	0.0716	0.1348	0.1677	0.0632	0.0329
Commerce	0.0047	0.0060	0.0139	0.0446	0.0006	0.0697	0.1521	0.1950	0.0824	0.0429
Chemicals	0.0023	0.0122	0.0148	0.0226	0.0120	0.0638	0.0821	0.0916	0.0183	0.0095
Mining and iron and steel industry	0.0044	0.0061	0.0132	0.0386	0.0014	0.0636	0.0904	0.1043	0.0268	0.0139
Farming and forestry	0.0028	0.0098	0.0231	0.0254	0.0007	0.0618	0.1242	0.1566	0.0623	0.0325
Food industry	0.0032	0.0091	0.0208	0.0267	0.0011	0.0609	0.1149	0.1430	0.0539	0.0281
Agriculture	0.0034	0.0089	0.0205	0.0223	0.0010	0.0561	0.1214	0.1554	0.0653	0.0340
Nonmarket services	0.0029	0.0038	0.0086	0.0286	0.0005	0.0444	0.1296	0.1739	0.0851	0.0443
Other manufacturing	0.0028	0.0043	0.0086	0.0268	0.0015	0.0439	0.0722	0.0869	0.0282	0.0147
Wood products	0.0024	0.0051	0.0098	0.0235	0.0021	0.0428	0.0663	0.0785	0.0235	0.0122
Other services	0.0026	0.0037	0.0073	0.0257	0.0014	0.0407	0.1142	0.1526	0.0735	0.0383
Auxiliary transport services	0.0025	0.0033	0.0064	0.0243	0.0014	0.0379	0.0826	0.1059	0.0447	0.0233
Metal products	0.0020	0.0041	0.0084	0.0183	0.0014	0.0342	0.0612	0.0752	0.0269	0.0140
Market services	0.0016	0.0031	0.0069	0.0156	0.0005	0.0277	0.1277	0.1798	0.1000	0.0521
Textile and leather	0.0015	0.0026	0.0058	0.0139	0.0006	0.0244	0.0490	0.0618	0.0246	0.0128
Vehicles	0.0008	0.0014	0.0031	0.0081	0.0003	0.0137	0.0317	0.0410	0.0180	0.0094
Machinery	0.0004	0.0007	0.0016	0.0042	0.0002	0.0071	0.0169	0.0220	0.0098	0.0051
Oil and natural gas	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**

Note: Bold text represents energy branches.

Table 3 c_{eI} and c_{eF} emissions coefficients in kilotonnes of carbon dioxide per million pesetas

	Coal	*Oil and natural gas*	*Oil refining*	*Electricity*	*Manufactured gas and water steam*
Intermediate uses (c_{eI})	265.10	0.00	90.32	0.00	40.83
Final uses (c_{eF})	188.21	0.00	31.28	0.00	21.91

In order to apply equation (8) to energy value flows in 1995, the equation needs to be corrected to account for changes in the price of energy:

$$c_{ej} = \bar{c}_e \frac{\bar{X}_{ej}^{85}}{p_e^{85}\bar{X}_{ej}^{85}} \frac{p_e^{85}}{p_e^{95}}. \quad (9)$$

Only two average coefficients for intermediate and final uses, c_{eI} and c_{eF}, have been calculated and applied to intermediate and final energy flows:

$$c_{eI} = \bar{c}_e \frac{\sum_{j=1}^{P} \bar{X}_{ej}^{85}}{p_e^{85} \sum_{j=1}^{N} \bar{X}_{ej}^{85}} \frac{p_e^{85}}{p_e^{95}}, \; c_{eF} = \bar{c}_e \frac{\sum_{j=1}^{F} \bar{X}_{ej}^{85}}{p_e^{85} \sum_{j=1}^{F} \bar{X}_{ej}^{85}} \frac{p_e^{85}}{p_e^{95}}. \quad (10)$$

The coefficients in equation (10) are in terajoules per million 1995 pesetas, and can be applied to calculate the emissions caused by intermediate or final flows measured in 1995 pesetas, $\tilde{X}_{ej}^{95}$, resulting in final emission coefficients in units of kilotonnes (kt)[6] of CO_2 per million pesetas:

$$c_{eI}\tilde{X}_{ej}^{95} = \left(\bar{c}_e \frac{\sum_{i=1}^{P} \bar{X}_{ei}^{85}}{p_e^{85} \sum_{i=1}^{P} \bar{X}_{e.}^{85}} \frac{p_e^{85}}{p_e^{95}} \right) p_e^{95}\tilde{X}_{ej}^{95} = \bar{c}_e \tilde{X}_{ej}^{95}. \quad (11)$$

Table 3 presents the average intermediate and final demand emissions coefficients used in this article. Notice that there is a large difference in the emissions coefficients for intermediate and final uses, due to the larger taxes supported by consumers, and therefore the increased amount of pesetas that go into calculations for the final uses.

Endogenous and Exogenous Carbon Dioxide Emissions

Emissions caused by productive sectors can be calculated by applying the intermediate emissions coefficients to energy value flows:

$$E_I = c_{eI}^T A_{ep} y_p, \quad (12)$$

where c_{eI}^T is the transpose vector, A_{ep} is the $E \times P$ submatrix of expenditure coefficients defined for energy commodities in all production activities, and y_p is the income vector of production sectors given by equation (6).

Emissions caused by nonproduction accounts can be calculated by adding those emissions due to nonproductive endogenous accounts (i.e., private consumption) to those caused by exogenous accounts:

$$E_F = c_{Fe}^T (A_{em-p} y_{m-p} + A_{en}(A_{mn} y_n - x)), \quad (13)$$

where $m - p$ denotes the nonproduction endogenous accounts, x is the exports vector, and $A_{mn}y_n - x$ is the income vector of exogenous accounts with exports subtracted.[7]

Table 4 Estimates of carbon dioxide emissions in Andalusia in 1995, measured in kilotonnes

	SAM model	*Regional government*
Production Activities (E_I)	40,847.4	39,173.7
Electricity	12,912.5	11,115.0
Transportation services	7,098.1	6,831.6
Final demand (E_F)	3,208.7	2,849.3
Total emissions ($E_T = E_I + E_F$)	44,056.0	42,023.0

Carbon Dioxide Emissions in 1995

The first column in table 4 estimates the amount of CO_2 emissions with a SAM model where all production activities, labor and capital income, and private consumption are endogenous. It can be seen that production and final demand emissions are slightly higher than the official values published by the regional government.[8] The figures for two key sectors—electricity and transportation—are also very similar to those of the regional government, and our estimate of total emissions differs by just 4.83%.

Carbon Dioxide Emissions in 2005

Next, we present estimates of the effects of changes in investment, government expenditure, and exports with a SAM model, assuming, as before, that production sectors, labor and capital income, and private consumption are endogenous. Instead of using arbitrary increases, as in Manresa and Sancho (2004) and Cardenete and colleagues (2008), the flows of exogenous accounts are replaced by the corresponding vectors in the 2005 IO framework.[9]

Table 5 summarizes the emissions estimates in the four scenarios we considered. In the first three simulations, the values for 2005 are found by replacing a vector in 1995 with the corresponding vector for 2005 for a single final demand component—gross capital formation, government consumption, or exports, respectively. In the last scenario, all three vectors are replaced. In all simulations, total emissions are broken down into those caused by production activities and those caused by final do-

Table 5 Estimates of carbon dioxide emissions in kilotonnes: 1995 and 2005

	1995	*2005*	*Percentage change*	*Elasticity*
Scenario 1. Gross capital formation. Accumulated increase: 76.93%				
Production activities	40,847	51,195	25.33	0.33 (0.33)
Domestic final demand	3,209	4,391	36.85	0.48 (0.48)
Total emissions	44,056	55,587	26.17	0.34 (0.34)
Scenario 2. Government consumption. Accumulated increase: 44.25%				
Production activities	40,847	45,899	12.37	0.28 (0.32)
Domestic final demand	3,209	3,775	17.64	0.40 (0.46)
Total emissions	44,056	49,674	12.75	0.29 (0.33)
Scenario 3. Exports vector. Accumulated increase: 55.20%				
Production activities	40,847	49,911	22.19	0.40 (0.22)
Domestic final demand	3,209	3,856	20.16	0.37 (0.20)
Total emissions	44,056	53,767	22.04	0.40 (0.22)
Scenario 4: Final demand vector. Accumulated increase: 58.57%				
Production activities	40,847	65,311	59.89	1.02 (0.28)
Final domestic demand	3,209	5,604	74.65	1.28 (0.35)
Total emissions	44,056	70,915	60.96	1.04 (0.28)

Note: In the first three scenarios, the values for 2005 are found by replacing a vector in 1995 with the corresponding vector for 2005 for a single final demand component: gross capital formation, government consumption, or exports, respectively. In the last scenario, all three vectors are replaced.

mestic demand. Emissions estimates for 2005 are reported in the second column and the accumulated growth rate, from 1995 to 2005, is reported in the third column. The elasticity, found in the last column, is the ratio of the accumulated emissions growth rate over the accumulated growth rate of the vector total from 1995 to 2005.

The impact on emissions caused by changes in the exogenous accounts depends on the accumulated growth rate of the vector total and its share of final demand in the base year. Although the percentage increase in emissions from final demand is higher than in production activities in all simulations, the increase in production emissions accounts for 91.08% of the total emissions increase from 1995 to 2005. Therefore policies oriented toward curbing CO_2 emissions should focus on reducing technical energy coefficients in production activities rather than expenditure coefficients in final demand operations.

The results in table 5 also indicate that investment (gross capital formation) is the final demand component responsible for the largest increase (26.17%) of total emissions, followed by exports at 22.04%, and public consumption (or government consumption in table 5) at 12.75%. As indicated, these increases depend on the accumulated growth rate of each component and its relative importance in the base year. For the interpretation of the elasticity column, it is necessary to take into account that a 1% increase in gross capital formation adds 25,566.01 million pesetas to the final demand, while a 1% increase in exports increases final demand by 46,523.84 million pesetas. Therefore these figures need to be corrected if one is interested in comparing the effects of an identical increase in final demand. The corrected values that appear in parentheses in the last column of table 5 indicate the increase in emissions caused by a 1% increase in gross capital formation, 1.15% increase in government consumption, 0.55% increase in exports, and 0.27% increase in final demand.[10]

Although exports have no direct impact on emissions (see equation 6), the indirect effects on production activities are similar to those of investment (or 22.19%, according to table 5). The elasticity column indicates that a 1% increase in total exports increases total emissions by 0.40%, a figure greater than that for either investment or public consumption.

As in 1995, total emissions of CO_2 estimated with the SAM model for 2005 (70,915 kt) exceeds by 7.71% the official figure of 65,840 kt calculated by the regional Andalusian government. It is hard to know whether the discrepancy is due to the different procedures followed to calculate emissions or to efficiency gains not accounted for by the government model.

Some Counterfactual Experiments

Emissions estimates indicate that the growth of total emissions in Andalusia from 1995 to 2005 widely exceeded the 15% increase allowed by the Kyoto Protocol for 1990 to 2012. What efficiency increase in production activities would have been necessary to maintain emissions from 1995 to 2005 within that range? Table 6 shows that in order to fully counteract the increase in emissions caused by the expansion of final demand, a reduction of between 20% and 30% in technical energy coefficients in production activities would have been necessary. In actuality, a gain of 26.5% is required to balance the increase in emissions due to final demand growth during the period.

In order to understand the individual contribution of each energy factor to emissions, table 7 presents estimates of total emissions in 2005, assuming a 26.5% reduction in the technical coefficients of one type of energy at a time. For instance, the first row indicates that total emissions due to coal in 2005 would have been 49,136 kt, only 11.53% higher than total emissions (44,056 kt) in 1995, had coal technical coefficients in all production activities been 26.5% lower than in 1995.

Table 6 Production and final demand carbon dioxide emissions in 2005

	1995	*2005*	*Percentage change*
Scenario 5: 20% reduction in all energy coefficients in production activities			
Production activities	40,847	45,890	12.35
Final demand	3,209	4,031	25.62
Total emissions	44,056	49,921	13.31
Scenario 6: 30% reduction in all energy coefficients in production activities			
Production activities	40,847	37,759	−7.56
Final demand	3,209	3,484	8.56
Total emissions	44,056	41,243	−6.39

Table 7 Total carbon dioxide emissions in 2005 assuming a 26.5% reduction in technical coefficients

Production Activity	*2005 (emissions in kilotonnes)*	*Percentage change from 1995*
Coal	49,136	11.53
Oil and natural gas	70,461	59.93
Refined oil	47,297	7.35
Electricity	62,708	42.34
Manufactured gas and water steam	70,114	59.15

The results in table 7 indicate that in order to satisfy the Kyoto Protocol, it would have been enough to cut down the technical coefficients of either coal or refined oil in all productive sectors by 26.5%, or approximately a 3% decrease per year. Efficiency gains in the coefficients of oil, electricity, and gas clearly have rather insignificant effects on emissions.

Conclusions

Energy type I and II multipliers calculated with SAM models indicate the importance of each energy input in the production of one unit of net output in different sectors, while the compound effect can be interpreted as the energy costs incurred to produce one value unit of net output. Four conclusions are worth stressing in regard to the Andalusian economy. First, three energy sectors (electricity, oil refining, and manufactured gas and water steam) are the most important users of energy inputs. Electricity, for instance, is a large user of coal; electricity and oil refining are large users of refined oil. Second, other sectors, such as water, transportation and communications, construction materials, and the remaining extractive industries, also use energy inputs intensively, mainly electricity. Third, some manufacturing industries, such as machinery, vehicles, textiles and leather, metal products, wood products, and other manufacturing, are at the bottom of the ranking, mixed up with nonmarket services, auxiliary transport services, and market services, meaning that they use, comparatively, the least amount of energy inputs. Fourth, market services, nonmarket services, commerce, and other services register the largest absolute and relative increases in energy intensities when income factors and consumption accounts are made endogenous. Changes observed when the savings–investment account is also endogenous reinforce that conclusion. Therefore, the view that services have low energy requirements should be abandoned and energy saving policies should not lose sight of the induced effects of service branches. In our view, it would be interesting to pursue this issue further to estimate energy requirements of the service subsystem of the Andalusian economy (Alcántara and Padilla 2009).

Control of CO_2 emissions has become, at least formally, a policy objective of the European Union (EU) countries that signed the Kyoto Protocol. Spain, for instance, committed to increasing emissions no more than 12% through 2012. However, in the case of Andalusia, official figures indicate emissions grew by 56.68% from 1995 to 2005. Using the emissions coefficients constructed in this article and the deflated values of gross investment, government consumption, and exports calculated for 2005, the SAM model with endogenous factor incomes and household accounts estimates that emissions grew by a total 62.13%, even more than the official numbers. The breakdown of total emissions into production and final demand emissions indicates that production activities are responsible for 91.08% of that increase. Growth in investment and exports account for 42.30% and 37.05%, respectively, of total production emissions; government expenditure is responsible for the remaining 20.65%. These results indicate that in order to cut down total emissions, it is essential to curb production emissions. The counterfactual experiments performed with the model indicate that a 26.5% decline in all direct energy coefficients of production activities would have allowed constant Andalusian emissions from 1995 to 2005. A decrease of the same magnitude in the direct coefficients of coal or refined oil would have been enough to keep total emission growth below 12%. Similar reductions in the direct coefficients of electricity have much lower effects, meaning it would not be as efficient a method for reducing emissions.

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Notes

1. Other authors also include the accounts of the government and rest of the world in the endogenous subset, as in the work of Manresa and Sancho (2004). In our view, the underlying assumption that an increase in government income (along with rest of the world) raises government expenditure (exports) to balance the account is rather arbitrary.

2. The peseta was the unit of account in Spain prior to joining the European Monetary Union (1 euro = 166.386 pesetas). As of August 18, 2011, the exchange rate was 1.43 U.S. dollars to 1 euro.
3. Capital income is the income of the capital factor, while the capital account is that due to investment and/or savings.
4. One terajoule (TJ) = 10^{12} joules (J, SI) ≈ 9.48 × 10^8 British thermal units (BTU).
5. The entrances for nonenergy commodities of vector c_e^T are zero.
6. One kilotonne (kt) = 10^3 tonnes (t) = 10^3 megagrams (Mg, SI) ≈ 1.102 × 10^3 short tons.
7. The exports vector, *x*, is subtracted from the total, as the emissions from the consumption of exported products occurs abroad.
8. The difference in the consumption estimates may be due to the fact that private transportation emissions are included with public transportation in land transportation.
9. The 2005 income flows in euros were first expressed in pesetas and then deflated to 1995 values.
10. Adopting gross capital formation as the reference, the factor of correction for exports would be 0.5495 = 25,566.65/46,523.84 and the elasticities corrected by relative size are 0.22, 0.20, and 0.22 instead of 0.40, 037, and 0.40.

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