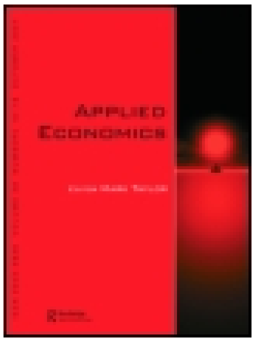

Applied Economics

ISSN: 0003-6846 (Print) 1466-4283 (Online) Journal homepage: http://www.tandfonline.com/loi/raec20

Socio-economic impact of a nuclear power plant: Almaraz (Spain)

Patricia D. Fuentes-Saguar, Juan A. Vega-Cervera & Manuel Alejandro Cardenete

APPLIED ECONOMICS, 2017
http://dx.doi.org/10.1080/00036846.2017.1293793

Socio-economic impact of a nuclear power plant: Almaraz (Spain)

Patricia D. Fuentes-Saguar[a], Juan A. Vega-Cervera[b] and Manuel Alejandro Cardenete[c,d]

[a]Department of Economics, Pablo de Olavide University, Seville, Spain; [b]Department of Economics, Extremadura University, Badajoz, Spain; [c]Department of Economics, Loyola University of Andalusia, Seville, Spain; [d]School of Management and Business, Universidad Autónoma de Chile, San Miguel-Santiago, Chile

ABSTRACT

An analysis is made of the socio-economic impact in a region in which a nuclear plant is decommissioned. The average age of nuclear power plants around the world is high, so that many are close to the end of their useful life. The issue of this impact will be important in a few years for various reasons, especially because those plants tend to be drivers of the economic activity in the areas in which they are located. The focus of this communication is on these socio-economic effects. Methodologically, socio-economic analysis uses a linear Social Accounting Matrix model that improves traditional Input–Output approaches by covering the induced effects generated from the receptors of income out to other sectors of the economy. The procedure is applied to an empirical analysis of the Almaraz Nuclear Power Plant in Spain. This was purposely chosen as sharing many of the general characteristics of nuclear plants around the world. If the plant is closed down, our results suggest that there will be a clear negative impact in terms of employment and added value generation.

KEYWORDS

Social Accounting Matrices; economic impact; linear models; nuclear power

JEL CLASSIFICATION

D57; Q43

1. Introduction

Nuclear fission has been a source of electrical power in the world since the second half of the twentieth century. Nuclear power plants (NPPs) as we now know them began to come on-line in the 1960s, with there being a boom in this type of energy in the 1970s and especially the 1980s. Given their years of service, many of these plants are beginning to have problems connected with their age. Most international nuclear watchdogs have been sounding warnings concerning this issue, but no clear conclusion has yet been reached as to what is the effective operating lifetime of a nuclear plant. The two options which owners and regulators have to consider are extending a plant's operating life by making a considerable investment in updating and maintaining it, or closure and subsequent decommissioning. It would be of great interest to be able to compare the effects of the two. In the former case, these would include the reduction in activity during the updating as well as the impact of the investment required. Although an interesting possibility because of the shock that this would generate on incomes in the region, there are no pertinent data available, thus making it difficult to quantify. However, it is the impact of the latter case, the closure of the plant that we shall be evaluating in this present work, focusing on the effects from a socio-economic perspective.

The problems involved in decommissioning a nuclear plant are not only technical but also social and socio-economic. However, while the technical procedures have been carefully studied with specific action protocols, the socio-economic implications in many cases remain unknown. Indeed, one finds technical details in the decommissioning reports, but nothing on the economic and social impacts. Such impacts may be of at least two types – microeconomic and macroeconomic. Microeconomic impacts are more important because of the direct, indirect, and induced effects on the environs of the plant. Most NPPs are located in rural areas, and constitute a major motor of the local economy. Closure of the plant will logically impact the area's employment and value generation. There are also macroeconomic impacts affecting national energy accounts since the amortized cost of a kWh produced by a NPP is extremely competitive with respect to other energy sources. In this article, we

CONTACT Patricia D. Fuentes-Saguar pfuesag@upo.es Universidad Pablo de Olavide, Ctra. de Utrera, km. 1, Seville 41013, Spain

shall focus on the microeconomic impact of the closure of a plant on the area around it.

The measurement technique we shall use is to fit a linear Social Accounting Matrix (SAM) model to the data using a cross-entropy approach. The choice of a SAM model (extension of traditional Input–Output models) rather than other possible models to analyse the question proposed in this article, is due to its ability to collect all aspects of the issue. It accurately reflects the flows and interrelations between the productive and institutional sectors (households, companies, government, etc.) of the economy, allowing including in the analysis the effects on production, generation of income, consumption, etc. In addition, its intuitive character makes it easily understandable in front of other multi-sectorial models.

This model clearly expands the possibilities of the traditional Input–Output models as it covers induced ('circular') effects as well as direct ('own') and indirect ('open') effects. Its origin is the theory of multipliers in the work of Stone (1978) and Pyatt and Round (1979), subsequently developed with other studies such as that of Defourney and Thorbecke (1984). Since in the present case, the model will be applied to a Spanish nuclear plant, that of Almaraz, in this paragraph we shall mention the literature describing the development and analysis of this type of modelling in Spain. For instance, Kehoe et al. (1988) and Polo, Roland-Host, and Sancho (1990) developed the first square SAM for Spain for 1987, Uriel et al. (1997) presented the 1990 SAM for Spain, and Cardenete and Sancho (2006) the 1995 SAM. Cardenete and Fuentes (2009) made a detailed study of SAMs in the Spanish energy context. For the Spanish Region of Extremadura (henceforth, the Region) in which Almaraz is located, the only existing SAM is that elaborated by De Miguel and Manresa (2004) for 1990. This matrix will serve as the basis for the present work.

The main results will be seen to suggest a major effect on employment and on the generation of added value in the area in which the plant is located. It is complicated to make comparisons with other analyses, however, because there is very little specific literature on the economic impact of a nuclear plant, even internationally. Nevertheless, we would highlight the classic works of Shurcliff (1975), Lewis (1986), and Bergmann and Pijawka (1981). Other more recent studies which have focused on the economic impact of nuclear plants are Slovic et al. (2006), Greenberg et al. (1999), Frisch et al. (1998), Nolan (2006), and NEI (2006, 2008). In the Spanish case, Vega (1997a), Vega (1997b), and Rodríguez Silva (2005) provide differentiated analyses of the economic impact of a nuclear plant. The methodological approach used in most cases is that of either Input–Output models or cost–benefit analyses. Some analyses are of the impacts associated with the construction of a nuclear plant or with its decommissioning and closure, and some of the cited studies report results indicating that nuclear plants have little socio-economic impact on their immediate environs. The problem is, however, that Input–Output model and cost–benefit analyses mostly omit any estimation of induced effects, which will in our case be seen to represent over 70% of the impact measured. Such an omission may have affected the conclusions drawn from those works.

In sum, our work has a twofold objective – first, to present a methodological approach that could be particularly appropriate for measurements in this type of study; and second, to make the magnitude of the economic impact that occurs when a nuclear plant is closed better known. In particular, we have observed that these impacts are generally poorly understood and seldom taken into account by the firms that own the plants or by national energy authorities. The work thus aims to provide an economic and social vision of the panorama following the closure of a nuclear plant.

2. Age of the world's nuclear power installations

One of the main topics of current debate concerning nuclear power is the age of most of the world's installations. As of 31 December 2014, the mean age of currently operating nuclear reactors in the world was 26 years and 8 months, with most reactors being well over 20 years old (361 of a total of 440). There are major differences between countries (see Table 1). On the one hand, for example, are the United States (97% of its nuclear plants over 20 years old), Russia (85% over 20 years), and the countries of the European Union (87.2%), while on the other hand are India (55% of its plants under 20 years), South Korea (60% under 20 years), and, above all, China, all of whose 14 NPPs have been less than 20 years in commercial operation. It seems

Table 1. Age as of 31 December 2014 of the world's operating nuclear reactors.

	Less than 20 years		At least 20 years		Mean age
	Nº	Net power (MW)	Nº	Net power (MW)	Years
Argentina	0	0	2	935	34.5
Armenia	0	0	1	376	33.0
Brazil	1	1275	1	626	31.0
Canada	0	0	20	12,577	30.1
China	14	1130	2	1223	9.25
South Korea	12	11,036	8	6611	15.8
The U.S.	3	209	100	92,474	35.3
India	11	2798	9	1600	19.3
Japan	14	19,378	36	26,579	28.3
Mexico	1	680	1	680	21.5
Pakistan	2	600	1	125	19.0
Russia	5	4750	28	17,968	31.7
South Africa	0	0	2	1800	28.5
Switzerland	0	0	5	3238	38.2
Taiwan	0	0	6	4949	31 3
European Union 27	18	22,034	123	109,464	28.1
Ukraine	3	4750	12	8357	22.2
Total	**84**	**87,240**	361	289,582	**26.9**

Source: International Atomic Energy Agency and the U.S. Nuclear Regulatory Commission (2014).

Table 2. Sectoral structure of the SAM of Extremadura, 2010.

1	Agriculture, forestry, and fisheries	13	Credit and insurance institution services
2	Energy	14	Other services intended for sale
3	Chemicals	15	Services not intended for sale
4	Metal products, machinery, and electrical equipment	16	Labour factor
5	Transport material	17	Capital factor
6	Food, drinks, and tobacco	18	Private consumption
7	Textiles, leather and footwear, clothing	19	Saving/investment
8	Paper, paper products, printing	20	Net indirect taxes
9	Products of sundry industries	21	Direct taxes
10	Construction	22	Government
11	Recovery and repair, retail, and hospitality	23	Foreign sector
12	Transport and Communications		

Source: Own elaboration.

clear that, while countries such as China, South Korea, India, Mexico, and Brazil have several years ahead of useful life of their currently operating nuclear plants, other countries such as Switzerland, Argentina, the United States, and Russia have reactors that are far older.

There are no clear international criteria for a nuclear plant to be considered obsolete at a certain age. For example, in the United States, the life of NPPs may be extended up to 60 years provided they meet the appropriate safety requirements, and in France they are inspected after 30 years and permits are renewed if the corresponding criteria are met. Other countries, such as Spain, tend to consider a fixed lifetime of 40 years, although this criterion has undergone notable variations.

Figure 1 shows the total number of reactors operating in the world in 2014 and their age. Clearly, the bulk of the operating generators are more than 25 years in age, although there are a considerable number of generators that are less than 20 years old. The peak occurs at 30 × 30, that is, there are about 30 operating units of about 30 years in age. It is in this range of ages that there is greatest number of units. They are generators of around a 1000 MW of installed capacity, built in the early and mid-1970s, mostly in rural areas and not far from major centres of consumption. The plant that we shall use for analysis, the Almaraz Nuclear Power Plant in Spain, has similar characteristics.

This plant has two pressurized light water reactors (930 MW each). In Spain, about 20% of power demand is provided by nuclear plants (5 points above the world average), and Almaraz accounts for a quarter of that nuclear power output. Indeed, it is Spain's most important power production plant. It produced 16 088 GWh in 2014, accounting for 5.6% of total Spanish power production. The first of its reactors came on-line in mid-1981, and the second in 1983. For a reference date of 31 December

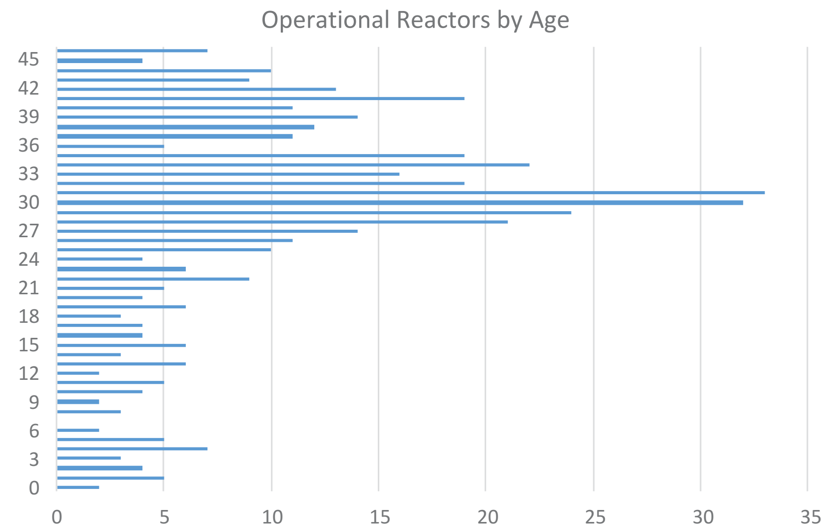

Figure 1. Operational reactors by age.
Sources: the U.S. Nuclear Regulatory Commission; Natural Resources Defense Council.

2014 therefore, the average age of the plant is some 32 years. The mean age of Spain's NPPs is 28 years, similar to the global average. The location of Almaraz is in a rural setting affecting about 30,000 people in a number of scattered municipalities some 180 km west of Madrid, which city receives most of its output. The plant directly employs about 700 workers, a number that triples during the annual refuelling process. In short, in productive structure, age, location, and the economic environment in which it operates, Almaraz is in general representative of the world's nuclear plants, and therefore well-suited to an economic impact study such as that to be described here.

3. The SAM model

In this section, we shall describe briefly the methodological approach taken in the present work. SAM models are an extension of the well known Leontief Model. In an economy with n sectors, the classical equation of the Leontief Model is:

$$Y_j = A_{ij} Y_j + D_j \qquad i, j = 1, \ldots, n., \tag{1}$$

where Y is the output vector, A the matrix of average expenditure propensities of the SAM whose elements represent the average expenditure coefficients $a_{ij} = Y_{ij}/Y_j$ corresponding to the payments to account i per unit of income j, and D is the final demand vector.

Solving (1) for the output vector Y, one obtains the Leontief Inverse Matrix M = $(I–A)^{-1}$. Its elements (m_{ij}) are the simple multipliers of the Leontief Model, interpretable as the input requirements per unit increase in expenditure or income. They are termed simple because they do not capture the relationships between output, factor income, income distribution, and final demand. The linear SAM model extends the Leontief Model precisely in order to capture those relationships. In particular, consider an $n \times n$ square matrix in which each row and column represents a financial account (productive sectors, consumers, government, capital account, etc.) which satisfies the equalities of economic accounting (total income equals total expenditure). Each component Y_{ij} of the matrix represents the bilateral flow between account i and account j. Each row i of the SAM represents the total revenue that account i gets from column j, the columns represent the total income of column j and how it is distributed among the various accounts i. The average expenditure coefficients, $a_{i,j}$ = 1,. . ., n again show the payments to account i per unit of income of j. From this definition one obtains:

$$Y_i = \sum_{j=1}^{n} \left({}^{Y_{ij}}\!/_{Y_j} \right) Y_j = \sum_{j=1}^{m} a_{ij} Y_j + \sum_{j=m+1}^{m+k} a_{ij} Y_j$$
$$n = m + k. \tag{2}$$

The indices m and k represent the division of the SAM into endogenous and exogenous accounts. This splits the $n \times n$ matrix into four submatrices: A_{mm}, A_{mk}, A_{km}, and A_{kk}. Also, Y_m and Y_k denote the total income of the endogenous and exogenous accounts, respectively, so that one can solve for Y_m and get:

$$Y_m = A_{mm} Y_m + A_{mk} Y. \tag{3}$$

Then, following the same procedure as for the Leontief equation, one obtains the extended multiplier matrix from:

$$Y_m = (I - A_{mm})^{-1} Z, \tag{4}$$

where Z is the vector of exogenous columns $(A_{mk}Y_k)$ and $(I–A_{mm})^{-1}$ is the SAM extended multiplier matrix. The interpretation of this matrix, which we shall denote by M, is similar to that of the Leontief Inverse. If dZ represents the changes in the exogenous account vector, the changes in receipts of the endogenous accounts would be:

$$dY_m = M\,dZ = M\,d(A_{mk}\ Y_k) = M\,A_{mk}\ d_{Yk}, \tag{5}$$

where a generic element m_{ij} indicates the effect that the exogenous injection of a unit of income received by an endogenous account j has on the endogenous account i. The method allows other relationships to be incorporated in addition to those (inter-industry relationships) mentioned above – relationships which arise between the primary factor revenues and the various institutions making up the final demand.

We now apply the multiplier decomposition method of Defourney and Thorbecke (1984) and Pyatt and Round (1985) to this matrix, M. As just mentioned, the M matrix captures other effects as well as those deriving from inter-industry relationships. That is why we decompose this matrix in order to identify which part of the impact is due to the circular flow of income.

Operating on the basic equation derived above, one obtains:

$$Y_m = (I - A^{*3})^{-1}(I + A^* + A^{*2})(I - A'_{mm})^{-1} Z, \tag{6}$$

where $A^* = (I - A'_{mm})^{-1}(A_{mm} - A'_{mm})$. From this, one can separate out the following matrices:

(1) $M_1 = (I - A')^{-1}$, which comprises the own, direct, or transfer effects due to intra-activity transfers, reflecting the effects on an account of an exogenous injection of income into that account.
(2) $M_2 = (I + A^* + A^{*2})$, which comprises the open or indirect effects, reflecting the effects of an exogenous injection of income into an account on the other endogenous accounts.
(3) $M_3 = (I - A^{*3})^{-1}$, comprises the circular or induced effects due to feedback.

The multiplier matrix is decomposed into three matrices by means of a multiplicative expression as in Pyatt and Round (1985). Expressing the multipliers additively, one has:

$$\begin{aligned} M &= M_1.M_2.M_3 \\ &= I + (M_1 - I) + (M_2 - I)M_1 + (M_3 - I)M_2M_1, \end{aligned} \tag{7}$$

where

- $M–I$ is the net total multiplier effect;
- $N_1 = (M_1 - I)$is the net own effect (effect on endogenous production activities);
- $N_2 = (M_2 - I)M_1$ is the net open effect (effect on the rest of the endogenous accounts);
- $N_3 = (M_3 - I)M_2M_1$ is the net circular effect (effect due to the circular flow of income).

Then (7) can be expressed as:

$$M - I = N_1 + N_2 + N_3. \tag{8}$$

In these expressions, the identity matrix I allows the initial injection of income for each of the effects to be subtracted, so that the decomposition is expressed in net terms.

Let us now consider in detail what the three N matrices resulting from this decomposition mean. Firstly, $N_1 = (M_1 - I)$ reflects the net effects that an exogenous shock on one of the extracted block of endogenous accounts (in this case, the block of productive activities) has on the set of those accounts due to the subsequent demand for intermediate inputs between them to meet their new production requirements. In this case, extracting the productive activities block would be the net equivalent to the usual Input–Output model multipliers. But this generation of new demands and outputs also has its effect on the rest of the endogenous accounts because it requires factors of production, etc. In other words, whenever one of the extracted block's endogenous accounts increases output and demands more inputs, it will also demand more factors of production and will generate more income in the private consumption sector. This effect is what $N_2 = (M_2 - I)M_1$ reflects, that is, its elements show the own effects that all these increases in output of the productive activities have on these other endogenous accounts. Since these effects feed back to the system successively in the endogenous accounts of the extracted block, the total feedback that results corresponds to the closure of the circular flow of income, which is reflected in $N_3 = (M_3 - I)M_2M_1$.

4. Application and results

The simulation we made was under the assumption that plant performs no activity in the year 2010, and therefore has no consumption or wage payments. The choice of 2010 was because it had both the most recent available SAM of Extremadura and the availability of primary data on the cost and operational structure of the Almaraz NPP. The original data used were obtained from the only Regional SAM existing which refers to 1990 (De Miguel & Manresa, 2004; Llop, Manresa, and De Miguel 2002). It was necessary to update this matrix because of the major time-lag between it and the date chosen for the study. To this end, we used the cross-entropy upgrading method (Golan, Judge, and Robinson 1994; Robinson, Cattaneo, and El-Said 2001). In general terms, this procedure requires only a starting SAM matrix (in our case, the previous SAM-1990) together with the row or column (marginal) totals in the new reference year for each of the accounts included. In this update, we opted to take the year 2000 as the base year for the new SAM, then projected it out to 2010. We used the values available in the Spanish Regional Accounts as well as data from other economic sources (Family Expenditure Surveys, Statistics National Institute of Spain (INE), 2010; Regionalization of the National Accounts; etc.). In the following paragraphs, we shall describe the structure of this SAM.

We considered 17 endogenous accounts, namely 16–18 (labour, capital, consumption), and 14 of the 15 accounts relating to productive sectors, that is, all but the energy account (see Table 2).

The model was specified by subtracting from the exogenous account vector (in particular, the energy account) the nuclear plant's endogenous account expenditure for each year. The consumption left after performing the simulation is concentrated in three sectoral accounts: *Chemicals, Transport and Communications*, and *Other services intended for sale* plus salaries (*Labour account*).

The results of the multipliers decomposition of the SAM are presented in Table 3. They confirm the advantages of this analysis as against the traditional Input–Output approach, since the circular effects represent the main impact of any shock to this economy. Failure to incorporate them would clearly devalue any study of this type. Therefore, including

Table 3. Decomposition of the total net effects into own, open, and circular effects (%).

	% N1	% N2	% N3
	Own effect	Open effect	Circular effect
1. Agriculture, forestry, and fisheries	23.7	6.4	69.9
3. Chemicals	29.8	7.3	62.9
4. Metal products, machinery, and electrical equipment	29.4	7.2	63.4
5. Transport material	8.8	7.3	84.0
6. Food, drinks, and tobacco	30.2	7.2	62.6
7. Textiles, leather and footwear, clothing	25.3	6.8	67.9
8. Paper, paper products, printing	21.0	7.2	71.8
9. Products of sundry industries	31.7	7.3	61.0
10. Construction	25.0	7.2	67.8
11. Recovery and repair, retail, and hospitality	20.4	7.2	72.4
12. Transport and Communications	23.8	7.4	68.8
13. Credit and insurance institution services	12.7	7.3	80.0
14. Other services intended for sale	8.4	7.1	84.6
15. Services not intended for sale	19.5	6.4	74.1
Average[a]	**18.2**	**9.2**	**72.5**

[a]The average is calculated over all 17 endogenous accounts considered.
Source: Own elaboration.

the analysis of circular and open effects helps understand the more detailed mechanisms involved in economic interdependence. In this sense, the table is straightforward to interpret.

For example, consider a shock occurring in the Region's economy (since, in the present work, the productive activities have been extracted from the total of endogenous accounts, this shock would be the final net effect of an exogenous injection in the Energy sector). Account 1 (*Agriculture, forestry, and fisheries*) would have an own effect (i.e. an effect on its own productive activity) of 23.7%. This represents the effect of the demands for input from other productive sectors to meet the new output, which in turn will generate successive demands for new inputs in the corresponding sectors (including Energy), conforming an internal effect on productive activities due to their structure. There would be an open effect (i.e. an effect on the rest of the endogenous accounts) of 6.4%. This is the effect that each of these successive increases in the outputs of the activities would have directly on the rest of the endogenous accounts (factors of production and private consumption, households, and businesses).

And finally, the effect of feedback from the above increases in the open effect on the productive assets of the extracted block, and of these on the rest of the endogenous accounts, that is, the closure of the circular flow of income, would give rise to a circular effect (i.e. an effect due to the circular flow of income) of 69.9%.

In this regard, it is noteworthy that in all cases the circular effect (i.e. due to the circular flow of income, N_3) is the greatest of the three, showing the interest of incorporating the extension applied in this model. Next in importance is the own effect (N_1). This was to be expected since one is evaluating a shock mainly affecting productive activities.

In the following paragraphs, we shall present the projections of the simulations made for how a potential inactivity of the Almaraz Nuclear Power Plant affects the area's economy. We shall consider one scenario, the year 2010, and focus on two variables, the impacts on sectoral output and on employment. Specifically, we shall present the changes in sectoral output disaggregated, as well as the impact represented by the generation of unemployment. To this end, once we had obtained the SAMs, we then determined the employment vectors (from the INE data) needed to transform the model's monetary units into jobs, and then constructed the model for 2010. The data for the simulation came from a questionnaire presented to the NPP, which in its responses provided information on its major expenditures for 2010 and on jobs.

Starting with the variation in the output of 2010 (Table 4), the first thing to notice is that the impact of the plant's closure means a direct reduction in expenditure and jobs in the industry itself of 47.77% and 21.22%, respectively. This implies that more than half of the impact on output is due to 'non-own' effects (i.e., N_2 and N_3). With respect to the analysis of the sectors, one observes the outstanding

Table 4. Impact on sectoral output and employment, 2010.

	Output		Employment	
	Impact (*000 s of euros)	%	Impact (lost jobs)	%
1. Agriculture, forestry, and fisheries	−7136.2	6.21	−195.8	10.03
3. Chemicals	−1900.3	1.65	−47.5	2.43
4. Metal products, machinery, and electrical equipment	−1873.4	1.63	−6.0	0.31
5. Transport material	−524.6	0.46	−5.6	0.29
6. Food, drinks, and tobacco	−7666.5	6.67	−2.1	0.11
7. Textiles, leather and footwear, clothing	−2713.7	2.36	−37.4	1.92
8. Paper, paper products, printing	−469.5	0.41	−0.9	0.05
9. Products of sundry industries	−1163.0	1.01	−12.5	0.64
10. Construction	−1373.6	1.19	−29.3	1.50
11. Recovery and repair, retail, and hospitality	−14,629.8	12.72	−386.2	19.79
12. Transport and Communications	−3816.6	3.32	−58.1	2.98
13. Credit and insurance institution services	−1876.4	1.63	−25.4	1.30
14. Other services intended for sale	−14,448.4	12.56	−688.8	35.30
15. Services not intended for sale	−853.3	0.74	−41.6	2.13
2. ENERGY (Direct impact)	−54,549.8	47.44	−414.0	21.22
Total	**−114,995.0**	**100.00**	**−1951.2**	**100.00**

Source: Own elaboration.

fall suffered by *Other services intended for sale*. This was to be expected, since this sector is the most affected by expenditure cuts. It will bear 12.56% of the total impact of the plant's closure. The percentages are even greater for Account 11 (*Recovery and repair, retail, and hospitality*), even though this account undergoes no direct reduction in demand from the nuclear plant. This is probably because, within the Region's economy, this sector is very sensitive to changes in income. Thus, if the plant had been closed as was originally set out in the Spanish government's plans, together these two sectors would have accounted for 25% of the total impact of the closure (48% if one leaves out the direct impact on the Energy sector).

Next in importance are the primary sectors, *Agriculture, forestry, and fisheries*, and *Food, drinks, and tobacco* which, like Account 11 although to a lesser extent, are strongly affected by the shock despite undergoing no direct reduction in demand. Again, these are important sectors for the area's economy, being highly sensitive to any change in income that might occur.

The overall effect of this impact on the Region's economic accounts is greater than €54 million in 2010, with the circular effects accounting for €39 million, and own effects €10 million. More residual is the variable N2 – open effects – which accounts for just over €5 million. The shock itself is less than the sum of these (~€54 million) since, according to the data obtained, part of the reduction of expenditure is concentrated in the Energy sector which, being an exogenous account, only receives the direct impact of the closure. In particular, the shock is of ~€43 million, distributed, as we discussed earlier in this section, among *Chemicals, Transport and Communications*, and *Other services intended for sale* plus salaries (*Labour account*).

In sum, of the 15 sectors studied, just 4 (Account 14: *Other services intended for sale*; Account 11: *Recovery and repair, retail, and hospitality*; Account 6: *Food, drinks, and tobacco*; and Account 1: *Agriculture, forestry, and fisheries*) account for 38.2% of the total impact (70% if one leaves out the direct impact on the Energy sector). Two aspects stand out: first, the atomization of the effect in the sense described above, although in all cases these are sectors of economic importance for the zone, and second, the smallness of the impact on sectors which, a priori, could well have been affected, such as *Products of sundry industries* and *Metal products, machinery, and electrical equipment*.

With respect to the impact on employment, one observes that the same sectors are those most affected. There again appear the aspects of atomization described above. Just two service sectors (Accounts 11 and 14: *Recovery and repair, retail, and hospitality*, and *Other services intended for sale*) account for 70% of the decline in employment, and this reaches 80% if one includes the primary sector and 86.3% with the addition of the direct employment lost in the plant. In other words, the circular effects on the service sector, primary sector, and the plant itself due to the plant's inactivity account for more than 80% of the economic impact in terms of employment. It has to be borne in mind that by employment, we mean employment of at least 1-year duration. If one were to include shorter duration jobs, jobs that are customary in some of the sectors most affected, the impact would be even greater.

Our estimate of the total effect on jobs is an increase in unemployment of just under half a per cent of the Regional total for 2010 (i.e. about 0.41% in this case). This percentage would be considerably greater if one were to constrain the affected area to the northern part of the region, in which the plant is located, and in which most of the impact would be concentrated. Specifically, while the impacts on output and employment in the region as a whole are 0.64% and 0.53%, respectively, these figures rise to 1.8% and 0.84% by taking only the Province of Caceres in which the plant is located. (These percentages are relative to the INE's Provincial Production and Employment data.) Another conclusion that can be drawn from these figures is that the impact on output is greater than on employment, and this may indicate that the loss is of highly productive, and therefore skilled, jobs.

The especially significant impacts on employment merit some additional remarks. The causes of the variability in the estimates are aspects such as the model used, the starting assumptions, and gaps in the databases, as well as the different behaviour of the Region's economy after such a long period.

The results confirm the work's hypothesis: The socio-economic impact of the closure of the Almaraz NPP would go far beyond the loss of jobs in the plant itself and the implications for businesses that are direct suppliers of goods and services – the *Energy* sector; *Chemicals; Transport and Communications*; and *Other services intended for sale* (computing services, consulting and auditing, advertising, legal services, janitorial services, and a series of ancillary services). Indeed, the direct effect was only half of the true ultimate effect of the plant's closure. The declines in output (by about ~€55 million) and in employment (by 441 jobs either direct or immediately indirect – e.g. affected suppliers) are only a half and a quarter, respectively, of the estimated total losses for the Extremaduran economy: ~€115 million and nearly 2000 jobs in an economy which already have serious problems in this sense, and in a zone with particular social dependence on the economic activity of the plant.

This is precisely one of the principal contributions of this present study. The use of a multi-sectoral method based on SAMs has allowed the true impact of this economic shock to be seen by capturing the successive feedbacks that the consequent losses of production, employment, income, and demand generate among themselves. Comparing the impact on sectors that were direct suppliers of the plant, one sees the direct and total effects on them. For instance, in the branch of *Services intended for sale*, the direct effect of the closure is to reduce the *Energy* sector's expenditure in this sector by ~€3911, while the indirect effects cause a loss of ~€14,448.4 (Table 4).

But when one considers those sectors seemingly unrelated to the activity of the plant, for example, *Recovery and repair, retail, and hospitality*, or the primary sector, one observes that, even though they are not direct suppliers to the plant, they undergo a loss of jobs and output which in the former of these cases is almost ~€15 million and 386 jobs (just a few less than those lost by the plant itself).

Although there are also important effects on agriculture, the global results show a particularly significant effect on the services sector, which should be a key sector in the recovery and subsequent economic development of the area after the closure of the plant. The effects are especially important in employment and this requires taking of palliative and compensatory measures, and also development-oriented policies, based on investment and the implementation of active employment policies. All this represents an important financial effort, especially from the public sector, to compensate for the negative effects of the closure of the plant in socio-economic terms, leaving aside the possible environmental or safety benefits.

These results could be extended to similar region or areas where nuclear plants are close to being closed. That means, the process of dismantling nuclear plants has just started. Currently, 110 commercial reactors have been dismantled in the world. In fact, that quantity is greater if experimental or research reactors are considered. In the Table 5 are standing out the nuclear plants have been closed and dismantled or they are in process of dismantling between 2010 and 2016. They are about 16 plants which have a similar power that the plant in this study and traits of the geographical location to

Table 5. Decommissioning Nuclear Power Plants 2010–2016.

Country	Reactor	Type	MWe net each	Start-up	Years operating each	Shut down
Canada	Gentilly 2	PHWR	638	1982	30	2012
France	Phenix	FNR	233	1973	37	2010
Japan	Genkai 1	PWR	529	1975	40	2015
Japan	Mihama 1	PWR	320	1970	45	2015
Japan	Mihama 2	PWR	470	1972	43	2015
Japan	Shimane 1	BWR	439	1974	41	2015
Japan	Tsuruga 1	BWR	341	1970	45	2015
Japan	Fukushima Daiichi 6	BWR	1067	1980	32	2011
Spain	Garoña	BWR	446	1971	42	2012
Sweden	Oskarshamn 2	BWR	638	1974	39	2013
The U.K.	Wylfa 1–2	GCR	490	1971	44	2015
The U.S.A.	Crystal River	PWR	860	1977	35	2013
The U.S.A.	Fort Calhoun	PWR	479	1973	43	2016
The U.S.A.	Kewaunee	PWR	566	1974	39	2013
The U.S.A.	San Onofre 2	PWR	1070	1982	31	2013
The U.S.A.	San Onofre 3	PWR	1070	1983	30	2013

Source: Own elaboration with data from Word Nuclear Association, OECD-NEA (Nuclear Energy Agency), and International Atomic Energy Agency (IAEA).

Almaraz plants with one or more generators, in rural environments and at medium distance of large consumption centre. In all cases, dismantling processes are studying in a strong way while social and economic impacts are obviating because of the plant disappearance. This is a striking fact, as the getting results show in this study, the places most affected because of the plant disappearance are submitted by an economic result clearly negative.

5. Conclusions

This work has focused on evaluating the impact the closure of a nuclear plant may have socio-economically. NPPs are usually located in rural areas relatively close to large centres of consumption. While one finds abundant literature regarding safety protocols, dismantling processes, and the technical analysis of materials following the decommissioning of a NPP, there is very little empirical evidence on the socio-economic impact.

We found that the world's NPPs have a high average age, with their reactors being mostly between 25 and 35 years old, but we also found ambiguity regarding the interpretation of when an NPP is old.

We chose a typical plant, Almaraz in Spain, whose fundamental characteristics are like those of most NPPs in the world in terms of location, size, population directly affected, and direct and indirect employment generated by its operation. The ultimate idea that we were seeking was to get a first approximation to what the closure of many other plants with similar characteristics also close to decommissioning and dismantling might mean. Just the number of jobs lost, whether directly or indirectly, would involve an unquestionable impact in socio-economic terms for the zones in which they are located.

The use of a SAM instead of the traditional Input–Output table allowed one to more realistically quantify and distribute the impact on the society and economy of the zone analysed since it enables the circular flow of income to be captured completely. Together with this factor, the decomposition analysis allowed the components of these indirect effects on the economy to be identified in detail.

The model used in the present study has shown itself to be appropriate for determining the economic impact of the closure of a nuclear plant. In particular, it was used to estimate the real impact of the closure of the Almaraz Nuclear Power Plant on the local economy where it is located. The analytical tool used was a linear SAM model adapted to the context of the study. The model parameters were obtained from the only Regional SAM available, which was for 1990, which we updated to 2010. The use of the multi-sectoral method based on SAMs allows the true impact of this economic shock to be captured by taking account of the successive feedbacks that the consequent losses of output, jobs, income, and demand generate among themselves.

The results showed a major negative impact in terms of both output and employment. Furthermore, it is important to bear in mind that the simulation did not take into account all of the reduction in activity. For example, it did not include the reduction in energy consumption even though this is of great importance in the present case since the energy account is exogenous and thus fixed. But even without this being included, one can already conclude that the reduction of the activity of the NPP would have a major negative effect on the Region's economy.

Specifically, if the plant is to close with the currently existing socio-economic structure of Extremadura, the economic outlook described by the simulation would be a loss of around 2000 jobs (direct, indirect, and induced) and a shock of around €114 million on the Region's economic accounts. We believe that, since the area closest to the plant would receive the direct impact, there should be some arbitration of aid to partially offset this effect.

Indeed, given that the world's nuclear power installations are in general now fairly old, for plants which are being or are to be decommissioned, or for which such a decision is being planned, economic effects of this kind should be anticipated, and there should be consideration of potential compensation or aid, especially for the areas closest to the plants. It would be necessary a special effort in productive investment and employment policies to compensate for the negative socio-economic effects of the closure of the plant. This conclusion could be extended to similar region or areas where nuclear plants are close to being closed.

Countries such as Canada, France, particularly Japan, Spain, the U.K., and the U.S.A. have dismantling processes of nuclear plants in force or very recent completion. Those protocols of dismantling are exhaustive in a technical rigor but they obviate the potential of a social-economic impact the disappearing plants could have, most of all in a close environment. The topic is even more important being in mind that, the media age of the world nuclear park, the process of dismantling of nuclear plants has only just begun. It would be suitable a greater sensitivity by the authorities respect this topic at the beginning in the decommissioning process of nuclear plants.

Acknowledgement

The authors wishes to express their gratitude Almaraz Nuclear Power Plant.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Bergmann, P. A., and K. A. Pijawka. 1981. “The Socioeconomic Impacts of Nuclear Generating Stations: An Analysis of the Rancho Seco and Peach Bottom Facilities.” *GeoJournal* 31 (Supplement): 5–15.

Cardenete, M. A., and P. Fuentes. 2009. *Análisis Del Sector Energético Español a Través De Un Modelo De Crecimiento Sostenible Colección EOI MA Medio Ambiente*. Madrid: Fundación EOI, 2009. ISBN 978-84-936547-5-7.

Cardenete, M. A., and F. Sancho. 2006. “Elaboración De Una Matriz De Contabilidad Social a Través Del Método De Entropía Cruzada: España 1995.” *Estadística Española* 48 (161): 67–100.

de Miguel, F. J., and A. Manresa. 2004. “Modelos SAM Lineales Y Distribución De La Renta. Una Aplicación Para La Economía Extremeña.” *Estudios De Economía Aplicada* 22-2: 577–603.

Defourney, J., and E. Thorbecke. 1984. “Structural Path Analysis and Multiplier Decomposition within a Social Accounting Matrix Framework.” *The Economic Journal* 94: 111–136. doi:10.2307/2232220.

Frisch, M., L. Solitare, M. Greenberg, and K. Lowrie. 1998. “Regional Economic Benefits of Environmental Management at the US Department of Energy.” *Journal of Environmental Management* 54: 23–37. doi:10.1006/jema.1998.0216.

Golan, A., G. Judge, and S. Robinson. 1994. “Recovering Information from Incomplete or Partial Multisectoral Economic Data.” *Review of Economics and Statistics* 76: 541–549. doi:10.2307/2109978.

Greenberg, M., L. Solitare, M. Frisch, and K. Lowrie. 1999. “Economic Impact Accelerated Cleanup on Regions Surrounding the U.S. DOE,S Major Nuclear Weapons Sites.” *Risk Analysis* 19 (4): 635–647. doi:10.1111/j.1539-6924.1999.tb00434.x.

Kehoe, T. J., A. Manresa, C. Polo, and F. Sancho. 1988. “Una Matriz De Contabilidad Social De La Economía Española.” *Estadística Española* 30: 5–33.

Lewis, P. 1986. “The Economic Impact of the Operation and Closure in a Nuclear Power Station.” *Regional Studies* 20 (5): 425 432. doi:10.1080/09595238600185371.

Llop, M., A. Manresa, and F. J. de Miguel. 2002. “Comparación De Cataluña Y Extremadura a Través De Matrices De Contabilidad Social.” *Investigaciones Económicas* 26 (3): 573–587.

NEI. 2006. *Economics Benefits of Grand Gulf Nuclear Station*. USA: Nuclear Energy Institute NEI & Entergy. Ed, NEI.

NEI. 2008. *Economic Benefits of North Anna Power Station*. USA: Nuclear Energy Institute NEI & Entergy. Ed, NEI.

Nolan, M. 2006. “The Economic Implication of a North Korean Nuclear Test.” *Asia Policy* 2: 1–39.

Polo, C., D. Roland-Host, and F. Sancho. 1990. “Distribución De La Renta En Un Modelo SAM De La Economía Española.” *Estadística Española* 32 (125): 537–567.

Pyatt, G., and J. Round. 1979. “Accounting and Fixed Price Multipliers in a Social Accounting Framework.” *Economic Journal* 89: 850. doi:10.2307/2231503.

Pyatt, G., and J. Round. 1985. *Social Accounting Matrices. A Basis for Planning*. World Bank:Washington D.C.

Robinson, S., A. Cattaneo, and M. El-Said. 2001. “Updating and Estimating Social Accounting Matrix Using Cross Entropy Methods.” *Economic Systems Research* 13: 47–64. doi:10.1080/09535310120026247.

Rodríguez Silva, M. 2005. *Impacto Económico Del Desmantelamiento De La Central Nuclear*. Madrid: Vandellos I, ENRESA ed.

Shurcliff, A. W. 1975. Local Economic Impact of Nuclear Power Plants. MIT EL, 75 005 Working Paper. MIT.

Slovic, P., M. Layman, N. Kraus, J. Flynn, J. Chalmers, and G. Gessell. 2006. “Perceiver Risk, Stigma, and Potential Economics Impacts of a High-Level Nuclear Waste Repository in Nevada.” *Risk Analysis* 11 (4): 683–696. doi:10.1111/j.1539-6924.1991.tb00658.x.

Stone, R. 1978. The Disaggregation of the Household Sector in the National Accounts. World Bank Conference on Social Accounting Methods in Development Planning, Cambridge.

Uriel, E., P. Beneito, J.,. Ferri, and M. L. Moltó. 1997. *Matriz De Contabilidad Social De España 1990 MCS-90*. Madrid: Instituto Nacional de Estadística e Instituto Valenciano de Investigaciones Económicas.

Vega, J. 1997a. *Análisis Del Impacto De Las Inversiones En La Central Nuclear De Almaraz*. Madrid: Senda Ed.

Vega, J. 1997b. *El Principal Activo Industrial De Extremadura: La Energía. Situación. Serie De Estudios Regionales*. Extremadura: BBV.